Advances in Energy Research, *Vol. 5, No. 4 (2017) 305-320*
DOI: http://doi.org/10.12989/eri.2017.5.4.305

Ocean energy in Indian coasts and islands for sustainability– A roadmap for future

Saha Dauji*[1,2]

[1]*NRB Office, Bhabha Atomic Research Centre, Mumbai 400094, India*
[2]*Homi Bhabha National Institute, Mumbai 400094, India*

(Received February 1, 2018, Revised October 8, 2018, Accepted October 11, 2018)

Abstract. Limited quantity and non-uniform distribution of fossil fuel over the world, along with the environmental concerns of increasing CO_2 emissions, indicate that gradual and planned switchover to the sustainable energy sources is the need of the day. Ocean energy is well-distributed over the coasts, abundant, renewable and available in the form of wave energy, tidal energy and thermal energy. India has gathered precious experience from the pilot plants utilizing these methods over the last few years. One of the main constraints is deemed to be the grid connectivity. Time has come to transform this limitation into opportunity. Ocean power can be a very suitable option for the coastal belts and the islands. Implementation of this concept would require large-scale industry participation along with favourable government policies in the coming years. This article attempts a review of the ocean energy initiatives in India and proposes a roadmap for the future.

Keywords: ocean energy; sustainable; renewable; wave energy; tidal energy; ocean thermal energy converter

1. Introduction

Over the last century, the ever increasing population and the rapid exploitation of the fossil fuels have resulted in primary energy consumption rate of around 15 trillion watts of power worldwide (Armaroli and Balzani 2011). Though other sources like hydropower, solar and wind power and nuclear power have been used in many countries to different extents, the global trend of the energy supply and consumption have been predominantly fossil fuel based and generally unsustainable. The gap between the industrialized and the developing nations need to be bridged which would require more energy. The trend in of energy consumption as depicted in Fig. 1 is rising quite steeply (India falls under 'Non-OECD Asia'; 'Non-OECD Asia' excludes China). However, the aggressive consumption of fossil fuels in the forms of coal, oil and natural gas, have to be moderated due to their depleting reserves, increasing cost and most importantly, the environmental concerns (CO_2 emissions).

*Corresponding author, Scientific Officer, Lecturer,
E-mail: acad.dauji@gmail.com or dauji_saha@yahoo.com

http://www.techno-press.org/?journal=eri&subpage=7 ISSN: 2287-6316 (Print), 2287-6324 (Online)

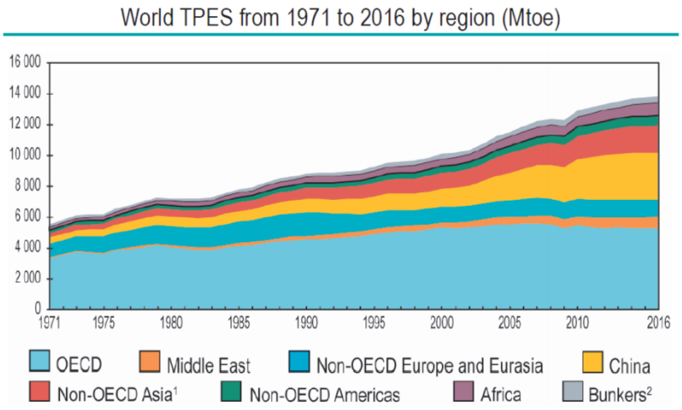

Fig. 1 Total energy production in World from year 1971 to year 2016 (Reproduced from International Energy Agency 2018a)

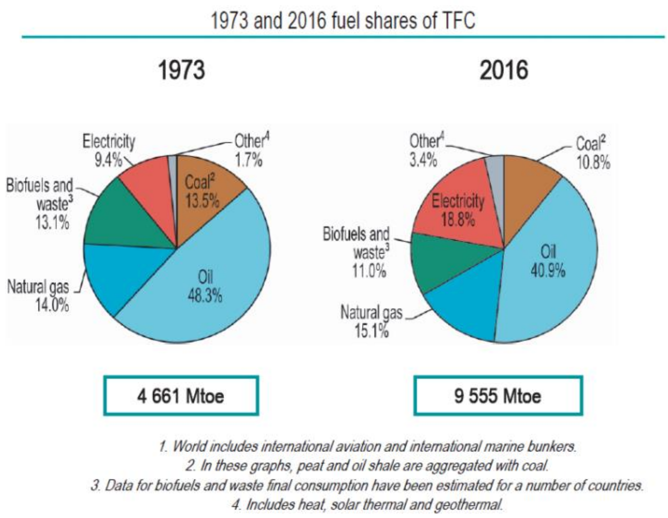

Fig. 2 Total primary energy supply (fuel-wise) in World: years 1971 and 2014 (Reproduced from International Energy Agency 2016)

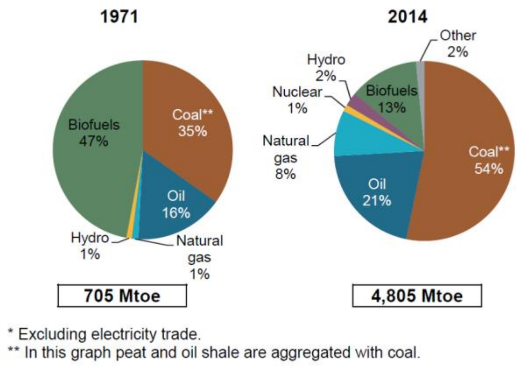

Fig. 3 Total primary energy supply (fuel-wise) in Asia: years 1971 and 2014 (Reproduced from International Energy Agency 2016)

In year 2014, the production of the fossil fuels (coal, natural gas, oil) increased by +1.3% and the non-fossil fuels (bio-fuels and waste) development growth slowed from 2.8% to 1.7%.

