

Energy and freshwater in the context of blue economy

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Blue economy is seen as monetization of resources from the ocean in a sustainable manner. However, intangible resources like energy and freshwater from the sea are as important and can play a dual role in not only mitigating climate change, but also helping the economy through better health of the people, job creation, wealth generation, capacity building of the offshore industry and developing indigenous technologies. The energy–water nexus can be addressed efficiently with novel ocean technologies for harnessing both power and freshwater from the oceans. National Institute of Ocean Technology, Chennai, India has developed several technologies which can and have changed the lives of the coastal and island populations in a sustainable manner.

Keywords: Blue economy, climate change, energy, freshwater, ocean technologies.

Introduction

TODAY, the world over climate change, sustainable technologies and blue economy are being considered important. The current scenario has climate change and global warming as impending world disasters. In the Indian context effects of climate change are many and one of them is water stress. Apart from water management and rainwater harvesting, the need now is for augmentation of water by various means. This can be achieved by wastewater treatment and desalination. However, all such methods require energy and thus while trying to mitigate the effects of climate change, we are worsening it. This can be addressed using renewable energy. This is a known mitigator of carbon emissions and greenhouse gas (GHG) emissions. At present the primary source of energy in the world is from fossil fuels. Oil, coal and natural gas dominate the share of fuels used and are also relatively easy to extract. However, it is also now established that the burning of fossil fuels causes air pollution and emission of anthropogenic GHGs with carbon dioxide being the most important. The Paris Climate Agreement or COP21 (December 2015) under the United Nations Framework Convention on Climate Change (UNFCCC), aims to reduce the emission of gases that contribute to global warming. The Agreement was signed by several countries, but issues still prevail where some deve-

loped countries would like to withdraw when they are known to be large polluters, and the less developed countries have larger issues like eradication of poverty and would need technologies and finances to implement the reduction of gas emissions. Subsequent COP meetings are still debating the issues involved. In such a scenario where consensus is not likely soon, the move to renewable sources of energy will continue to be slow.

The other reason for the slow move to renewables is the technological aspects leading to high costs. Most of the renewable sources are not baseload sources and the range of occurrence varies from region to region around the globe. The design and continuous operation of these technological systems with issues in grid integration are challenging. However, solar and wind energy today have been able to break the barrier to a large extent. In India, the targets and mandates set by the Government have led to larger penetration of solar photovoltaic (PV) and onshore wind turbines which are being extensively installed to meet specified goals.

Apart from solar and wind energy, we need to explore other forms like ocean energy as well. Given the long coastline of India and a huge exclusive economic zone (EEZ), towards the efforts for mitigation of climate change, it is important to develop new technologies for harnessing ocean energy. However, it may also be emphasized that ocean energy has an important role in the blue economy domain.

As is known, blue economy consists of several areas like mapping of the seas, maritime security measures, harnessing economic potential out of the oceans, and several more. Both ocean energy and water apart from reducing carbon emissions and mitigating water stress respectively, also have economic potential and are important in the blue economy domain.

Ocean energy devices apart from serving coastal communities can be used as offshore hubs for various charging purposes leading to fewer port entries and berthing charges. Freshwater generation using seawater desalination can be addressed using a revenue model with local water authorities for the coastal states. Thus, both ocean energy and desalination can play a big role in the blue economy objectives. The Indian coastal areas have a paucity of power and water. New technologies and their scaling-up at the commercial level are necessary to mitigate the shortages.

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Figure 1. Hydrokinetic turbine tested at Andaman Islands, India.

The National Institute of Ocean Technology (NIOT), Chennai, Tamil Nadu, India is involved in the development of devices to harness energy from the ocean resources in a clean and efficient manner along the coastline of Indian mainland and islands. The three forms of energy, viz. hydrokinetic energy from the ocean currents, wave energy and energy from the ocean thermal gradient have been the prime focus at NIOT. Various devices at small scales have been developed and successfully demonstrated in the sea. The oceans are a huge repository of renewable energy resources and no road map is available for harnessing them. Apart from the potential benefits to coastal populations, the offshore expertise developed for harnessing these resources can directly assist the offshore capability and indigenization. The next section discusses the various resources available and device development by NIOT.

