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Sustainable desalination technologies: Avenues for cooperation in the Indo-Pacific

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ABSTRACT

Desalination technologies using ocean thermal energy are a sustainable method of producing fresh water, especially for ecologically fragile regions and small island nations. India has tested this technology in the Lakshadweep Islands and has the capability to share it with its Indo-Pacific partners. This paper explores the benefits, market and prospects of sustainable desalination technologies in the Indo-Pacific region. It outlines the possible multilateral platforms that can be used to share this technology and the various challenges that this endeavour faces. The paper concludes that such technology sharing will have a positive impact on regional integration and will strengthen India's position as a responsible regional power promoting the blue economy.

KEYWORDS

Desalination; Indian Ocean region; ocean thermal energy; small island developing states (SIDS); technology sharing

Introduction

Fresh water is one of the fastest depleting natural resource on this planet. The available resource of fresh water is being overused and contaminated by exponential population growth, industrialisation, and urbanisation. Cities like Bangalore (India), Beijing (China), Cairo (Egypt), Jakarta (Indonesia) and Tokyo (Japan) face the risk of running out of drinking water in the near future, while those like Cape Town (South Africa) are already experiencing such a situation. Currently, the world over, over one billion people lack access to fresh water and an additional 2.7 billion face scarcity that lasts for at least one month a year.[1] According to UN projections,[2] by 2030, the world's demand for freshwater will exceed the supply by 40 per cent. With climate change, extreme weather events, and phenomena like pollution and salinisation,[3] the available freshwater resources are likely to be further contaminated and rendered unusable, thereby reducing the already depleted reserve of freshwater.

The conservation of available freshwater resources and their judicious use through recycling, and, sustainable industry and agriculture, are some of the important measures being propounded by the global community to delay the inevitable, while providing more time for exploring possible avenues for "creating" fresh water. Currently, the ocean seems to be the most obvious raw material supplier for this endeavour. It is with this idea that desalination plants, which aim to convert "salt water from the oceans" into "fresh water", have been developed around the world, using a variety of technologies.

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Since the Indo-Pacific region is home to nearly 60 per cent of the world's population, it is natural that the region has the largest installed capacity for desalination with most of these plants being installed in West Asia, North Africa and China. However, the existing conventional desalination technologies are energy intensive and the rising fossil fuel costs (that result in increased cost of operation) and the associated environmental drawbacks (such as atmospheric and marine pollution) necessitate more sustainable desalination technologies.

With this understanding in mind, the paper discusses the available sustainable desalination technologies and shows how desalination using energy from the thermal gradient of ocean water is one of the most suitable methods for obtaining fresh water in the Indo-Pacific. By studying the current status of this technology, it establishes that India is in an excellent position to support the transfer of this technology to other countries in the region as it has done with other technologies and on various occasions, such as with the successful launch of the South Asia Satellite (SAS) by the Indian Space Research Organisation (ISRO)[4] and technical arrangements with various African and Asian countries for undertaking projects in diverse areas such as biotechnology, food science technologies for rural applications, indigenous knowledge systems, nanotechnology, and renewable energy.[5] Building on this trend, this paper first outlines the benefits of bilateral and multilateral technological cooperation in sustainable desalination technologies, and thereafter provides an overview of the organisations through which this can be done, while highlighting the challenges being faced and those likely to be faced, in commercialising the technology.

Sustainable desalination technologies

Although the oceans hold 70 per cent of the world's water, this is unusable for drinking, due to its high salinity and the presence of other dissolved materials. In some countries, especially the Small Island Nation States and arid countries in the West Asia and North Africa, desalination of ocean water has been a major source of fresh water. The process involves removal of mineral components from the sea water to make it potable. Popular technologies that have been experimented with include the Multi-Stage Flash (MSF) seawater desalination process and the Multi-Effect Distillation (MED) process in West Asia and North Africa, and, the Reverse Osmosis (RO) in China and various island nations. However, these technologies are expensive, energy-intensive, slow, and polluting, all of which has pushed countries to turn to more sustainable alternatives.

Amongst these, solar-powered desalination plants and ocean thermal energy powered plants are considered to be the most promising. This paper is limited to Ocean Thermal Energy Conversation (OTEC) and Low-Temperature Thermal-Desalination (LTTD) technologies.

Ocean thermal energy conversion (OTEC)

Ocean Thermal Energy Conversion is a process of generating energy using the temperature gradient that exists in tropical ocean waters. It relies on the persistent temperature difference of approximately 20°C between surface water, which is warmer (between 24°C and 29°C), and water at about 1,000 m depth, which is cooler (between 4°C and 5°C). As shown in Figure 1, in the heating cycle, warm water from the surface of the

