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Ocean Energy Unleashed: A Sustainable Frontier in the Indian Ocean

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***Abstract*- The vast expanse of the Indian Ocean holds untapped energy riches, waiting to be harnessed. Its impact is palpable during natural calamities-tsunamis, tidal surges, and inland floods. Climate change, with pollution from fossil fuels, has intensified the search for alternative energy fuels. Ocean power development has traditionally centered on regions with robust tidal forces, yet littoral nations bordering the Indian Ocean are making strides in Blue and Green Technology. Like hydroelectric dams, power plants at river estuaries harness tidal water, releasing it to generate electricity. India's tidal energy potential is estimated at 9,000 MW. Devices floating on the ocean surface or anchored to the seabed convert wave motion into power. Underwater turbines, akin to wind turbines, tap marine currents for electricity. Lower-velocity currents hold promise for large-scale projects. The temperature contrast between warm surface waters and cold depths can drive steam-based power generation through Ocean Thermal Energy Conversion (OTEC). India's coastline harbors around 54 GW of ocean energy potential-12.45 GW from tides and a whopping 41.3 GW from waves. Currents in the Macpherson Strait near Andaman Island offer hydrokinetic energy. Prototype turbines have been tested, hinting at an annual energy potential of 4.8 MWh/m. Despite a 7,600 km-long coastline, India lacks operational offshore wind plants. Gujarat and Tamil Nadu alone account for 71 GW of offshore wind energy potential by 2050. Other regions and hybrid projects hold promise and are also discussed. This paper provides a comprehensive review of the untapped potential of ocean energy in the Indian Ocean, emphasizing India's capacity, ongoing developments, and future project proposals. The paper aims to contribute by analyzing specific technologies and estimating their feasibility in real-world applications, filling gaps in current research by focusing on geographic, economic, and technical challenges.**

Keywords*- *wave energy, tidal energy, renewable, sustainability, SDG

I. INTRODUCTION

Wave energy harvesting is the process of converting the kinetic energy of ocean waves into usable electricity. The potential of ocean wave energy as a renewable energy source is huge, and it can be a reliable and sustainable power source for coastal communities and offshore industries. There are several ways to harvest ocean wave energy, but the most common methods include:

1. Wave energy converters (WECs): [1]
2. Floating platforms: [2]
3. Oscillating water columns (OWCs):[3]
4. Salter ducks: [4].

The development of ocean wave energy is still in its early stages, but advances in technology and increasing demand for renewable energy sources are driving progress in this field. With the right investment and infrastructure, ocean wave energy has become a significant source of clean, sustainable energy for the future.

Several types of wave energy harvesting devices can be deployed in the Indian Ocean. *Point absorber* devices use a buoy that moves up and down with the wave, generating electricity through a hydraulic generator. *Oscillating water column* devices capture energy from the oscillating wave motions, which drive air through a turbine to generate electricity. *Over-topping devices* use the energy of waves to drive water onto a reservoir, which then passes through a turbine to generate electricity. Despite the potential of wave energy harvesting, there are still several challenges to be overcome, including high capital costs, maintenance requirements, and the need for reliable and efficient power transmission and grid integration. Wave energy could play a significant role in meeting the growing demand for clean and renewable energy in the region. Several countries bordering the Indian Ocean, including India, South Africa, and Australia, have invested in wave energy technology and infrastructure. In India, the government has proposed several wave energy projects along the country's coast, which could generate up to 1,500 MW of renewable energy (but as of 2021 these are on hold). In South Africa, the government has established a dedicated wave energy research program, to deploy commercial wave energy systems by 2025.

Sri Lanka is one of the countries with the potential to develop wave energy harvesting technologies. The island is at an ideal location for wave energy production and has already initiated several projects to develop wave power technologies. The government has set a goal to generate 200 MW of ocean energy by 2030. Several private companies have also shown interest in investing in wave energy projects in Sri Lanka due to its favorable location and growing demand for renewable energy

Wave energy scavenger devices are mechanisms that capture and convert the energy from ocean waves into usable

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electricity. These devices utilize the movements of waves, tides, and currents to generate clean, renewable energy without emitting greenhouse gases or polluting the environment.