Simultaneously, hydropower increased by 2.5%, whereas the other renewable sources reported high growths (wind, solar thermal, solar PV, geothermal, +11.1%, +7.7%, +35.1%, +8.3% respectively) and nuclear energy increased by 4.7% (International Energy Agency 2016). However, the other renewable energy sources still totalled to 1% of global production of energy. As reported in literature, the total primary energy supply (TPES) multiplied 2.5 times from 1971 (India: 29%) to 2014 (India: 16%) (International Energy Agency 2016). India produced around 13.2% of the energy produced in Asia in year 2014 (International Energy Agency 2016).

Fig. 2 presents the share of the different fuel sources in the total primary energy supply in World between the years 1971 and 2016. Similar distribution for Asia, between the years 1971 and 2014 is presented in Fig. 3. It may be noted that the share of coal and oil have increased from 41% to 75% whereas the share of bio-fuels reduced from 47% to 13%. Combined with the fact that the total energy has increased by 2.5 times, it may be easily concluded that the dependency on fossil fuels has increased by around 4 to 5 times. Fig. 4 presents the country-wise breakup of the total primary energy supply in Asia in the year 2014. It can be noted that the share of the coal and oil combined account for around 75% of the total for India, and similar values exist for Asia too. This calls for renewed efforts for the harnessing the available renewable energy sources for India. Among the renewable energy sources in India, ocean energy appears to be one of the high potential sources, which has received negligible attention. This situation demands correction if the share of renewable energy in the future energy demand of India is desired to be augmented.

The solution to the problem of increasing energy cost and CO_2 emissions could be reduction in energy consumption, increasing energy efficiency, and tapping of the vast supply of renewable energies. Europe and U.S.A. have, over the last decades, taken positive steps towards reduction in emissions, improving the energy efficiency, and increasing use of renewable energies (Armaroli and Balzani 2011). Similar studies for Australia had been conducted recently for the deep ocean current energy sources for changing over to renewable energy from 90% coal fired stations (Parkar 2015). Ocean energy was deemed suitable as the solar power and wind power technologies had proved to be expensive and ineffective. The non-tidal ocean current speed maps were generated at 30-40 m and 10-20 m from bottom to estimate the recoverable power densities.

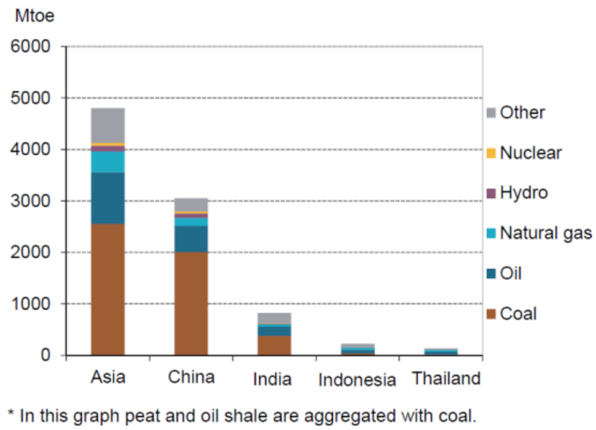

Fig. 4 Total primary energy supply (country-wise) in Asia: 2014 (Reproduced from International Energy Agency 2016)

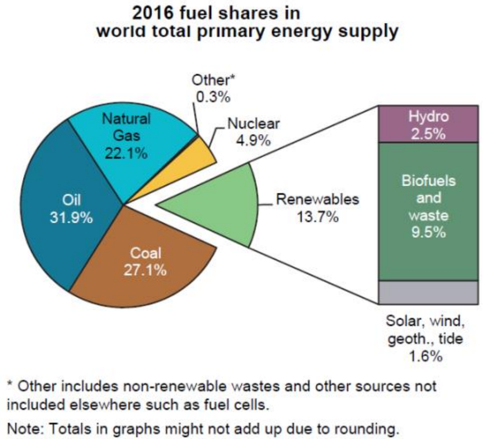

Fig. 5 Fuel Shares in Total Primary Energy Supply in World: 2016 (Reproduced from International Energy Agency 2018b)

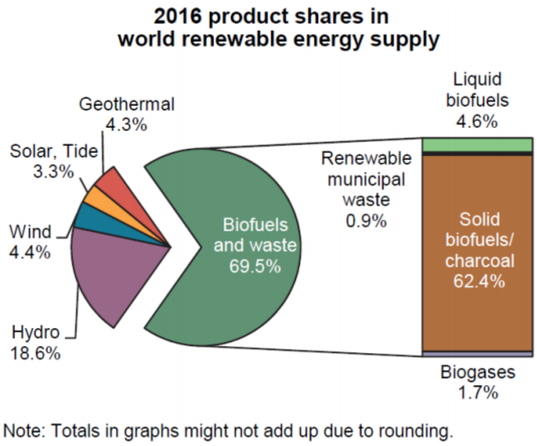

Fig. 6 Fuel Shares in Renewable Energy Supply in World: 2016 (Reproduced from International Energy Agency 2018b)

The various renewable energy sources include hydroelectric energy, wind energy, ocean energy, geothermal energy, and biomass energy. There is some scope of reduction in the use of diesel with the partial replacement of fossil-based diesel with biodiesel. As compared to the fossil fuels like coal and oil, the energies based on the sun, wind, water and earth are better distributed over the planet and are safe (except large hydroelectric plants) due to the low power densities (Armaroli and Balzani 2011). Thus, these sustainable sources should yield the future energy of mankind. The share of renewable in total energy production of the world was 13.7% (1882 MToe) in 2016, as depicted in Fig. 5 (International Energy Agency 2018) and for India the figure is much less.