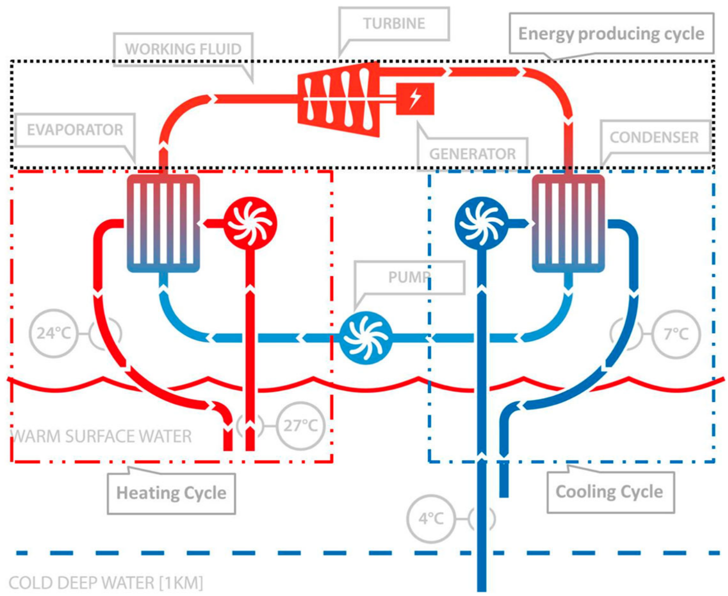

Figure 1. Schematic of the OTEC process.

Source: Adapted from Bluerise Technologies. Available at http://www.oceanpotential.com/wp-content/uploads/2014/02/OTEC.jpg.

ocean, is used to heat a working fluid that has a low boiling point (usually ammonia). In the energy-producing cycle, the vapour that has been produced is pressurised and then used to drive a turbine-generator in order to generate electricity. In the cooling cycle, this vapour is condensed, using the cold seawater from the deep. Finally, a pump drives the working fluid back into the evaporator, to complete the closed cycle and allow repetition of the process. The freshwater produced in the cooling cycle through the distillation of seawater is the major by-product of this process.

The technology used for OTEC is relatively old, with the concept having first been proposed by the French physicist, Jacques-Arsène d'Arsonval, in 1881. However, it was not until the 1930s that extensive surveys with OTEC as an alternate energy source were undertaken by countries like the United States, France and the Netherlands. Subsequent technological breakthroughs led to OTEC becoming a possible reliable source of alternate energy that could be commercially exploited, but commercialisation has not occurred to-date due to want of both technology and capital development.

According to current estimates, the global potential for OTEC-generated energy is 7 terawatts (TW), which translates to 70,000 plants of 100 MW capacity each, and a projected cost of around $750 million to build and operate. This makes OTEC a large potential market that could be tapped by both, OTEC-operating countries and technology-providing ones.

Table 1 provides the changing cost and a comparison of power generation for various processes over the years because of technological development. One notices that even though the associated cost of energy obtained from a large-scale commercial OTEC power plant is found to be marginally lower than that of a coal-fired power plant in the long run,[6] OTEC is not sufficiently developed to make commercial utilisation possible, due to infirmities in technology as well as a lack of capital development. However, OTEC

Table 1. Cost comparison of power generation over the years through various methods.

Type	Power Generation Cost (JPY/kWh)	
Ocean Thermal Energy Conversion (1 MW – demonstration)	40∼60	
Ocean Thermal Energy Conversion (10 MW – pre-commercial)	15∼25	
Ocean Thermal Energy Conversion (50 MW – Fully Commercial)	8∼13	
	2010	**2030**
Nuclear	Over 8.9	Over 8.9
Coal-fired (The new policy scenario)	9.5	10.3
LNG-fired (The new policy scenario)	10.7	10.9
Wind (On shore)	9.9∼17.3	8.8∼17.3
Wind (Offshore; fixed-bottom)	9.4∼23.1	8.6∼23.1
Photovoltaic (Residential)	33.4∼38.3	9.9∼20.0

Source: "Cost Estimation and Review Committee Report" Power generation cost (fig.36) (2004 calculation / Year 2010, 2030 Model plant) National Policy Unit, Energy and Environment Council (December 2011). http://www.xenesys.com/english/products/otec.html.

scores over other existing technologies, since the environmental impact of energy generated through this process, in terms of the production of carbon-di-oxide is negligible.[7] Another area in which OTEC scores, is the fact that it produces freshwater as a primary by-product. This potable water, if used, can reduce the overall cost of electricity generation by a third. An open-cycle OTEC plant with a capacity to generate 1–10 MW of electricity can produce 1,700–35,000 m^3 (1,700–35,000 kl) of water per day,[8] which is considered enough to meet the domestic, agricultural and industrial needs of a territory with a population ranging from 4,500 to 100,000 people.[9] Hence, even though lack of technological development[10] currently makes commercial production of electricity using OTEC unviable[11] it is considered an environmentally viable option to power self-sustaining desalination plants.

As a technology, OTEC is considered suitable between the latitudes of 20°N and 20°S that have the required thermal gradient with a few exceptions along the west coast of South America and the western coast of southern Africa due to strong cold currents,[12] as seen in Figure 2.