Ocean renewable energies

Energies that can be harnessed from or at the ocean are wave, tidal, thermal gradient or ocean thermal energy conversion (OTEC), offshore wind and floating solar PV. The latter two forms are not considered ocean energies since the motive force is not water. Salinity gradient is also a possible form, but not yet viable. Today all or any of these forms is the need of the hour for coastal regions, and remote locations and islands. It is known that wave energy density as also marine currents are lower in the tropical regions than in the northern latitudes. This has led to the understanding that it may not be viable to harness wave energy in India. However, what is seldom understood is that, in the northern latitudes though the potential is high, large prototypes have failed in severe cyclonic conditions due to which though the devices are successful, their safety and reliability are still under question. Various devices at small scales have been developed and successfully demonstrated by NIOT in the open sea, which are discussed in the following sub-sections.

Marine hydrokinetic turbines

Ocean currents are driven by wind and solar heating of the waters near the equator, although some currents result

from variation in water density and salinity. Ocean currents are much slower compared to wind speeds. However, water is about 835 times denser than wind; so a smaller water flow can be equivalent to wind with extremely high velocity. Energy from ocean currents can be extracted using submerged turbines that capture energy from hydrodynamic lift and drag forces acting upon them.

Towards developing these turbines, a small capacity unit has been indigenously developed using computational and experimental techniques. Upon successful testing of the turbine in controlled conditions of the laboratory, it was successfully tested in the MacPherson strait, South Andaman, India, by suspending the turbine from a floating platform specially designed for this purpose (Figure 1). The turbine generated electricity of about 300 W and consistent performance was achieved throughout the sea trial of a few weeks. Following the satisfactory open sea trial of this small unit, now the efforts are on to scale up the turbine¹. Modules of 1–5 kW ocean current turbines are in advanced stages of development since off-grid units of these ratings are of great utility in the Andaman and Nicobar Islands, India.

Wave energy

NIOT has pioneered the development of wave energy harnessing systems in India. It has carried out several experiments at the bottom-mounted oscillating water column (OWC)-based wave energy test facility at Vizhinjam, Kerala, India², and successfully generated electricity which was used to power a seawater reverse osmosis (SWRO) plant³. The facility was decommissioned after successful demonstration of the wave-powered desalination system. Subsequently, NIOT has developed a floating wave energy device, backward-bent ducted buoy (BBDB) (Figure 2), and a wave-powered navigational buoy (Figure 3). The technology for the latter has been transferred to industry since it has great utility in ports and harbours. This device has produced ~1 kW in the sea, much more than the requirement. This indigenous OWC-based navigational buoy can be an alternative to the solar-powered navigational buoys mostly imported now.

Ocean thermal energy conversion

Being close to the equator, the sea surface always remains warm in the Indian waters (27° – 30°C). The temperature of the ocean varies with depth. The profiles indicate that the temperature in around 1000 m water depth could be as low as 6° – 8°C . This difference in temperature between the sea surface and at greater depths can be utilized to harness energy by running a Rankine cycle-based power plant with suitable working fluid. This is known as the ocean thermal energy conversion. NIOT started work on OTEC by building a 1 MW barge-mounted plant⁴⁻⁷. Due to severe paucity of offshore infrastructure, this project had to be carried out with serious limitations and hence could not be completed. However, the same concept of utilizing the thermal gradient was employed by NIOT in shallower waters for the development of low-temperature thermal desalination (LTTD) technology initially in the laboratory and then in Kavaratti Island of Lakshadweep, India. Further details are discussed in the next section.



Figure 2. Backward-bent ducted buoy.

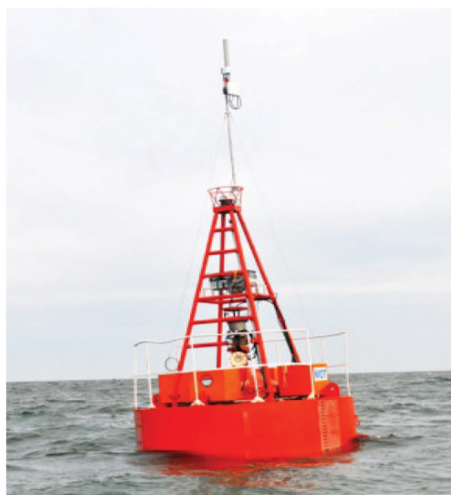


Figure 3. Wave-powered navigational buoy.

Other forms of energy

The other form of energy that needs serious consideration is bioenergy. While algal blooms are otherwise detrimental to the coastal habitat, marine algae can be used to obtain biodiesel and several studies are underway in Council of Scientific and Industrial Research laboratories in this regard. However, these studies are still confined to the laboratory and need to be scaled-up to commercial levels.