Looking more closely, the share of ocean energy combined with the solar power is a dismal 3.3% (Fig. 6) of the renewable energy supply for the world in 2016. Especially for the tropical countries with long coastlines, such as India, this share could be much higher, thereby addressing the energy concerns for the remote localities, villages and islands. Particularly, in India, though solar power generation has received some support from the government, similar thrust for ocean energy is yet to come. With a 6000 odd kilometres of coastline, the ocean energy generation has immense potential for being a major contributor to the renewable energy supply in India in coming years.

But due to various factors like traditional use, well established infrastructure, and time-proven technologies, there definitely exists hesitation in the shift from the fossil fuels to renewable energy. The changeover is not possible overnight, but would have to be carefully planned and strategically implemented for the smooth transition towards the sustainable energies. The use of renewable energies would not be 'one solution fits all' option but has to be specially tailored to the availability and technological status for that locality.

The responsibility of bringing about this switchover lies both with the government and the industries. Development of policies favouring use of sustainable energy and providing incentives in form of reduced taxes for such endeavours should be implemented by the government to encourage and slowly direct the energy trend to the sustainable sources. The onus of imparting the education for the sustainable energy also lies with the government. The industries have been the heaviest users of fossil fuel energies and thus, would have to bear the burden of implementation and can enjoy, in the process, discounts in taxes etc. to balance the additional expenses towards the use of renewable energies.

The CO_2 emission by India (according to 2007 figures) was around 4.9% of the world with the electrical consumption around 3.3% of the world (Armaroli and Balzani 2011). The population of India was around 17% of the world at that time (Armaroli and Balzani 2011). Thus, though we are having a low per capita energy consumption, we need to focus on the energy efficiency and the CO_2 emissions. In India, many remote places like islands and small coastal villages, which are far from the national power grids, are susceptible to intermittent or no power supply. There are around 336 Indian islands in Bay of Bengal and Arabian Sea (Joseph and Baba 2012). The tapping of the local renewable energy sources will go a long way to improve the quality of life of the population in such places. India has gathered precious experience in running three types of ocean energy devices over the last few decades. Concerted effort is presently required for utilizing this experience in establishment of small ocean energy plants for coastal villages and islands. These plants may supply electricity as well as fresh water (Ravindran and Raju 2015) for the communities, thereby improving their quality of life. Renewable energy systems have been advocated for small villages and island in literature (Liu *et al.* 2018).

It has been reported that there was no conclusive evidence that marine energy technology would actually cause significant environmental impacts and further advocated that information and research be performed for evaluating the different possible effects (U.S. Department of Energy 2009). The effects would include alteration of currents, wave strength and direction; sediment transport and deposition; transfer of large volume of seawater between different depths; changes in water temperature, nutrients, and gases; habitat of benthic organisms; generation of electromagnetic fields and noise during operation; toxicity of different chemicals used; interference with movement and migration of aquatic organisms by intake and discharge plumes; strike by rotor blades or other moving parts (U.S. Department of Energy 2009). The report further suggests monitoring and adaptive management be adopted for existing and future marine energy plants.

This article broadly reviews the potential and the initiatives of ocean energy in India and outlines a roadmap for the better utilization of the same in future. This would be suitable for solving the energy needs of coastal villages and islands. After introduction to the topic in the present section, the ocean energy technologies are briefly discussed in Section 2. The potential of ocean energy in India is presented in Section 3. The ocean energy initiatives in India are discussed in Section 4 and the various environmental, ecological and other concerns are enumerated in Section 5. The author’s roadmap for future is proposed in Section 6. The article is summarized in Section 7 and this is followed by list of references.

2. Harnessing ocean energy

It has been established from past research and the pilot plants run at few locations in India that the viable ocean energy options for the Indian coastal belts are tidal, wave, and thermal. The idea would be to apply the most appropriate ocean technology device for the remote coastal villages and islands, as a renewable energy source in future. A brief account of each ocean energy technology is presented below.

2.1 Power from tidal energy

The cyclic variations caused by the gravitational attractions of the sun and the moon over time in seas and oceans, are known as tides. Extraction of the energy may happen by the utilization of the cyclic rise and fall for generation of electricity by the use of barrages. The other option is to harness the energy from the ocean currents caused by the tides through the use of the current meter turbines (Meisen and Loiseau 2017). However, in India, the focus has been on the tidal power through barrages, and tidal current technology is not much developed. For further details of the tidal energy devices and technologies readers may refer literature (Waters and Aggidis 2016, Niell *et al*. 2016). Research into tidal current energy devices for the Indian coast would be required to achieve the full potential of the ocean energy in India.

2.2 Power from thermal energy: Ocean thermal energy converter (OTEC)

As concluded by (Meisen and Loiseau 2017), on an average day, 60 million square kilometers (23 million square miles) of tropical seas absorb an amount of solar radiation equal in heat content to about 250 billion barrels of oil. If less than one tenth of one percent of this stored solar energy could be converted into electric power, it would supply more than 20 times the total amount of electricity consumed in the United States on any given day (Meisen and Loiseau 2017). The heat captured by the sea water causes the temperature to rise. The difference in temperature between shallow and deep water are used to drive a heat engine. OTEC is best feasible on the equator. The option of desalination of water for drinking and irrigation along with the generation of electricity makes OTEC attractive option. For further details of the devices and the thermal technologies, literature (Meisen and Loiseau 2017) may be referred. Being a tropical country, Indian coastline can benefit immensely from OTEC devices with the supply of energy as well as potable water.