Bangladesh can generate substantial renewable and wave energy (a report published by the International Renewable Energy Agency [5])

The country has initiated several programs and projects to promote renewable energy, including wave energy, to reduce its dependence on fossil fuels and mitigate the impacts of climate change. Some of the notable initiatives include the Bangladesh Sustainable Renewable Energy Development Authority (SREDA), which aims to develop policies, plans, and strategies to promote renewable energy, and the Bangladesh Oceanographic Research Institute (BORI), which has been researching the wave energy potential of the Bay of Bengal, [6]. In addition, several international organizations, including the World Bank and the Asian Development Bank, have provided financial and technical assistance to support Bangladesh's renewable energy programs.

The Palk Straits wave energy power generator is a proposed renewable energy system that harnesses the power of ocean waves to generate electricity. The Palk Straits are a narrow channel of water that separates India and Sri Lanka, and they are known for their strong and consistent waves. The power generator would consist of a series of buoys or turbines anchored to the seabed in the Palk straits. As the waves pass over these devices, they will cause them to move, which in turn generates electricity through the use of a generator. This renewable energy source can provide a significant amount of clean energy to the region, as the Palk Straits have some of the highest wave energy potential in the world. Furthermore, it would not produce greenhouse gas emissions, making it an environmentally friendly option. While the technology to generate electricity from ocean waves is still in its infancy, the Palk Straits wave energy power generator represents an exciting opportunity to harness the power of the ocean and move towards a more sustainable future.

The Bengal wave energy power generator is a device that harnesses the power of ocean waves to generate electricity. A buoyant structure is moored to the ocean floor. As waves pass by the buoy, it rises and falls, causing the mooring line to stretch and contract. This motion is converted into electricity through a generator housed in the buoy. The device usually consists of several buoys, which are connected to a central hub. The electricity generated by the buoys travels to an onshore facility through a transmission cable. The electricity generated by the Bengal wave energy power generator can be used to power homes, businesses, and even entire communities.

Kerala, in southern India next to the Arabian Sea, has tremendous potential for wave energy power generation. The state government has initiated several projects to tap into this potential and promote the use of renewable energy sources. The Indian Ocean Rim Association (IORA) has also identified Kerala as a potential hub for wave energy technology development and research. The state has already installed a pilot wave energy farm in Vizhinjam that generates electricity from the waves. The government is also planning to set up a 10 MW wave energy park in Alappuzha district, which will be the largest wave energy project in India. Wave energy power generator technology can meet the growing energy demands of the state contributing significantly towards reducing greenhouse gas emissions.

Despite the potential, a critical question remains: What are the key challenges and technological innovations required to unlock ocean energy potential in the Indian Ocean region?

In other regions, several ongoing wave energy projects and companies have focused on developing wave energy power generators, including:

1) ***EDF Energies Nouvelles****:* This French renewable energy company has an ongoing research project focused on developing a wave energy converter called Wavegem. The technology is designed to convert wave energy into electricity through oscillating water columns.[7]

2) ***HydroQuest***: A French company specializing in tidal and river energy, HydroQuest is also developing wave energy converters that leverage sea levels to generate electricity. The company's wave energy converters are designed for shallow water offshore applications.[8]

3) ***Subhydro***: Another French company focused on wave energy, Subhydro has developed a prototype wave energy converter that uses a buoy to collect wave energy and transfer it to an onshore turbine for electricity generation.

4) ***Ocean Power Technologies***: While not a French company, Ocean Power Technologies has deployed several wave energy buoys off the coast of France as part of ongoing trials. The company's PB3 PowerBuoy is designed to convert wave energy into electricity through a direct drive generator system, [9]

Overall, France's wave energy projects and companies are focused on developing technologies that can provide a consistent energy source from the often unpredictable nature of ocean waves. While still in the early stages of development, wave energy has the potential to play a significant role in France's transition to renewable energy sources, [7,8,9]

II. TECHNOLOGY

There are several types of wave energy scavenger devices, including:

1) ***Oscillating water columns (OWC)*** - OWC is a device that uses the rise and fall of water within a chamber to compress air, which drives a turbine or generator to produce electricity.