While large solar fields are already functional on land, floating PV is an area that needs focus. Floating solar PVs have been employed in lakes and other calm water bodies. The challenge is to go offshore and design the platforms for all-weather performance. This needs to be taken up since land in coastal areas is at a premium and going offshore is the way forward. Offshore wind energy is also required to be expanded. Offshore power generated from wind turbines is expected to be higher than onshore power owing to higher wind speeds offshore. However, marine installation of wind power generators is yet to be done in India. Efforts are being made by the Ministry of New and Renewable Energy (MNRE), Government of India, to install the first offshore wind project. Its success can lead to more such plants, especially off Rameshwaram or off the Gujarat coast, where the wind potential is higher than in other locations.

While we consider of mega/giga watts as the only way forward to achieve the targets of renewable energy, in a large populous country like India with a huge coastal population and severe power deficit, every watt matters. Remote



Figure 4. Saline water lantern.



Figure 5. Desalination plant at (a) Kavaratti Island; (b) Agatti Island; (c) Minicoy Island, India.

coastal locations invariably face power shortages and the need of the hour is a small, clean energy lamp which would not need batteries. The saline water lantern developed by NIOT is one such example (Figure 4). This lamp uses two electrodes and salt water. The small power it generates powers a LED lamp lighting the power-deficit coastal areas. This can serve as a common lighting device in every home not only on the coast but also in the hinterland, since it can work with ordinary tap water mixed with salt. Additionally, it can also charge mobile phones and hence can be useful for communication in disaster-prone areas.

Thus, ocean energy is not only the future path to alleviate climate change by reducing GHG emissions, but also a revenue generator for the blue economy. The other focus of this article is the alleviation of water stress using desalination and the next section presents some details.

Desalination

Desalination of seawater/brackish water has become a technologically viable solution to tackle the challenges associated with increasing water shortages existing in many parts of the world, with reasons also being attributed to climate change. Desalination refers to the process by which potable water is recovered from seawater/brackish water by removing dissolved solids using different forms of energy.

There are largely two types of desalination, viz. the thermal and membrane technologies. Some of the popular technologies are listed below^{8–11}.

The thermal technologies include: multi-stage flash (MSF), multi-effect desalination (MED) and mechanical/thermo vapour compression (MVC/TVC).

The membrane methods include: reverse osmosis (RO), forward osmosis (FO), electrodialysis (ED) and membrane distillation (MD).

These technologies have been deployed around the world and RO has a large market share today. Thermal technologies tend to be more energy-intensive but are robust and easy to operate. Membrane methods can have environmental impacts and are hard to operate. NIOT has developed a technology using the ocean thermal gradient described in the next section.

Ocean-based low-temperature thermal desalination

Lakshadweep and Andaman Islands have power scarcity as well as water stress. Their power requirements are met by diesel generators and water stress is still rampant. In Lakshadweep, RO plants were employed earlier, but they failed due to higher maintenance and periodic replacement of the membrane. Further, RO needs chemicals for pre- and post-treatment, and skilled operators. The quality of input seawater dictates the quantity of output water. Additionally, brine disposal is another burden. Though RO was used due to paucity of good-quality drinking water, repeated failure of the units demanded other technologies for the Islands.

In 2005, a 100 m³/day land-based plant was commissioned at Kavaratti Island (Figure 5 a). This plant has been continuously generating freshwater for the past 18 years to meet the drinking water needs of the Island community. The water is of excellent quality and has truly changed the lives of the islanders, especially the health of the people. This indigenized technology has been deployed in two more islands of Lakshadweep, namely Agatti and Minicoy in 2011 (Figure 5 b and c respectively) and also in Kalpeni and Amini in 2023 (Figure 5 b and c). Installation of LTTD plants in another four islands (Androth, Chetlat, Kadamat, and Kiltan) is now nearing completion.

In these plants, the thermal gradient between surface and deep layers of the ocean water column that provides huge reservoirs of warm and cold water was effectively utilized for desalination^{12–14}. Figure 6 shows a schematic diagram of the LTTD unit.

When seawater at around 28°C is passed through vacuum, it can boil even at this low temperature and the vapour so generated can be condensed using the cold water siphoned from greater depths. The water thus generated is of high quality and this cycle can run continuously since the thermal gradient in the ocean is nearly uniform for most of the year. As Figure 6 indicates, only a flash chamber and condensers are required along with the vacuum and seawater pumps, making the system easy to operate and maintain.