2.3 Power from wave energy

The power in the ocean waves come from the renewable energy of the wind currents over water. Low profitability has restricted the commercial applications (Meisen and Loiseau 2017). The stochastic nature of the wave energy further reduces their utilization opportunities. The most common wave energy device is the oscillating water column. Other wave energy options include the Pelamis, the wave dragon etc. Azimov and Birkett (2017) presented a feasibility study on wave power station coupled with decommissioned offshore oil platform. The proposed concept saved the cost of decommissioning and provided the offshore oil platform with new life of electricity generation from a renewable source as well. Research should be encouraged for such innovative options for the Indian coasts. Further details for the wave energy devices and technologies may be obtained in literature (Meisen and Loiseau 2017, Azimov and Birkett 2017).

3. Ocean energy potential in India

India has around 150 GW or greater in all the renewable sources like tidal, wave, geothermal, solar while the contribution of the renewable is around 33 GW out of the total installed capacity of 256 GW (October 2014) including all fossil fuel plants (Yadav 2015). The ocean energy sources include the wave energy, tidal energy, tidal and ocean currents, ocean thermal energy converter (OTEC), and salinity gradients. It is indicated that with around 6000 m tropical coastline, wave power, tidal power and OTEC are suitable for India.

In the National Institution for Transforming India (NITI) Aayog program, holistic development of islands and focus on renewable energies are included. The Union Cabinet has approved India becoming a member country of the International Energy Agency-Ocean Energy Systems (IEA-OES) by signing the Implementing Agreement (IA) in January 2016. The nodal agency for the membership would be Earth System Science Organisation-National Institute of Ocean Technology (ESSO-NIOT) under the Ministry of Earth Sciences (Government of India 2016). Ministry of New and Renewable Energy (MNRE) have already initiated research and development in ocean energy for post-2022 India and promised up to 50% funding for ocean energy projects.

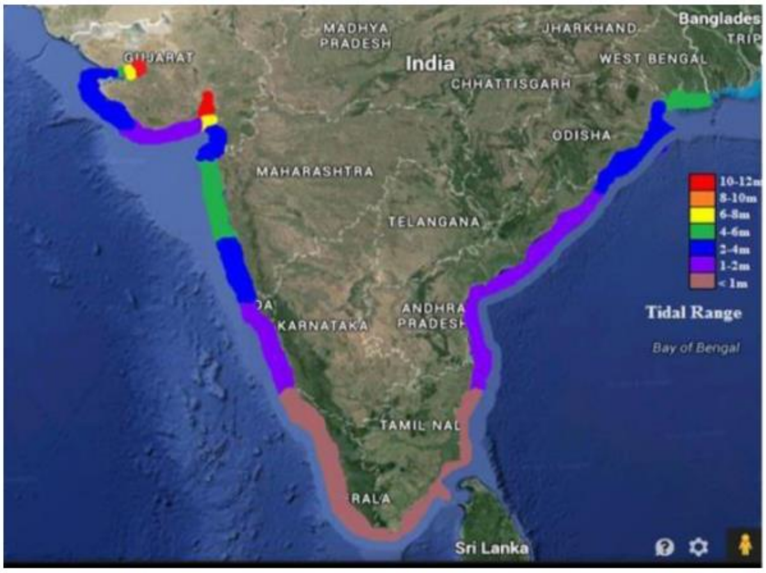

Fig. 7 Tidal range along Indian coast (Reproduced from Agence Francaise de Development *et al.* 2014)

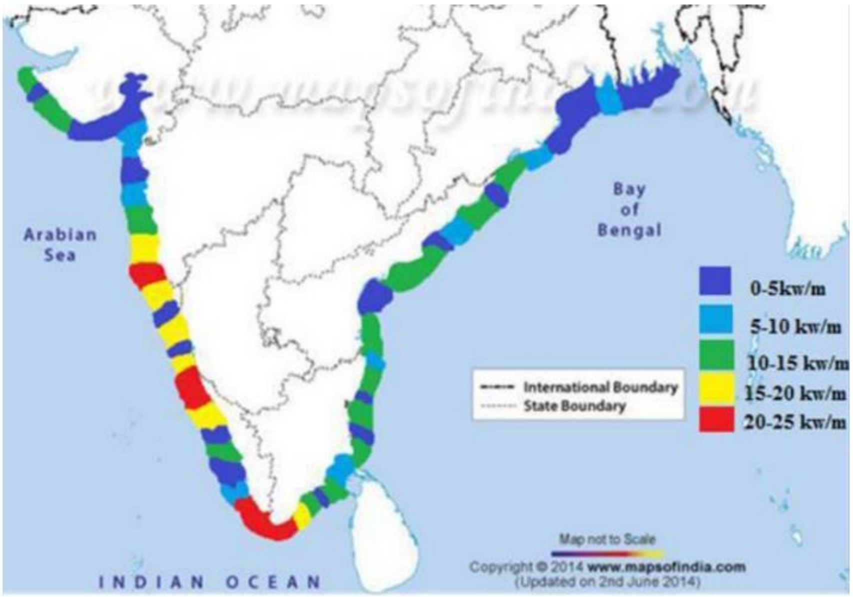

Fig. 8 Wave energy potential along Indian coast (Reproduced from Agence Francaise de Development *et al.* 2014)

3.1 Tidal energy

The tidal power potential along the Indian coast is presented in Fig. 7. Along the coast, it is seen that the most attractive sites are the Gulf of Cambay and the Gulf of Kachchh on the west coast where the maximum tidal range is 11 m (average 6.77 m) and 8 m (average 5.23 m) respectively. Another potential site is in the Ganges Delta (Sunderbans) in West Bengal where the maximum tidal range is approximately 5 m (average 2.97 m). The identified economic tidal power potential in India by MNRE is of the order of 8000-9000 MW with about 7000 MW in the Gulf of Cambay about 1200 MW in the Gulf of Kachchh and around 100 MW in Sundarbans (Sharma and Sharma 2013, Energy Alternatives India 2017).