2) ***Point absorbers*** utilize the up-and-down motion of a buoy or floating object to capture the kinetic energy of waves, which then powers a generator. The Salter duck wave energy power generator is a device used to capture energy from ocean waves. It is also known as the Salter duck wave energy converter (SDWEC), after its inventor, Stephen Salter.

A buoy-like structure that bobs up and down with the waves moves and drives a power generator. The Salter duck wave energy power generator is unique because it is specifically designed to amplify the motion of ocean waves. This is achieved through the shape of the buoy, which features a curved, elliptical cross-section that increases the sensitivity to waves. The technology is based on Salter's observation that ducks bob along the surface in a manner that allows them to ride the waves more effectively than simple buoy structures. Several different Salter duck designs over the years use the same basic concept. The SDWEC can be used in a single unit or in a group of interconnected units to generate more power. It is a promising technology, but more research remains to refine the design and optimize its efficiency. Recent innovations to optimize this device have occurred. [4]

3) ***Wave snakes*** - Pelasmis is a series of connected floating modules, moving up and down independently with wave action. This movement drives hydraulic rams that pump high-pressure fluid through hydraulic motors, generating electricity transmitted to shore via cables and integrated into existing power grids. Pelamis is named after a genus of sea snake, due to its long, snake-like shape. It has been successfully tested in Portugal and Scotland. The Pelamis generator can be a significant source of renewable energy in coastal regions around the world.[10]

This device uses hydraulic systems to convert linear motion into rotational motion,[11]. Energy scavenger devices can provide a significant amount of clean energy, as wave power is a consistent and reliable energy source. However, they are still in the development stage.

III. METHODS OF ESTIMATION

Steps for calculating the power output of a wave energy generator:

1) Determine the energy density. This measures the potential power extractable from wave motion, measured in units of kilowatts per meter (kW/m).

2) Estimate the size of the wave energy generator. Wave energy generator converters range from a few meters to tens of meters in length.

3) Calculate the capture width of the wave energy converter. This is the effective area that captures wave energy. It depends on the device's design and the incoming wave direction.

4) Estimate the conversion efficiency of the wave energy converter. Typical efficiencies range from 30% to 50%.

5) Calculate the power output of the generator with the formula: Power = Energy density x Capture width x Converter efficiency For example, if the energy density is 20 kW/m, the capture width is 20 meters, and the converter efficiency is 30%, the power output would be: Power = 20 kW/m x 20 m x 0.3 = 120 kW. The wave energy generator could generate up to 120 kilowatts.

Other refinements use statistics and spectral methods to estimate the net power output.

IV. FEASIBILITY ANALYSIS

Sea waves are considered an energy source with high power generation potential. Sri Lanka, can significant amount of power for the national grid from wave energy conversion. It has over 1300 km of coastal shoreline.

A. A. Wave Power Potential in Sri Lanka:

Sri Lanka has significant potential for wave energy generation. The southwest to south-east coasts of the country experience an annual average wave power of **12-15 kW/m**, which is suitable for offshore, large-scale wave energy harvesting,[12]. It has identified **14 sites** along its coastline for building power plants that utilize energy from ocean waves. This move aligns with Sri Lanka's goal to shift to renewable energy sources and reduce reliance on fossil fuels,[13]. The research analyzed wave patterns in the coastal belt to identify suitable locations for implementing wave energy converters. Existing wave energy conversion technologies were compared, and computational simulations were conducted to determine the best technology for local wave conditions. The study found that the **point absorber type** wave energy converter was the most compatible solution for the selected coastal region. Buoy geometry was further analyzed using simulations, revealing that the **half-capsule shape** resulted in the highest force extraction compared to other shapes.[14]

B. Prospects of Meeting SDGs

Wave energy power generation directly contributes to achieving multiple Sustainable Development Goals (SDGs) established by the United Nations, underscoring its importance as a clean, renewable energy source and its role in promoting sustainable economic growth and environmental protection.