LTTD has been a remarkable story of indigenous technology development touching the lives of the people while mitigating climate change. The local islanders with training

are running and maintaining the plant, which has become the main source of good drinking water. Medical surveys indicated that the health of the islanders has improved considerably due to the availability of good-quality drinking water.

These are the first ever plants in the world from concept to commissioning using naturally occurring temperature differences, completely designed and implemented by NIOT. The construction and establishment enhanced NIOT's expertise in complex civil construction and installation of pipelines. Today, these plants stand as a shining example of the 'translation of engineering for societal benefit', and also for addressing water stress in an environment-friendly manner with no toxic by-products, thus eliminating anthropogenic impacts on the pristine island ecology.

In general, pollution has a connotation of harmful contaminants in air and water bodies through chemicals, solid wastes, dumping of garbage and vehicular emissions. However, thermal pollution is an important issue today, which needs to be addressed in the context of climate change. Thermal pollution occurs when harmful heated liquid is let out in the body of water, or heat is released into air due to industrial discharges/waste. The power-generating units use water at normal ambient temperatures and let out large quantities into open water systems at higher temperatures, leading to thermal pollution.

Environmental norms dictate a certain margin above the ambient for the hot water from power-plant condensers. However, due to various reasons, the temperature of the discharged water by most coastal thermal power plants is higher than desirable.

The LTDD technology was therefore utilized for the generation of freshwater from waste heat from the coastal thermal power plants, and a pilot project was successfully demonstrated at North Chennai Thermal Power Station (NCTPS) using their condenser reject water (Figure 7). The NIOT plant tapped the intake to the condenser and outlet from the condenser to demonstrate the technology and generated around 150 m³/day using a temperature gradient of ~9°C.

Large quantities discharged at less warmer temperatures can truly prove to be beneficial to the environment, thus

mitigating climate change. If this system is adopted when power plants are in the early stages of planning, the LTDD plant can play the role of cooling towers, avoiding the requirement of energy to cool the outlet water and produce freshwater useful for nearby coastal communities.

As stated earlier, desalination systems need energy. However, from the climate change perspective, powering desalination systems with renewable energy can be a game changer. An OTEC-powered LTDD desalination would be the right solution. NIOT has taken up the challenge of building a 0.1 million litres per day (MLD) plant in Kavaratti. Details are provided in the next section.

Renewable energies and water

All treatment and desalination systems are energy-intensive and hence we need to address the energy–water nexus. The more we desalinate or treat waste/grey water, the more the requirement of energy. The time has come, therefore, to address this need by the use of renewable forms of energy. It is therefore important to use renewables to power the process. There have been some developments for such hybrid systems, but they are few and need further proliferation in various sectors. Following are some of the systems which have been successfully proven and are being used for scaling-up/commercialization.

Solar pumps

Solar PV water pumping system, commonly known as a solar pump, is an off-grid, stand-alone system operating on power generated by solar PV panels¹⁵.

Solar PV–RO

Solar PV systems connected with RO systems have been used in several places. This is considered to be one of the

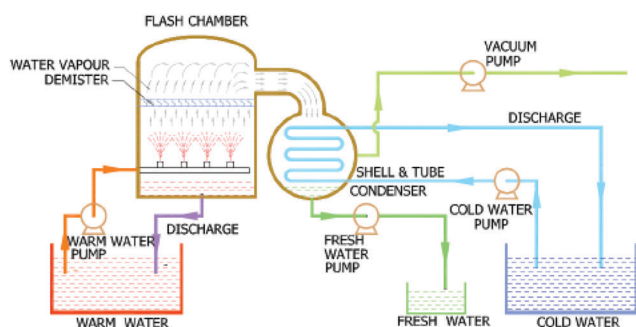


Figure 6. Schematic of the low-temperature thermal desalination unit.



Figure 7. NCTPS desalination plant.

best options for renewable energy-powered desalination, particularly for remote areas and the hinterland, as both PV and RO are highly modular and scalable.

Solar – multi-effect distillation

In thermal desalination, solar thermal has been used in a MED system and has been successfully demonstrated. The solar thermal field with a sophisticated tracking system was used to generate steam, which in turn enters the MED system to generate freshwater. Here again, the lack of availability of solar energy throughout the day makes the system depend on another form of energy (Figure 8).