3.2 Wave energy

The wave power potential along the Indian coast is presented in Fig. 8. Being close to the equator, the Indian potential is poor compared to more northern and southern latitudes. Primary estimates by MNRE indicate that the annual wave energy potential along the Indian coast is between 5 MW to 15 MW per meter, thus a theoretical potential for a coast line of nearly six thousand kilometres works out to 40000-60000 MW approximately (Energy Alternatives India 2017).

3.3 OTEC

For efficient production of power, OTEC requires a temperature difference of about 20℃ (36℉) between the warm surface water and the cold deep water (Energy Alternatives India 2017). Tropical countries like India have high sea surface temperature and hence OTEC would be a good option. Though it is commercially cost prohibitive in the present day, with a long coastline, OTEC has a potential installed capacity of 180,000 MW in India as estimated by MNRE (Energy Alternatives India 2017).

4. Ocean energy initiatives in India

4.1 Tidal energy

Tides are formed due to the gravitational attraction of the moon on the ocean water. Particularly in the estuaries and the enclosed bays, the energy of the tidal rise of water reaches high values, which can be converted to electrical energy. One of the first ocean energy applications in the world was based on tidal energy. The Rance tidal plant was commissioned in 1966 on the Rance river estuary in France. This boasts of an installed capacity of 240 MW and is functioning even today (Ravindran and Raju 2015). Tidal energy plants have been utilized and more projects are planned in future in many countries including Russia, Canada, Korea, New Zealand, Australia, and China.

During high tide, the water level in and around the estuaries and closed bays are substantially higher and this causes a strong flow of water towards the open ocean during ebb. By allowing the water to flow through turbine located in a barrage constructed across the entrance of the bay, power can be generated. Another option is to use the tidal current to drive the turbines distributed in the estuary, creek or channels. Shrouded turbines are known to be capable of generating 3 to 4 times the power as compared to the open turbines. Tidal current energy being periodic, it can be forecasted with accuracy over long time horizons but are highly variable on hourly basis (Uihlein and Magagna 2016).

As mentioned earlier, the most suitable areas in India for exploitation of tidal energy lies in the Gulf of Cambay in Gujarat boasting of a tidal range of 11 m. Another potential application area is the Sundarban region which has a tidal range of 5 m. With government funding, a 3.65 MW tidal power plant has been started in Durgaduani creek in Sunderbans in 2007 (Ravindran and Raju 2015, Sharma and Sharma 2013). Commercial tidal plants are proposed for the Gulf of Kutch by Government of Gujarat (Sharma and Sharma 2013). Government of India (MNRE) would fund up to 50% of the cost of setting up of tidal energy plants (Energy Alternatives India 2017).

4.1.1 Challenges

In case of the barrage concept, the installation cost is very high as the barrage is to be built across the wide bays or estuaries. The power in tidal plants can be improved upon by employing shrouded turbines. There is necessity to innovate and reduce the installation cost of the turbines. Another concern is the possible alteration of the ecosystem of the bay. The power is available only when the tide moves in or out, around 10 hours per day (Energy Alternatives India 2017).

4.2 Wave energy

Wave energy is harvested from the surface waves or the pressure fluctuations below the surface. The kinetic energy generated by the wind blowing over the water surface give rise to the waves. The wave energy converters generate mechanical energy from the motion of the waves. The mechanical energy is subsequently converted to electricity. There are various types of wave energy devices. Float or Buoy System are a series of buoys, mounted on a floating raft or anchored to the seabed, rise and fall with the waves and this movement is used by a generator to generate electricity. Oscillating Water Column (OWC) Device is by far the most popular device. Here, due to the in and out motion of the waves, water alternately rises and descends in a column and force compressed air to turn a turbine. Tapered Channel relies on shore-mounted structure to drive the water coming in with the waves to an elevated reservoir, from which electricity is generated by usual hydropower techniques.

Japan was the first to use the wave power almost 50 years back and application was in navigational buoys. U.K., U.S.A., Australia, Korea, China and India have all started working towards the wave power technologies from 1980s. A prototype 150 kW plant has been installed at Vizhinjam Fisheries Harbour in Thiruvananthpuram (Ravindran and Raju 2015, Sharma and Sharma 2013, Energy Alternatives India, 2017). The average unit cost from this plant works out to be 0.73 Rupees which is almost half of the average unit price of 1.5 Rupees for hydroelectric power (Joseph and Baba 2012). The integration of the wave power plant with the breakwater demonstrates that both the harbour authorities as well as the electricity producer may profit by such associations (Joseph and Baba 2012). The advantages for electricity generator is sharing of cost with the harbour while the harbour authorities benefit with the breakwater facing reduced wave height and loads as the energy is used to turn the turbine and absorbed (Joseph and Baba 2012). Employing the wave power from 50 kW OWC plant, desalination of seawater could be performed for supplying 10,000 litres of fresh water to nearby fishing village (Ravindran and Raju 2015). Such dual applications herald a new era of harnessing the ocean energy along with supplementary benefits, which would positively affect the project life cycle cost.