Wave energy, being 5 times more concentrated than wind energy and 10 to 30 times more than solar energy, provides a continuous electricity supply throughout the year, offering a high potential for sustainable power generation in regions like Mexico [15]. By utilizing untapped clean energy sources such as ocean waves, wave energy power generation can supply a substantial part of the world's electricity needs, significantly contributing to the global pursuit of affordable and clean energy (Goal 7) [16].

Moreover, wave energy generation contributes to reducing emissions from ships and promoting the utilization of marine energy, aligning with environmental protection and energy-saving initiatives, thus supporting efforts to combat climate change and its impacts (Goal 13),[17]. It also offers an alternative to fossil fuels, helping to reduce environmental harm and global warming while meeting the increasing demand for electrical energy worldwide, which is crucial for fostering innovation and infrastructure development (Goal 9) and ensuring access to affordable, reliable, sustainable, and modern energy for all [18].

The wide distribution, high quality, and vast potential value of wave energy in the global energy market emphasize its role in driving economic growth and promoting sustainable industrialization (Goals 8 and 9). However, challenges such as low efficiency and instability necessitate further research and testing for full exploitation [19].

Devices based on wave energy offer a promising solution for achieving sustainable development goals by harnessing a pollution-free, clean, and renewable energy source, contributing to marine construction and economic development,[20]. An estimated potential worldwide contribution of wave energy to the electricity market is about 2,000 TWh/year, representing about 10% of the world's electricity consumption, significantly furthering efforts toward sustainable consumption and production patterns (Goal 12),[21].

In summary, wave energy's integration into the global energy mix presents an effective avenue for mitigating climate change, fostering economic growth, and promoting social well-being in conjunction with environmental sustainability, echoing the interconnected and holistic nature of the SDGs. Studies have also been done to test conformity with IEC standards,[22]

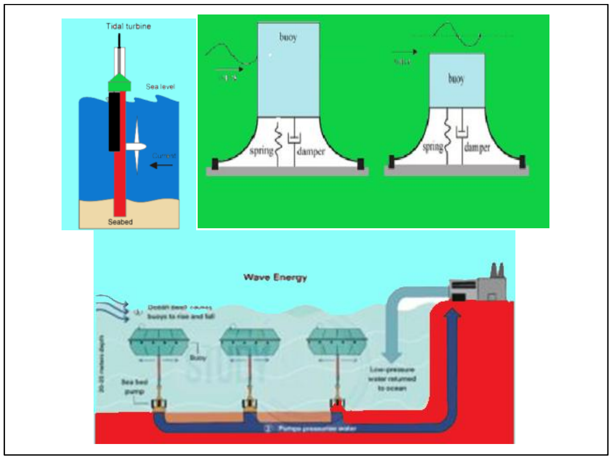

Fig. 1. Schema of turbo and point generators

C. Self Financing of Renewable Projects

A commonly raised objection to renewable energy projects is the high capital outlay. Funding agencies are wary of investing in projects where there is high risk involved. To counter these misgivings, it needs to be emphasized that the source of energy is perpetual, being solar energy and gravitation ultimately. Amortization tables for various payback periods, rates of interest and annual income streams are available for renewable energy schemes Recent studies based on the Pelamis generator calculated the costs,[23,24]. Different WECs were installed in the same place, and the Pelamis generator was evaluated. The levelized cost of energy (LCOE) for the Pelamis was estimated to be **EUR 735.94/MWh**

The cost of Energy is estimated as [Capital Cost + PV(O&M)]/[PV(Energy Production)]

Economic analyses of wave energy projects often involve the use of key financial indicators such as Net Present Value (NPV) and Levelized Cost of Energy (LCOE).

1) A Review of the Levelized Cost of Wave Energy Based on a Techno-Economic Model: This study discusses LCOE as an indicator for calculating the generating cost of wave energy. The LCOE is calculated by combining capital expenditure (CAPEX), operational expenditure (OPEX), and decommissioning cost with the inclusion of the annual energy production, discount factor, and project lifespan. The study found that as the CAPEX and OPEX dramatically drop, the availability and capacity factors slowly increase, and the LCOE decreases from a maximum of USD 470/MWh to a minimum of USD 120/MWh.