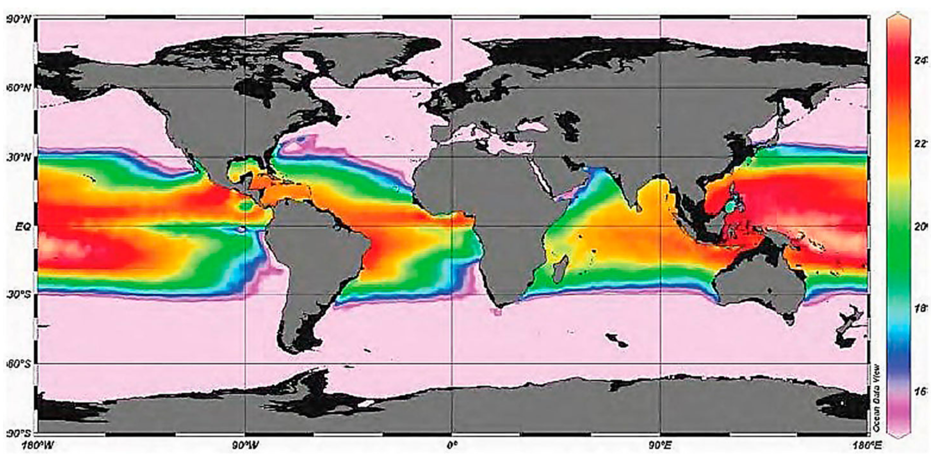

Figure 2. Worldwide average ocean temperature differences between 20 and 1,000 m depths.

Source: Bindu Lohani and L.A. Vega, "Wave Energy Conversion and Ocean Thermal Energy Conversion Potential in Developing Member Countries," Asia Development Bank. (2014). https://think-asia.org/bitstream/handle/11540/51/wave-energy-conversion-ocean-thermal-energy.pdf?sequence=1.

Low temperature thermal desalination (LTTD)

Low Temperature Thermal Desalination is a process like OTEC where the temperature difference between the warm surface water and cooler deep water is used to produce fresh water, but not electricity. Warm ocean water is evaporated at *low pressure* (27 millibars) using the high-temperature surface-water and condensed using the deep cold water to produce fresh water as condensate. The process of LTTD requires a lower thermal gradient of 16°C as compared a 20°C gradient required for OTEC and a lesser minimum depth of 600 m as compared to 1000 m for OTEC, making it feasible in more areas of the world than OTEC.

The technology for LTTD has been indigenously developed in India and successfully tested at multiple sites on the mainland and islands. LTTD is a viable option for setting up desalination plants that are independent of external fuel supply and require minimal maintenance. The freshwater output of LTTD plants is comparable to OTEC-powered plants and, like OTEC plants, can be up-scaled to achieve commercial viability. Cost estimates of water production through desalination[13] indicates that while it cost about 9.0 $\$/m^3$ to desalinate seawater in 1960, the costs in 2004 was around 1.0 $\$/m^3$ for the MSF process and 0.6 $\$/m^3$ for brackish water desalination using the RO process. For LTTD, the cost estimates of 2011 indicate "the operational costs per litre of bottled quality fresh water at 19 paise (0.003 $\$/m^3$)".[14] This makes LTTD a cost-effective, environmentally friendly alternative to conventional desalination technologies.

As regards the spatial areas of suitability of LTTD plants, LTTD can be used in as many as 98 countries of the world that have the required geographical conditions (see Figure 2) to within their 200 nautical mile EEZs.[15]

Desalination in India

54 per cent of India faces high to extremely high water stress.[16] As per the Ministry of Water Resources, "the per capita water availability in 2025 and 2050 is estimated to come down by almost 36 and 60 per cent, respectively, of the 2001 levels",[17] while the demand for freshwater is projected to overtake the supply soon after 2030 (see Figure 3), putting the country under further water stress.[18] In such a scenario, desalination is the only viable way ahead. Additionally, if this desalination process was to be using no fossil fuel, it would be even more sustainable. India, with a long coastline of 7,517 km that includes the island territories, and an EEZ of 2.172 million square km,[19] lies in the zone where the temperature difference between the surface water and at 1000 m depth is 20°C or greater, making the use of both, OTEC and LTTD plants feasible.

Based upon a deep understanding of the principle of temperature-difference and given the ecologically fragile marine environment of the Lakshadweep Islands, the National Institute of Ocean Technology (NIOT) redesigned the OTEC process on independent parameters to develop a new process,[20] now known as LTTD,[21] and then went ahead to successfully develop a land-based LTTD plant after experimenting with the technology on a floating barge off Tamil Nadu. Studies indicate that the West coast of India is more suitable for offshore installations of LTTD plants rather than on-shore ones, since the depth of water increases only gradually. On the East coast and around the island territories of

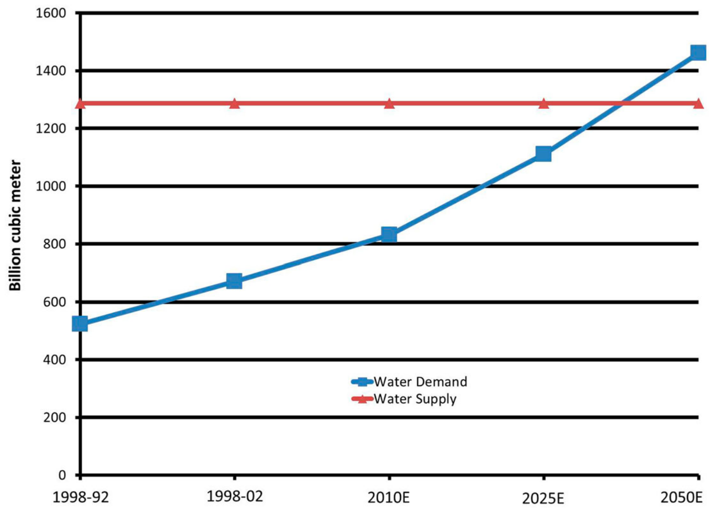

Figure 3. Water Demand Vs Supply Curve in India.