4.2.1 Challenges

Ocean wave energy is stochastic like the wind energy with low variability over short time scales (hourly) and can be high for longer horizons (Uihlein and Magagna 2016). Wave energy structures need to be robust as they need to withstand very rough weathers and corrosive environment. Another concern is the interference of the devices or transmission lines with the moorings and anchorage lines of commercial and sports fishing, which is common activity along the Indian coast. The low profile wave energy devices may pose threat to the navigation as they may be undetectable by direct sighting or by radar (Energy Alternatives India 2017). A soft issue would be the aesthetic effect of the devices and transmission lines on the scenic ocean face (Energy Alternatives India 2017).

4.3 OTEC

The generation of energy from OTEC is based on conversion of the solar energy stored in the seawater into usable energy. The seawater at different temperatures has different densities and this is used to drive a power cycle. Thus, with a difference of temperature of about 20℃ (36℉) OTEC plant can perform efficiently (Energy Alternatives India 2017).

A prototype 1 MW plant “Sagar Sakthi” has been established 35 km off Tiruchendur coast in 1982 (Ravindran and Raju 2015, Energy Alternatives India 2017). National Institute of Ocean Technologies (NIOT) is successfully operating a desalination plant of 0.1 million litre capacity employing open cycle OTEC technology at Kavaratti, Lakshadweep islands (Ravindran and Raju 2015). In year 2007, a floating desalination plant of 1 million litre capacity was deployed at a depth of 1000 m (Ravindran and Raju 2015).

4.3.1 Challenges

The main barrier for the OTEC to be commercially viable is the cost, which presently is more than the electricity generated from fossil fuels (Energy Alternatives India, 2017). The ocean depths should be available close to the shore for shore-based operations and also have a temperature difference of around 20℃ (36℉). Thus, identification of locations would be challenging. Establishment of the OTEC farms and the pipelines would affect the ecosystem; monitoring and minimizing these effects would be desired.

5. Environmental, ecological and other considerations

Like other technologies of harnessing natural resources, ocean energy technologies have environmental impacts which have to be carefully considered along with other issues like legal, economic and social. These are briefly discussed in this section. A study by U. S. Department of Energy evaluated possible environmental effects that might occur due to the marine and hydrokinetic energy technologies. They enumerated nine such potential impacts and further discussed the role of monitoring and adaptive management principles for evaluation and mitigation (U.S. Department of Energy 2009). The impacts identified included human use conflicts, aesthetics, view-sheds, noise in terrestrial environment, light, recreation, transportation, navigation, cultural resources, socio-economic effects.

5.1 Environmental

Though the ocean energy generation does not directly produce greenhouse gases, the production of the components and development of the infrastructure does produce them. However, during operation of the ocean power plant does not cause emission issues. The life cycle analysis of the ocean energy plants since 1980-s suggested that lifecycle GHG emissions from wave and tidal energy systems are less than 23 g CO_2eq/kWh, with a median estimate of lifecycle GHG emissions of around 8 g CO_2eq/kWh for wave energy (Lewis *et al.* 2011). The visual impact of the near-shore installations have to be considered. There may be reduction in the waves and this needs consideration particularly for the surfing beaches. Fishing, boating, swimming and other recreational activities may be hampered due to the ocean energy installations.

Positive effects from ocean energy farms may include the strengthening of energy supply and regional economic growth, employment and tourism (Lewis *et al.* 2011). The ocean current energy devices would be having insufficient scale to alter ocean circulation or net mass transport but could change the meander patterns and upper-ocean mixing processes (Lewis *et al.* 2011). Alterations in wave and current strength and direction, sediment transport and deposition, noise during construction and operation, toxicity of paints, lubricants, and antifouling coatings would contribute to the environmental impacts (U.S. Department of Energy 2009).

5.2 Ecological

The ecological impact of the ocean energy farms have been discussed by Boehlert and Gill (2010). It had been mentioned that there can be possible positive effects from ocean energy such as avoidance of adverse effects on marine ecology due to reduction of other human activities in the area around the ocean devices. The potential adverse effects would include disruption to biota and habitats, water quality changes and possible pollution due to the noise and vibration, electromagnetic fields and injuries caused to the local biota by the collisions with the plant installations and the transmission cables. The operation of a barrage for tidal energy will affect the amplitude and timing of the tides inside the basin, and modify fish and bird life and habitat, water salinity and sediment movements in the estuary (Lewis *et al.* 2011).

Interference with animal movements and migrations, including entanglement as well as strike by rotor blades or other moving parts would be important issues (U.S. Department of Energy 2009). Generation of electromagnetic fields may interfere with the fauna such as whales which use the electromagnetic signals for navigation and search of prey (Boehlert and Gill 2010). For the OTEC, large volumes of cold deep ocean waters and warm shallow water would be mixed thereby altering the temperature, gas and nutrient content of the seawater discharged into the water surrounding the plant (U.S. Department of Energy 2009, Lewis *et al.* 2011). This could adversely affect the local ecology. Entrainment of the aquatic organisms into the intake and discharge plumes would have to be considered (U.S. Department of Energy 2009).

5.3 Legal and social

The wave or current energy devices installed in international waters by a country might affect the available ocean energy, and hydrodynamics on another country's waters and this have to be resolved by International regulations (Ocean Energy Resource 2017). Once constructed, barrages constructed for tidal plants could provide new and shorter road transport routes along the top of the barrage walls, thereby improving the socioeconomic conditions for local communities (Lewis *et al.* 2011). Submarine naval operations may get affected due to the submerged devices whereas the on-surface as well as the submarine naval operations and commercial vessels would get disturbed by the floating / on-bed installations.