2) A Proposed Guidance for the Economic Assessment of Wave Energy Converters at Early Development Stages: This work presents guidance for the economic evaluation of a wave energy concept at an early development stage by setting up the economic frame based on a target LCOE[2]. It involves understanding the entry cost to be achieved for a specific target market and evaluating the breakdown of cost based on a detailed technology-agnostic database of costs.

3) Productivity and Economic Assessment of Wave Energy Projects: This paper presents a novel productivity and economic assessment of wave energy projects, focusing on wave farm profitability and using detailed operational simulations[3].

4) Cost of Energy - Ocean Energy Systems: This work investigates the development and fabrication of leading wave, tidal, and OTEC systems, and their integration into commercial arrays and large-scale power plants. A few studies highlight the importance of economic analyses in assessing the viability and potential of wave energy projects. They provide valuable insights into the costs associated with wave energy and how these costs can be managed to make wave energy a more economically viable source of renewable energy. [25, 26}

V. DISCUSSION

A. International Commitments

According to the Paris Agreement: The Paris Agreement is a legally binding commitment entered into by 196 countries in Paris at the COP21 on 12 Dec 2015 and coming into effect on 2016 Nov 4. It works on NDX(Nationally determined contributions) in 5-year cycles. In COP27 it recognised that the 1.5 deg rise in global temperature required recommitting to the 2020 targets.[27]The commitment is to limit global warming to 1.5°C, greenhouse gas emissions must peak before 2025 at the latest and decline 43% by 2030. Unfortunately, the reality is far from reaching this goal. A question posed in the Indian Parliament in 2007 elicited a reply that renewable projects for wave energy were being scrapped if not kept on hold [28]

B. Future Directions

1) Challenges and Opportunities: Infrastructure: Extending grids to islands remains challenging and costly, [29]. Indeed, extending grids to islands presents unique challenges and can be costly.

2) Mini-Grids and Decentralized Energy Technologies: In rural areas and remote islands with scattered settlements, grid extension can be difficult. Mini-grids and off-grid solar home systems are options to bring electricity to consumers faster at lower cost.

3) Challenges in Island Grid Systems:. The primary source of electricity on the islands has been imported diesel fuel, with high financial costs for most utilities. Islands face challenges in adapting to renewable sustainable energy grids.

4) Operational Challenges in Small Grids: These smaller electricity island grids share similar operational challenges as larger systems but with more constraints. They are needed to manage their varying load profile and periods of peak and low demand. With fewer generation facilities and no interconnection, there are fewer options to solve supply constraints.

5) Cost of Grid Extension for Rural Electrification: The cost of grid extension for rural electrification can be high, and various factors can affect these costs. This is discussed in earlier works,[25,26]

C. Technology Maturation:

The importance of renewable energy sources such as ocean energy cannot be overstated. A few reasons why these innovations are so important:

1) Diversification of Energy Sources: Ocean energy allows diversification of our energy sources, particularly important for countries with limited natural resources.

2) Reducing Carbon Emissions: Ocean energy is clean energy with no greenhouse gases during operation. Innovations can help combat climate change and reduce our carbon footprint.

3) Energy Security: Ocean energy can be harnessed regardless of the time of day or weather conditions.

4) Economic Development: Ocean energy technologies can create jobs in manufacturing, installation, and maintenance. It can stimulate economic growth

5) Remote Power Supply: Ocean energy can be helpful for remote islands and villages, where electric supply can be challenging and expensive.

6) Innovations in energy conversion technologies can help overcome the current challenges such as high costs and low efficiency. It is a viable and significant part of our energy mix.

7) Sustainable Growth: Balancing energy needs with environmental conservation is paramount. A delicate balance between meeting energy needs and preserving the environment is needed. A few strategies that can help achieve this balance follow:

Promoting Renewable Energy: Renewable energy sources have minimal impact on the environment. Governments and businesses can incentivize using renewable energy through subsidies, tax breaks, and research funding.