Source: Enincon Perspectives, Burgeoning Water Demand in India (Enincon Perspectives, 2014). Available at https://eninconperspectives.com/burgeoning-water-consumption-and-its-decreasing-availability-in-india-a-demand-supply-mismatch/

Lakshadweep and Andaman and Nicobar islands, such depths are found very near the coast itself, making both onshore and offshore plants possible. Accordingly, the two areas wherein this desalination technology has been extensively employed are in the Lakshadweep islands and the state of Tamil Nadu.

Tamil Nadu

The southern state of India, Tamil Nadu, was where India's first experimental LTTD plant was set up. After attempts to install the OTEC plant with the help of foreign collaborators in the 1980s had failed, a different technique to desalinate water using the temperature gradient in the ocean was successfully demonstrated near Chennai by the NIOT. In 2007, an onshore plant using LTTD technology was set up near the North Chennai Thermal Power Station (NCTPS) to produce 1000 m^3 (10 lakh litres, 1 million litres) of water per day. Since the coast near Chennai does not have the required naturally occurring temperature difference and depth of water, heated water (rejected heat) discharged from the NCTPS was used to obtain the adequate temperature difference and carry out LTTD. The plant was installed in March 2009 with a capacity of 2–3 lakh litres (0.2–0.3 million litres) per day, preceded by the successful demonstration of a barge mounted (offshore) plant with the capacity to produce one million litres (MLD)[22] of water per day in 2007 off the coast of Chennai.[23] Similarly, a new desalination plant is planned near the Tuticorin Thermal Power Station (TTPS) to produce fresh water[24] using heated water from the TTPS as is being done for NCTPS.[25] In addition to these, the NIOT is working on a 10 MLD desalination plant 40 km off Ennore, where they would establish the world's first deep-sea desalination plant, using LTTD technology being supported by diesel-operated power units,[26] before eventually shifting to OTEC-generated power.

Lakshadweep islands

The islands of India's Lakshadweep group lie off the south-western coast, at an average distance of 400 km from the mainland, and are located between latitudes 8°N and 12°N and longitudes 71°E and 74°E.[27] The 36 islands that make up the group comprise coral reefs and atolls, with coral sand and coral limestone making up most of the landmass. Being isolated from the mainland, access to water is the main problem faced by this territory. Since the islands are made of corals and porous limestone, adequate groundwater is not retained and the little that is, frequently gets contaminated by seawater due to tidal action. The Central Ground Water Board (Ministry of Water Resources, Government of India) deems the state of ground water availability in Lakshadweep Islands to be "semi-critical".[28] By way of mitigation, rooftop rainwater harvesting, and the desalination of ocean water were attempted, but "could not be sustained due to difficulty in its maintenance"[29] and the accruing detrimental environmental effect on coral structures.

Using LTTD, that is "indigenous, robust, environmentally-friendly, and requires minimum operating and maintenance efforts",[30] the Earth System Science Organisation (ESSO) and NIOT, building upon research undertaken by them since 2000, set up an LTTD plant at Kavaratti Island, in May 2005, with a capacity of 100 m^3/day (0.1 MLD). Two more plants were set up, one each in Agatti Island (see Figure 4) and Minicoy Island, in April 2011 and July 2011, respectively, each with a capacity of 1 lakh litres per day. These plants are being maintained by the islanders since their installation. According to the annual report of the NIOT for the year 2016–17,[31] "while executing these plants in two distinct islands, ESSO-NIOT has evolved site-specific techniques in the design and installation of marine structure and deep-sea cold-water pipe".[32]

In order to perform, an LTTD plant needs electricity to run the pumps and condensers, which currently is supplied using fossil fuel. Owing to this drawback and to make the

Figure 4. Aerial view of the LTTD plant at Agatti.
Source: National Institute of Ocean Technology.

technology self-sustaining, the NIOT has proposed to install a self-powered desalination plant using OTEC in Kavaratti, where the electricity produced through OTEC will be used to power the desalination plant. It is estimated that this plant will generate 100 m^3/day of drinking quality water.[33] An open-cycle process has been chosen for this plant and preliminary surveys have already been undertaken (in 2016–17). The pilot project is expected to be commissioned by 2019.[34] This project, which has been a priority status project for the NITI Aayog, will "put India at the forefront of developing OTEC globally and pave way for large-scale self-powered desalination and development of standalone OTEC plants".[35]

Future potential of OTEC-LTTD in India

The installation and successful maintenance of LTTD plants at multiple locations in India and under various environmental and geographical conditions, has given the NIOT rich expertise in tailoring the technology for site-specific conditions. Since both, fixed and floating platforms, have been successfully experimented-with in India, there is considerable scope for the installation of such types of desalination plants to cater to the fresh water needs of cities on the eastern and the western coasts of India. This needs to be preceded by more research on how to store and transport the water that is produced using this technology, in order to integrate it into the water-supply system of the larger coastal cities.