5.4 Economic

The emerging and developing technologies are always more expensive till it reaches the commercially viable level. Same is the case with the ocean energy technologies. This may be addressed by Government policies such as direct funds assistance/easy loans, and indirect tax incentives (Ocean Energy Resource 2017). The other helpful Government policies may be promoting education in the ocean energy technologies through scholarships, research facilities and educational programs (Lewis *et al.* 2011). The ocean energy being in the fledging stage in India, the government policies would be a critical factor for tapping this vast renewable energy resource in India.

5.5 Prevention and mitigation of the adverse impacts

The U.S. Department of Energy study (U.S. Department of Energy 2009) identified the possible methods to prevent and mitigate the adverse impacts by the ocean energy installations on the environment and ecology which included avoiding the impact altogether by not taking a certain action; minimizing impacts by limiting the degree or magnitude of the action; rectifying the impact by repairing, rehabilitating, or restoring the affected environment; reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; and compensating for the impact by replacing or providing substitute resources or environments. Further details for the study for U.S. may be found in the report (U.S. Department of Energy

2009). The mitigation policies would have to be tailor-made for the particular type of ocean energy device and the ambient environment and ecology in which the device is being placed. In India such studies are scarce. Before and after studies for the ocean energy plants being presently installed might be taken up as mandatory activity for generation of data. This data would be helpful in formulation of the policy for monitoring and mitigation of the adverse effects of future ocean energy installations in India.

6. A roadmap for future

As brought out in the foregoing discussion, there is ample promise of the ocean energy for providing electricity to the remote coastal villages and islands in India. The various challenges for the different options of ocean energy in India have also been discussed. In order to actually harvest the ocean energy in the near future, the efforts have to be on different fronts like awareness, research, technology, infrastructure, and government policies. MNRE, Government of India, has already estimated the ocean energy potential for Indian coast and is putting funds into research and development, and implementation of ocean energy plants. A study for evaluation of the ocean energy potential for regions around the Western Indian Ocean by Hammer *et al.* (2012) focused on technology-specific requirements for ocean energy technologies (such as wave power, ocean thermal energy conversion, tidal barrages, tidal current turbines, and ocean current power) and the physical resources available. It was reported that the potential for wave power over long stretches in southern parts of the Western Indian Ocean was very high whereas potential for OTEC at specific locations in Mozambique, Comoros, Reunion, and Mauritius was promising. The temporal variations as well as the differences due to large scale and small scale installations for ocean energy were discussed. Similar studies would be required for the Indian coast and can be conducted by government agencies/government funded institutions.

The public awareness regarding the impending energy crisis and the inevitability of the switchover to sustainable sources have to nurtured–this would be the responsibility of the government as well as the non-governmental organisations (NGO) working hand-in-hand for propagating the sustainable energies.

One of the main reasons for the utilization of the ocean energies being limited is the commercial non-viability. Research has to be directed towards making the ocean energy cost-efficient with new technological innovations. Research is also required in analysis of the environmental and ecological impacts of the ocean energy farms, and towards evolving solutions to work around these environmental and ecological impacts to make the ocean energy truly sustainable.

Along with the partial funding as promised by MNRE, government policies should be formulated to reward the industry for making use of the renewable energy. The participation of the big industries towards the technological development required for making the ocean energy cost-effective has to be encouraged by the government in the form of tax rebates etc. The government should bear the expenses towards survey and analysis for the identification of the suitable ocean energy option for the target coastal villages or islands for ocean energy and / or freshwater need. This information may be made available on the web along with the incentives offered for the respective target locations for the corporate houses to evaluate and participate.

The author proposes that the industry be encouraged to ‘adopt’ one or more coastal village/island in respect of the energy / freshwater needs. The information and policy guideline for

Table 1 Suggested timeline for implementation of ocean energy program in coastal villages and islands of India

Sl. No.	Activity	Timeline (years)									
		1	2	3	4	5	6	7	8	9	10
1	Survey and publication of report on potential energy along Indian coastline	■	■			■	■	■			
2	Formation of guidelines, research grants, commercial rules and regulations (including declaration of government incentives)		■	■			■	■			
3	Public and industry awareness		■	■	■	■	■	■			
4	Research towards commercial viability, ecological and environmental impacts	■	■	■	■	■	■	■	■	■	■
5	Prototype development for different scenarios				■	■	■				
6	Pilot villages and islands					■	■	■			
7	Large scale implementation							■	■	■	■
8	Before and after studies, monitoring			■	■	■	■	■	■	■	■

tapping the ocean energy would be issued by the government. The research and development can come from the local educational institutions and there can be scholarships (by government and industries) for research in some particular area. The involvement of the local researchers would ensure better identification with the problem and motivation for solution. The finer details and the implementation plan would be developed by the corporate house and would be reviewed by an expert committee appointed by the government, especially with regards to the environmental and ecological impacts of the proposal. Here again, the educational institutions can play a vital role. The successful implementation and continued operation would assure the tax discounts for the corporate house. A suggested first-cut plan of timeline is presented in Table 1, which could evolve depending upon the technological breakthroughs, government policies, or other constraints. With the present planning, the remote coastal villages and the islands in India may benefit from the ocean energy within a decade. In certain locations, where OTEC devices would be viable, the benefit to the local community, in addition to the energy, would be potable water supply.

The local educational institutions as well as government bodies should be engaged in before-and-after studies for evaluation, assessment, prevention and mitigation of the adverse effects on the environment and ecology of the region, if any, due to establishment and operation of the different ocean energy technologies adopted for the various locations. The regulatory framework for the monitoring of this activity should be set up by the central government. The cost and the responsibility of implementation of the mitigation measures should again fall on the same agency, which runs the particular ocean power plant.