Energy Efficiency: Improving energy efficiency in industries, buildings, and transportation can significantly reduce energy consumption.

Sustainable Agriculture: Implementing sustainable organic farming and Agroforestry can help preserve the environment while meeting our food needs.

Conservation and Restoration of Ecosystems: Protecting and restoring forests, wetlands, and other ecosystems can help to sequester carbon and preserve biodiversity. This can be achieved through conservation laws, protected areas, and restoration projects.

Sustainable Urban Planning: Cities that minimize environmental impact can help achieve sustainable growth. This includes public transportation, green spaces, and the implementation of waste management systems.

Education and Awareness: Public awareness about the importance of sustainability and how to live sustainably can drive behavioral change and support for sustainable policies.

D. Ongoing efforts to integrate wave energy into power grids.

The **Centre for Ocean Energy Research (COER)** at Maynooth University in Ireland is conducting comprehensive research on different aspects of grid integration of wave energy generators, [30,31]

The sustained wave energy development makes it one of the most promising renewable energy resources.

1) Vizhinjam and Durgaduani wave energy projects:

The Vizhinjam Wave Energy Project is located off the Vizhinjam coast in Kerala, India. It is the first floating device in the country. The project is being implemented by the Agency for New and Renewable Energy Research and Technology (ANERT) and was conceptualized and developed by a US-based firm named M/S Oscilla Power Inc. The project cost is estimated between ₹15 to ₹20 crore. The earlier pilot plant was a 150kW fixed oscillating water column device installed at 10m water depth. The proposed plant will be a floating one at 40 to 50 m water depth and is expected to be commissioned in two years,[32]

2) Durgaduani Tidal Power Project:

The Durgaduani Tidal Power project is located in the Sundarbans area of West Bengal, India. The project has a capacity of 3.75 MW and spans an area of 4.5 km. Two barrages were built across the upstream and downstream ends of the Durgaduani Creek, which runs between the islands of Gosaba and Bali-Bijayanagar and connects the Bidyadhari and Gomdi rivers. A bypass canal built downstream houses a powerhouse and sluice gates. The project cost was Rs. 2.38 billion (Rs. 238 crore) – which is about Rs. 635 million per MW (Rs. **63.50 crore)**, [33]

These projects represent significant steps towards harnessing the power of ocean waves and tides for renewable energy generation in India. However, such projects involve many challenges, including high costs and the need for advanced technology.

3) The Kutch and Sri Lanka wave energy projects:

Kutch Tidal Energy Project: The Gujarat government in India is developing the first tidal energy plant in the Gulf of Kutch. The state has approved Rs 25 crore for setting up the 50 MW plant, that will produce tidal energy. The state government signed a MoU with Atlantis Resource Corporation, a UK-based developer of tidal current turbines. If the 50 MW plant is successfully commissioned, its capacity will be increased to 200 MW. The Gulf of Kutch has a total potential of 300 MW, [34]

Sri Lanka Wave Energy Projects*:* Sri Lanka has identified 14 sites along its coastline to build ocean power plants. This is to shift to renewable energy sources, reducing reliance on costly fossil fuel. The energy deficit is increasing as rapid economic growth generates higher electricity demand. Apart from this, there are other wave energy projects in Sri Lanka:

- Sri Lankan Wave Energy Resource Assessment and Characterisation Project: This project aims to conduct a systematic analysis of the wave energy resources in Sri Lankan waters,[35]
- WERPO Wave Power Plant: WERPO, an Israeli wave energy developer, has planned the construction of a 10 MW wave power plant in Sri Lanka,[36]
- **AW-Energy Project**: Finland-based AW-Energy, an ocean wave energy company, is working with the Government of Sri Lanka to harness the potential of ocean wave energy on the southern coast of Sri Lanka,[37]