While the technology is promising and is being improved to meet commercial demand, many unknowns remain – the largest being the environmental impact and resilience to natural disasters. Additional investigation needs to be conducted to determine the environmental impact of the deleterious effects during the construction and installation stage, the effect of withdrawal and discharge of ocean water, and the possibility of marine organisms being trapped against intake screens or accidentally entering the system (impingement and entrainment).[36] In addition, since the ideal location for LTTD plants frequently falls in cyclone and earthquake prone zones, more information is needed on the resilience of these installations against natural disasters.

Potential of OTEC-LTTD in the Indo-Pacific region

The demography, economy and geography of the countries in the Indo-Pacific make them ideal candidates for using sustainable desalination technologies such as LTTD. Using the plants installed in the Lakshadweep Islands as a template, technology-sharing with the island-nations of the Indo-Pacific region (see Table 2) has the potential to boost bilateral ties with these countries and help India further develop expertise in the process.

For Small Island Developing States (SIDS), switching to sustainable desalination technologies has several advantages. First, the OTEC and LTTD processes are independent of an external fuel source, thereby guaranteeing the perennial availability of fresh water. This significantly reduces the energy requirements of the nation and facilitates the transition to a "blue economy" model. Second, the highly concentrated brine discharged from conventional desalination plants and the pollution caused by the fossil fuels used to power such conventional plants result in severe ecological damage to these islands, almost all of which are environmentally fragile. Both these drawbacks are eliminated if OTEC-LTTD technology is used. Third, sharing OTEC-LTTD technology will contribute towards developing

Table 2. Areas with appropriate Ocean Thermal Resources within their 200-nautical mile Exclusive Economic Zones in the Indo-Pacific Region[a].

Asia			
Mainland		Island	
Australia	Malaysia	Cook Islands	Philippines
Bangladesh	Myanmar	Diego Garcia	Papua New Guinea
Brunei Darussalam	People's Republic of China	Fiji	Samoa
Hong Kong	Thailand	French Polynesia	Seychelles
India	Vietnam	Guam	Solomon Islands
Japan		Hawaii	Sri Lanka
		Indonesia	Chinese Taipei
		Kiribati	Tonga
		Maldives	Tuvalu
		Mauritius	Vanuatu
		Nauru	Wake Island
		New Caledonia	Walls & Futuna Island
		Northern Marianas	
		Okinawa	
Africa			
Angola	Kenya	Aldabra	Gabon
Benin	Liberia	Ascension	Madagascar
Cameroon	Mozambique	Comoros	Sao Tome & Principe
Congo	Nigeria		
Democratic Republic of Congo	Sierra Leone		
Equatorial Guinea	Somalia		
Ghana	Tanzania		
Guinea	Togo		
Ivory Coast			

Source: Abridged from L. Vega, Economics of Ocean Thermal Energy Conversion (OTEC): An Update. Paper presented at the Offshore Technology Conference. Houston. 3–6 May, 2010. http://hinmrec.hnei.hawaii.edu/wp-content/uploads/2010/01/OTEC-Economics-2010.pdf.

[a]Bindu Lohani and Luis Vega, "Wave Energy Conversion and Ocean Thermal Energy Conversion Potential in Developing Member Countries," Asia Development Bank (2014). https://think-asia.org/bitstream/handle/11540/51/wave-energy-conversion-ocean-thermal-energy.pdf?sequence=1.

local skill-sets and expertise in operating and maintaining the plants, thereby generating employment, and making coastal communities self-sufficient.

Technology-sharing in the Indo-Pacific

Most countries of the Indo-Pacific have diverse populations, economies, and, energy- and water-needs. This presents the pioneer in the field, India, with a unique challenge of having to design projects that suit the specific needs within the available sites of each country, so as to contribute towards the larger international goal of energy security, minimal carbon-footprint, and access to a reliable source of fresh water, all of which are entirely in line with the ethos of SAGAR (Security and Growth of all in the Region) and SDG 14 (Conserve and sustainably use the oceans, seas and marine resources for sustainable development).

The Indian Ocean Rim Association (IORA), along with its specialised agencies, is the single most important platform for expanding multilateral cooperation through technology and data-sharing, joint research-and-development, formulating strategies to adopt new technologies, and, commercialisation of these technologies within its existing structure by incorporating sustainable desalination technologies as one of its focus areas. Given India's track record in successful technology-led diplomacy, its position as one of the prominent members of IORA and its foreign policy objectives, India could and must use the IORA as a platform to promote further research and transfer of desalination technologies.