This policy would develop the technology, train local manpower and establish the ocean energy as a viable option for the future. The corporate houses would also be able to fulfil their moral obligation towards the society and to a certain extent, repay the debt they owe for being the heaviest users of the fossil fuels over the last century. The huge expenses required for extending the national energy grid to the remote places could be avoided. The government would be able to implement one sustainable energy plan with minimal changes in the budgetary allocations. The main beneficiary in this whole process would be the communities residing in the remote coastal villages and islands with their quality of life improved by availability of the electrical energy and fresh water, as well as the training of local manpower and creation of jobs. Thus this could become a realistic sustainable renewable energy option for the remote areas near oceans.

7. Conclusions

This article started with the pressing needs for the switch-over from fossil fuels to the renewable and sustainable energy options, as applicable for the world and particularly for India. Ocean energy was indicated as one of the possible energy solutions for the coastal villages and islands in India, which has received scanty attention from the researchers, government as well as the industry till date. With a long coastline of more than 6000 kilometres, the immense ocean energy potential in India was indicated and the ocean energy initiatives in the recent years were discussed along with the challenges in the respective areas. The possible adverse impacts of ocean energy installations were highlighted and the regulation and mitigation measures were discussed. A roadmap for the future, which calls for synergistic interaction of the educational institutions, the government, the corporate houses and the local community towards evolving the ocean energy solutions for remote coastal villages and islands, was proposed. With the present first-cut planning proposed by the author, the implementation of the ocean energy plants for the remote coastal villages and islands in India could happen within next decade provided the government and industry participation occurs along with the public awareness and active participation in the program. This would go a long way in solving the energy and potable water needs for the remote locations along the Indian coast.

References

Agence Francaise de Development (AFD), Indian Renewable Energy Development Agency Limited (IREDA) and I.I.T. Madras (2014), *IIT Madras Report: Study on Tidal & Waves Energy in India: Survey on the Potential & Proposition of a Roadmap*.

Armaroli, N. and Balzani, V. (2011), *Energy for a Sustainable World*, Wiley-VCH Verlag & Co., Germany.

Azimov, U. and Birkett, M. (2017), “Feasibility study and design of an ocean wave power generation station integrated with a decommissioned offshore oil platform in UK waters”, *Int. J. Energy Environ*., **8**(2), 161-174.

Boehlert, G.W. and Gill, A.B. (2010), “Environmental and ecological effects of ocean renewable energy development: A current synthesis”, *Oceanography*, **23**(2), 68-81.

Energy Alternatives India (2017) Ocean Energy in India: Energy from Tidal and Waves, <http://www.eai.in/ref/ae/oce/oce.html>.

Government of India (2016), Cabinet Press Release, <http://pib.nic.in/newsite/PrintRelease.aspx?relid=134427>.

Hammar, L., Ehnberg, J., Mavume, A., Cuamba, B.C. and Molander, S. (2012), “Renewable ocean energy in the Western Indian Ocean”, *Renew. Sust. Energy Rev*., **16**(7), 4938-4950.

International Energy Agency (2016), Key World Energy Trends: Excerpt from World Energy Balances, <http://www.iea.org>.

International Energy Agency (2018a), Key World Energy Statistics, <https://webstore.iea.org/download/direct/2291?fileName=Key_World_2018.pdf>.

International Energy Agency (2018b), Renewables Information: Overview from International Energy Agency, <https://webstore.iea.org/download/>.

Joseph, P.S. and Baba, M. (2012), “Linking of coastal wave energy utilization with coastal protection”, *ARPN J. Sci. Technol.*, **2**, 169-174.

Lewis, A., Estefen, S., Huckerby, J., Musial, W., Pontes, T. and Torres-Martinez, J. (2011), *Ocean Energy, in IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*, Cambridge University Press, Cambridge, U.K. and New York, U.S.A.

Liu, Y., Yu, S., Zhu, Y., Wang, D. and Liu, J. (2018), “Modeling, planning, application and management of energy systems for isolated areas: A review”, *Renew. Sust. Energy Rev.*, **82**, 460-470.

Meisen, P. and Loiseau, A. (2017), *Ocean Energy Technologies for Renewable Energy Generation*, Global Energy Network Institute, <http://www.geni.org>.

Neill, S.P., Hashemi, M.R. and Lewis, M.J. (2016), “Tidal energy leasing and tidal phasing”, *Renew. Energy*, **85,** 580-587.

Ocean Energy Resource (2017), <http://www.uprm.edu/aret/docs/Ch_3_Ocean.pdf>.

Parker, A. (2015), “Deep ocean currents energy resources–A case study of Australia”, *World J. Model. Simul.*, **11**(3), 163-173.

Ravindran, M. and Raju, V.S. (2015), “Ocean energy”, *Proc. Indian Nat. Sci. Acad.*, **81**(4), 983-991.

Sharma, R.C. and Sharma, N. (2013), “Energy from the ocean and scope of its Uutilization in India”, *Int. J. Environ. Eng. Manage.*, **4**(4), 397-404.

U.S. Department of Energy (2009), *Report to the Congress on the Potential Environmental Effect of Marine and Hydrokinetic Energy Technologies*, Wind and Hydropower Technologies Program, Energy Efficiency and Renewable Energy, U.S. Department of Energy, U.S.A.

Uihlein, A. and Magagna, D. (2016), “Wave and tidal energy–A review of the current state of research beyond technology”, *Renew. Sust. Energy Rev.*, **58**, 1070-1081.

Waters, S. and Aggidis, G. (2016), “Tidal range technologies and state of the art in review”, *Renew. Sust. Energy Rev.*, **59**, 514-529.

Yadav, H.J. (2015), “Recent developments of ocean energy in India–An overview”, *Int. J. Recent Innov. Trend. Comput. Commun.*, **3**(12), 6717-6721.

CC