Wave energy projects in Maldives, Fiji, and Tonga:Maldives**:** The Okinawa Institute of Science and Technology Graduate University (OIST) has signed a Memorandum of Understanding (MOU) with the Ministry of Environment and Energy (MEE) of Maldives and Kokyo Tatemono Company Limited (Kokyo) of Tokyo, Japan, to start a wave energy project in the Maldives. The project involves testing prototype Wave Energy Converter units (WEC-units) in the Maldives to supply sustainable energy and reduce carbon emissions. The experiment will be conducted with the assistance and cooperation of MEE, and Holiday Inn Resort Kandooma at South Male Atoll, Maldives, [38]

Fiji has monitored wave potential in 2 sites, Muani village, Kadavu, and Vuna village in Taveuni, actual implementation of projects will be expensive for a small country like Fiji. However, Fiji is making strides in other areas of renewable energy. A feasibility study is being set up to assess 300 remote communities lacking access to reliable and affordable electricity, and then to prioritize 75 sites for $40 million in capital investment for new solar-powered mini-grids with energy storage capacity,[39]

Tonga: The Kingdom of Tonga has signed an agreement with the Ireland-based Seabased Group, for the development and deployment of the first pilot commercial-scale two-megawatt (2 MW) Wave Power Park in the Pacific. The initial park in Tonga will be 2MW and can save Tonga $2 million in foreign exchange; displace two million liters of fuel; reduce carbon emissions by roughly 5.6 kilotons and generate enough power for 2,800 homes. Phase two will include 8 additional megawatts, and save $10.5 million and up to 42 million liters of fuel. It is expected to provide half of Tonga's energy needs and cut emissions by 20%. Phase two is planned to be operational in two years after signing the PPA,[40]

These projects signify significant steps towards harnessing ocean power for renewable energy generation**.** It is important to note that the development and implementation of such projects involve challenges, including high costs and advanced technology development.

For India, key challenges include the high infrastructure capital costs and the need for grid integration, whereas Sri Lanka faces unique issues due to its geographic isolation and lack of large-scale projects.

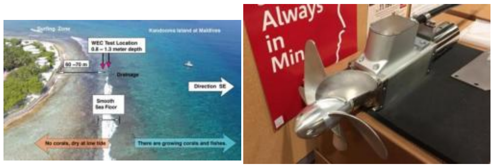

Fig. 2. & Fig 3 Details of Maldivian coastline and Japanese prototype (source: https://www.oist.jp/news-center/press-releases/oist-harness-energy-ocean-waves-maldives)

Policy Support: Governments must incentivize ocean energy projects. They can incentivize ocean energy projects by the following means:

E. Funding Research and Development:

Governments can provide grants and funding to develop more efficient and cost-effective ocean energy technologies. **Tax Incentives**: Tax credits or deductions could be offered to companies that invest in ocean energy projects. **Feed-in Tariffs**: Governments can guarantee a fixed price for the electricity generated from ocean energy. This can provide a stable income for producers and encourage more investment in the sector. **Public-Private Partnerships**: Governments can partner with private companies to share the risks and rewards of developing new ocean energy technologies. **Legislation**: Governments can pass laws that require a certain percentage of the country's energy to come from renewable sources, including ocean energy. **Education and Public Awareness**: Governments can also play a role in educating the public about the benefits of ocean energy and the importance of transitioning to renewable energy sources.

Some examples of government incentives for ocean energy projects:

India's O-SMART Initiative: The Ministry of Earth Sciences has initiated the O-SMART (Ocean Services, Modelling, Applications, Resources and Technology) scheme. It provides services to society, resource inventories for energy, fisheries, minerals, and niche technologies or subsystems. For instance, a self-powering desalination plant has been set up in Kavaratti, Lakshwadeep islands,[41]

Ocean Energy as Renewable Energy in India: The Ministry of New and Renewable Energy has declared ocean energy a Renewable Energy. Energy produced from tidal, wave, ocean thermal energy conversion, etc. shall be eligible for meeting the non-solar Renewable Purchase Obligations (RPO).

U.S. Department of Energy Funding: The U.S. Department of Energy announced up to $27 million in federal funding for research and development projects to convert ocean energy more efficiently into carbon-free electricity, [42]

EU Funding for Offshore Renewables: The European Union provides several funding programmes for offshore renewable energy projects, including wind and ocean energy,[43]

Offshore Wind Projects Incentives in the U.S.: The U.S. Department of Energy provides incentives such as investment tax credits, associated tax credit bonuses, and $100 million for offshore wind transmission planning.