Under IORA, the Regional Centre for Science and Transfer of Technology (RCSTT), which is a specialised agency that promotes "regional integration and co-operation among the IORA Member States by supporting applied research, networking, technology transfer and commercialization",[37] could be the nodal agency to encourage and support sharing of OTEC-LTTD technology with the states comprising IORA. This agency would facilitate "research on technology policy, marketing opportunities and possible joint ventures among member countries",[38] networking and the sharing of information and best practices among members and other stakeholders, and, training of policy makers and officials. The IORA RCSTT Coordination Centre for Desalination Technologies, established in 2015, would enable special focus to be placed upon LTTD- and OTEC-powered desalination,[39] with the projects related to deployment of desalination technology being implemented through the IORA Sustainable Development Program (ISDP). Since this programme has a special focus on Least Developed Countries (LDCs) in the region, it would enable SIDS to implement projects to promote sustainable development based on a principle of "open regionalism".[40] Similarly, the IORA Special Fund, established in 2006 to help members raise finances to implement projects that contribute to IORA's vision, could be mobilised to help SIDS and other LDCs to fund the proposed projects. It is pertinent to mention that the Jakarta Concord of 2017 further reaffirmed IORA's commitments to the objectives of cooperation in trade and investment, through technology-sharing, strengthening the IORA RSCTT, promotion of the Blue Economy, and, enhancing IORA's engagement with its external dialogue partners.[41] This vision was reiterated in October 2018, in the Delhi Declaration on Renewable Energy, which emphasises the need for "technology development and transfer" and calls for collaboration between members of IORA and other multilateral groupings such as the International Solar Alliance (ISA) and the International Renewable Energy Agency (IRENA).[42] This sets the stage for countries in the Indo-Pacific to enhance research and investment in the field of sustainable desalination technologies. It would also allow IORA to progress towards fulfilling the short, medium and long-term objectives under the Action Plan 2017–2021 particularly in the areas of trade and investment facilitation, academic, science and technology cooperation, institutional arrangements and broadening engagements and the blue economy.[43]

Promoting these technologies through IORA has many advantages over bilateral partnerships. First, it would strengthen the structure of IORA and increases its legitimacy as an agency to promote inclusive regional development in line with India's vision of SAGAR, since a multilateral organisation provides better safeguards from unexpected failures and a learning opportunity for other members and dialogue partners. Second, by increasing the number of partners that collaborate and share information, expertise and best practices, the technology can be commercialised rapidly, be customised for specific requirements, and, be disseminated to larger markets than is possible through bilateral fora. Third, by involving multiple regional powers, apprehensions of some nations over possible domineering by large nations such as India, can be overcome. Fourth, it opens possibilities of cooperation between various other sub-regional organisations like the African Union (AU), Association of South East Asian Nations (ASEAN), South Asian Association for

Regional Cooperation (SAARC) and Gulf Cooperation Council (GCC), since different member countries of IORA are simultaneously members of these other regional organisations.

For India, the advantage would be that of enhancing its own expertise in this field by cooperating with other countries that have a similar expertise in OTEC and desalination. Currently, India partners with Japan[44] on a bilateral basis, but cooperation with multilateral organisations like the International Energy Agency (IEA) can help India to diversify from desalination into energy-production and Deep Ocean Water Applications (DOWA)[45] using OTEC.

Challenges and recommendations

The proliferation of sustainable LTTD- and OTEC-based desalination technologies in the Indo-Pacific could solve many problems. However, before that stage can be reached, there are several challenges – technological, political and economic – that must be overcome to ensure the large scale use of this technology.

The lack of reliable and complete data is one of the first of these challenges – and it is, in and of itself, a significant one. There is a dearth of oceanographic data and information regarding the projected use and requirement of fresh water and energy for countries, especially SIDS. This makes assessment of the requirement and feasibility of desalination plants difficult. Collaboration with countries to undertake surveys of the oceans and prospective sites for installing desalination plants is a possible way to share technical expertise and best practices developed by India. This is especially relevant for countries that have large EEZs and relatively limited resources to comprehensively survey them.

Another area of concern concerns site-specific challenges that would need to be addressed on a case-by-case basis, as the use of LTTD technology is currently limited to India alone. Even though, the LTTD technology in India is ready for commercialisation, that for OTEC is still in its nascent stage and India's own experience in operating large-scale OTEC plants is limited. Here, collaboration with countries like Japan, France and the United States, which have been operating such plants, becomes crucial.

The effect of OTEC and LTTD plants on their immediate environment, over the short and long run, and on the process of climate change, pose major challenges. Even though these types of desalination plants do not require a constant supply of fossil-fuel or the continued use of polluting chemicals, Environmental Impact Assessments (EIA) are nevertheless required on order to avoid disruption of the biodiversity in the region. Similar concerns have, for example, prevented (or at least delayed) the establishment of large-scale OTEC plants in Australia.[46]

It is necessary to mention that the durability of LTTD- and OTEC-powered desalination plants in the face of natural disasters that are common in the Indo-Pacific (cyclones, earthquakes, floods, etc.) remains untested and is a challenge in the successful adoption of this technology.

In economic terms, the biggest challenge is to attract investors willing to invest in this technology. The scepticism among investors – both private and public – exists mainly because the testing of the technology on a commercial scale is lacking and currently appears to be a risky investment.[47] Countries such as Mauritius have stated that they are willing to invest in OTEC plants, but only after the commercial viability of the technology is proven in other countries.[48] In such a scenario, special incentives by India and by international organisations, to jumpstart investment for the commercial pilot-projects could go a long way. On the other hand, construction and successful operation of commercial plants within India would build confidence in the economic viability of the technology.