OTEC-powered LTTD

Since LTTD and OTEC utilize the same resources, it is logical that power generated by an OTEC module can also power an LTTD module from the same plant. Sharing the infrastructure for seawater handling systems can bring down the overall cost of freshwater generation. Towards this end, NIOT has now undertaken to establish an OTEC-powered desalination plant at Kavaratti. It will be the first ever prototype plant generating power and freshwater utilizing a naturally occurring ocean thermal gradient. The main challenge with OTEC is to generate significant amount of power from a small temperature difference. However, the ocean thermal energy is clean and renewable as the heat source and heat sink possess infinite heat capacities.

The thermal desalination plant being set up in Lakshadweep will be powered by the ocean thermal gradient which is $\sim 9^{\circ}\text{C}$. The power generation will use OTEC and desalination will use LTTD, eliminating the use of diesel generators. Though the plant has several complexities, it will be completely indigenous and is expected to be completed in 2024 producing 0.1 MLD of water.

The need therefore is to think out of the box and explore other forms of clean energy to power desalination systems,



Figure 8. Solar multi-effect desalination plant at Ramanathapuram, Tamil Nadu, India.

and ocean energy is one such arena. Since wave, solar and wind are all dependent on the time of day, season and other environmental conditions, all these forms of energy need storage or augmentation with the grid power. Base load power such as OTEC does not have such restrictions.

The indigenous LTTD technology developed by NIOT has no requirement for membranes; therefore no brine formation and environmental pollution. Thus, the LTTD technology is also environmentally and ecologically safe.

Challenges

Currently, the first ever OTEC-powered desalination plant is under implementation by NIOT in Kavaratti. Though OTEC is capital-intensive, scaling-up the technology with higher capacities can lower the costs.

The Indian offshore industry needs to be seriously improved and to this end, prototype demonstration projects are important to facilitate the learning curve. Offshore floating platform for OTEC in deep water involves a platform, moorings and a complex cold water conduit to draw water continuously from deep waters. The challenges involved are many and can lead to huge capacity building at all levels of engineers, analysts, designers, shipyards, installation contractors and handling mechanisms onshore and offshore. Today, world over, offshore wind is being studied and some implementations have taken place across the world. This also needs to be employed in India to understand the techno-commercial viability. Floating solar PV has been attempted in many countries, and many are on rivers and backwaters. The real challenge is to have floating solar platforms in the open sea.

An important fact is that even today solar power components are about 80% imported. To reduce dependency on imports, it is necessary to develop the panels and raw materials in India. This calls for a complete shift in perspective of the use of solar energy as a renewable energy. The shift to the Indian industry has several advantages – generation of skilled and unskilled jobs in the manufacturing sector, supply-demand chains and capacity building of Indian industry. In this context high capital, and novel technologies like offshore LTTD and OTEC plants need to be taken up in a big way as they can create jobs, build infrastructure and build the capacity.

Conclusion and the way forward

Thermal desalination plants are generally capital-intensive and also consume energy. However, the ecological and environmental costs must be considered when assessing the affordability. RO systems discharge brine. In pristine environments like the islands, this can lead to severe ecological damage. Brine consists of a thick concentration of salt and the increased density results in the sinking of the discharge, termed the desertification of seas, causing harm

to the prevailing ecosystem. However, there are positive benefits in installing desalination plants, such as MED or LTDD using flue gas/waste steam, or hot-water discharge from the power plants. Such plants reduce heat or waste discharge to the environment, and the carbon credit of this must be taken into account. LTDD also works with ocean temperature differences at suitable locations such as in the islands. In the case of LTDD, sea desertification is negligible, whereas the same from an RO plant is high. As a result, the adverse impact on fishermen involved in activities such as ornamental fishing is minimal from LTDD, MSF or MED plant vis-à-vis the RO alternative^{16,17}. Discharge water from the desalination plant is around 15–18°C and can be used for air-conditioning. Deep-sea cold water is rich in nutrients and this can be used for aquaculture. As a result of deep ocean water discharge into the sea, fishing activity will be enhanced. The potential ecological and economic benefits must be accounted for towards the cost of desalinated water of LTDD. If this is further improved by powering with renewable energy, especially ocean energy, the negative impacts will be further mitigated. By including carbon credits, monetization can be achieved.

Seawater being such a powerful resource of energy and freshwater can prove to be a backbone to all the activities being envisaged under the blue economy paradigm.

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