F. Potential Directions: Research and Collaboration:

Global collaboration to enhance ocean energy technologies.

Wave energy converters (WECs) are at an earlier stage of development than other power plants. Many concepts have been proposed worldwide, but only a few WECs have exported power to supply grids. "Wave farms" have been suggested to meet large and variable power needs, as also integrating wind, solar, and wave [44]

These examples illustrate how by implementing these incentives, governments can accelerate the development and adoption of ocean energy, contributing to a more sustainable and environmentally friendly energy future.

New advancements in wave energy converters, such as point absorbers, oscillating water columns (OWC's), Multimode converters, and hybrid wave can reduce costs and increase efficiency. This paper proposes that adopting these technologies in coastal regions like Kerala and Tamil Nadu could lead to energy output improvements of up to 30% to 50%.

G. Supply Chain Integration:

Develop local supply chains for sustainable growth.

Developing local supply chains is a key strategy for sustainable growth. **Reduced Carbon Footprint**: Local supply chains often involve shorter transportation distances, which can significantly reduce carbon emissions associated with shipping and transportation. **Economic Development**: Local supply chains can stimulate local economies by creating jobs and supporting local businesses. This can lead to increased income and improved living standards for local communities. **Resilience**: Local supply chains can be more resilient to global disruptions, such as those caused by pandemics or geopolitical tensions. This can ensure a more stable supply of goods and services. **Quality Control**: When supply chains are local, businesses have more control and visibility over the production process, which can lead to improved quality of goods and services.

H. Community Engagement:

Local supply chains can foster a sense of community by connecting consumers more closely with the production of goods and services. This can lead to increased consumer engagement and loyalty. Here are some strategies for developing local supply chains: **Support Local Businesses**: Governments and businesses can provide financial incentives, such as grants or tax breaks, to support local businesses. **Invest in Infrastructure**: Investment in local infrastructure, such as transportation and logistics, can make local supply chains more efficient and cost-effective. **Education and Training**: training can equip local workers with the skills needed to participate in the supply chain. **Collaboration**: Encouraging collaboration between businesses, governments, and community organizations can help to develop and strengthen local supply chains. **Sustainable Practices**: Promoting sustainable practices, such as recycling and energy efficiency, can make local supply chains more environmentally friendly. By implementing these strategies, we can develop local supply chains that contribute to sustainable growth and a more resilient economy. It's a win-win situation for everyone involved.

In light of the overriding mandate given by the Climate body of the UN, it can be said that many nations have acceded to this and have made or are making provisions in their local legislation to enhance the transition away from Fossil fuels. Excuses of the past no longer hold water and can be challenged legally. An international agency to help entrepreneurs to challenge entrenched bureaucracy needs to be set up independently or under UN auspices, to force compliance with International Law.

VI. CONCLUSION

The implementation of incentives to accelerate the development and adoption of ocean energy, can contribute to a more sustainable energy future. Local supply chain integration offers several benefits, including reduced carbon footprints, economic development, resilience, quality control, and community engagement. Strategies such as supporting local businesses, investing in infrastructure, providing education and training, fostering collaboration, and promoting sustainable practices can lbe a win-win situation for everyone involved. As the UN's climate mandate gains prominence, nations are increasingly transitioning away from fossil fuels. Excuses from the past no longer suffice, and bureaucracy can now be held accountable. A new international agency to enforce compliance with international law could further accelerate this transition. We cannot predict the future with certainty, time and tide will ultimately reveal whether the shift toward carbon neutrality has truly taken place by 2030 or 2050. It is to be seen if by 2030 / 2050 the shift away from fossil fuel has taken place.

This paper contributes to the current understanding of ocean energy by not only reviewing existing data but also proposing a roadmap for future projects. By focusing on technology adoption, economic feasibility, and regional challenges, it offers a framework for further exploration in the field.

There is no Crystal Ball available. Only Time and Tide will tell. And Time and Tide wait for No Man.

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