India's quintessentially "reactive" foreign policy and its inability to successfully engage other regional partners is yet another challenge, even if it is an indirect one. Since the technology for sustainable desalination is commercially untested, successful projects in India are necessary to market the technology abroad. One such effort is the OTEC-desalination plant proposed in Kavaratti Island, which was conceptualised in 2016, but has still not been built. Such delays reduce the region's confidence in India's ability to fulfil its commitments and act as a deterrent for investors. Additionally, there are other countries like Japan, Korea and most recently, China, which, too, are developing desalination and OTEC technologies for export, thereby providing potential client-States with no dearth of choices.

Conclusion

Current trends of water usage demonstrate the pressing need for desalination technologies. With the available desalination technologies being energy intensive and environmentally unfriendly, the need of the hour is to encourage and develop sustainable desalination technologies such as the OTEC-LTTD. While the technology for LTTD is sufficiently developed to allow immediate commercialisation, that for OTEC is still in its nascent stage, and requires more research to make it commercially viable.

For India, which is a leading country in this field, technology-sharing is a step towards the fulfilment of several goals and policies. India's record of accomplishment in science diplomacy and technology sharing has been strong so far, and LTTD will add to the repertoire of technological knowledge at India's disposal. By promoting sustainable development for coastal communities, energy security, water security and growth focused on LDCs, the vision of SAGAR will be implemented. Additionally, it will lead to a well-integrated Indo-Pacific through commercial and technology-sharing agreements. The Act East policy and India's position of putting neighbours first will be fulfilled through India's interaction with ASEAN, SAARC and BIMSTEC member-States, while cooperation with small island-nations will increase the credibility of the newly-formed Forum for India Pacific Islands Cooperation (FIPIC). Further, international cooperation will help increase India's expertise in the field of LTTD- and OTEC-powered desalination, and establish it as a responsible Indian Ocean power in promoting the "Blue Economy".

Notes

1. "The 11 Cities Most Likely to Run Out of Drinking Water," 2018. *BBC News*. https://www.bbc.com/news/world-42982959.
2. Ibid.
3. Increasing of salt content in soil. It is a natural rocess that causes soil salt fluctuation. Also called "primary salinity"
4. T.K. Arun, "Indian diplomacy rises above the stratosphere," *The Economic Times*, 2017. https://economictimes.indiatimes.com/blogs/cursor/indian-diplomacy-rises-above-the-stratosphere/

5. Samir Saran, and Malancha Chakrabarty, "India-Africa cooperation in science and Technology – Capacity Building," *Ministry of External Affairs, Government of India*, October 19, 2015. https://www.mea.gov.in/in-focus-article.htm?25947/IndiaAfrica+cooperation+in+science+and+Technology++Capacity+Building.
6. The cost of electricity production is based on two parameters: the cost of fuel and the credit received from the water produced. See, *for example*, "OTEC: Ocean Thermal Energy Conversion," 2018. *Xenesys.com*. http://www.xenesys.com/english/products/otec.html; L.A. Vega, "Economics of Ocean Thermal Energy Conversion (OTEC)," in *Ocean Energy Recovery: The State of the Art, American Society of Civil Engineers*, ed. R.J. Seymour (New York, 1992). http://hinmrec.hnei.hawaii.edu/wp-content/uploads/2010/01/OTEC-Economics-circa-1990.pdf.
7. A coal fired power plant generates approximately 1000 g of CO_2 per KWh of electricity produced while a plant using oil for the same process produces 700 g. By comparison, an open cycle OTEC plant produces about 7 g. Ibid., 30.
8. Bindu Lohani and L.A. Vega, "Wave Energy Conversion and Ocean Thermal Energy Conversion Potential in Developing Member Countries," Asia Development Bank, 2014. https://think-asia.org/bitstream/handle/11540/51/wave-energy-conversion-ocean-thermal-energy.pdf?sequence=1.
9. Ibid., 24.
10. In developing large diameter pipelines for cold water and low-pressure steam turbines, see, *for example*, L.A. Vega, "Economics of Ocean Thermal Energy Conversion (OTEC)," in *Ocean Energy Recovery: The state of the art, American Society of Civil Engineers*, ed. R.J. Seymour (New York, 1992). http://hinmrec.hnei.hawaii.edu/wp-content/uploads/2010/01/OTEC-Economics-circa-1990.pdf.
11. For a detailed analysis of the cost of electricity production and other economic dimensions of a hypothetical 100 MW OTEC plant, see, *for example*, Subhashish Banerjee, L. Duckers, and Richard E. Blanchard, "A case study of a hypothetical 100 MW OTEC plant analyzing the prospects of OTEC technology," *University of Boras*, 2015. https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/17644/3/OTEC%20MATTERS%20chapter.pdf
12. Ibid., 20.
13. Usually the cost of transporting water is considered to be benchmark when comparing the cost of producing water through desalination. Over the years with improving technology, the cost of water production has reduced, and is likely to reduce further. See, *for example*, Yuan Zhou and Richard S.J. Tol. "Evaluating the costs of desalination and water transport," https://web.archive.org/web/20090325031333/http://www.uni-hamburg.de/Wiss/FB/15/Sustainability/DesalinationFNU41_revised.pdf.
14. Press Information Bureau, Government of India, "Success of Low Temperature Thermal Desalination Technology," 2011. http://pib.nic.in/newsite/PrintRelease.aspx?relid=75249.
15. Ibid., 15.
16. Tianyi Lou, Deepak Krishnan, and Shreyan Sen, "Parched Power: water demands, risks, and opportunities for India's power sector," WRI Working Paper. World Resources Institute, January 30, 2018. https://wriorg.s3.amazonaws.com/s3fs-public/parched-power-india-0130.pdf
17. KPMG, "Water Sector In India: Overview And Focus Areas For The Future," *KPMG International*, 2010. https://www.kpmg.de/docs/Water_sector_in_India.pdf.
18. Ibid., 1.
19. "Exploring the Exclusive Economic Zone of India," 2018. *CISR – National Institute of Oceanography*. http://www.nio.org/index/option/com_newsdisplay/task/view/tid/4/sid/23/nid/35.
20. A.E. Muthunayagam, K. Ramamurthi, and J.R. Paden, "Low Temperature Flash Vaporization for Desalination," *Desalination* 180, no. 1–3 (2005): 25–32.
21. Low Temperature Thermal Distillations is a process similar to OTEC where the temperature difference between the warm surface water and cooler deep water is used to produce freshwater but no electricity. Water at low pressures (27 millibar) and condense the resultant vapour using colder water to obtain freshwater. Warm ocean water is evaporated at low

pressure using the high temperature surface water and condensed using the deep cold water to produce freshwater as condensate. The process of LTTD requires a lower thermal gradient of 16°C as compared a 20°C gradient required for OTEC and a lesser minimum depth of 600 m as compared to 1000 m for OTEC making it feasible in more areas of the world than OTEC.

22. Various units are used. These include Million cubic meters per day used by IDA, Million Litres per day (MLD) used by the Australians which is equal to one thousand cubic meters. The Americans use Million gallons per day (MGD) which equals 3,785 m^3/d while West Asia used Million Imperial gallons per day (MIGD) which equals 4,546 m^3/d.
23. "Low Temperature Thermal Desalination (LTTD)," 2014. *Ministry Of Earth Sciences*. http://www.moes.gov.in/programmes/low-temperature-thermal-desalination-lttd.
24. Eco-friendly thermal desal unit planned in Tuticorin power plant, 7 December 2017. http://www.newindianexpress.com/cities/chennai/2017/dec/07/eco-friendly-thermal-desal-unit-planned-in-tuticorin-power-plant-1720797.html.
25. "Energy and Fresh Water," 2019. National Institute of Ocean Technology. https://www.niot.res.in/index.php/node/index/27/
26. U Tejonmayam, NIOT to build India's first offshore desal plant near Chennai coast, 14 November 2017, Times of India, Available at https://timesofindia.indiatimes.com/city/chennai/niot-to-build-indias-first-offshore-desal-plant-near-city-coast/articleshow/61636889.cms (accessed September 5, 2018).
27. Shyam, Anitha, and G Sreenath, "Ground Water Information Booklet of Lakshadweep Islands," Thiruvananthapuram: Central Ground Water Broad, Government of India. p. 9. http://cgwb.gov.in/District_Profile/Lakshadweep/Lakshadweep.pdf.
28. Ibid., 12.
29. "Implementation of Desalination Plants in Agatti and Minicoy," 2017. National Institute of Ocean Technology. https://www.niot.res.in/index.php/node/index/213/.
30. National Institute of Ocean Technology, "Annual Report 2016-2017" (Chennai: National Institute of Ocean Technology, 2017). https://www.niot.res.in/documents/admin_annual_report/Annual%20Report%202016-17.pdf.
31. Ibid
32. "Implementation of Desalination Plants in Agatti and Minicoy," 2017. *National Institute Of Ocean Technology*. https://www.niot.res.in/index.php/node/index/213/.
33. National Institute of Ocean Technology. "Annual Report 2016-2017" (Chennai: National Institute of Ocean Technology, 2017), p. 17 https://www.niot.res.in/documents/admin_annual_report/Annual%20Report%202016-17.pdf.
34. India's first ocean power generation project coming up in Kavaratti, Lakshadweep, 22 September 2016, ANI, Business Standard, Available at https://www.business-standard.com/article/news-ani/india-s-first-ocean-power-generation-project-coming-up-in-kavaratti-lakshadweep-116092200284_1.html (accessed September 3, 2018).
35. Ibid
36. "Ocean Thermal Energy Conversion (OTEC) Environmental Impacts," 2010. *National Oceanic and Atmospheric Administration Office of Ocean and Coastal Resource Management*. https://coast.noaa.gov/czm/media/environmentalfactsheet.pdf
37. "Specialised Agencies and MOU's," 2017. *Indian Ocean Rim Association*. http://www.iora.int/en/structures-mechanisms/specialised-agencies-and-mous/specialised-agencies-and-mous.
38. Ibid.
39. Ibid.
40. "Objectives and Functions," 2012. *IORA Regional Centre for Science and Technology transfer*. http://www.iora-rcstt.org/about-us/objectives-and-functions.
41. "Jakarta Concord, The Indian Ocean Rim Association: Promoting Regional Cooperation for a Peaceful, Stable and Prosperous Indian Ocean," 2017. https://www.kemlu.go.id/Buku/JAKARTA%20CONCORD_FINAL_not%20signed.pdf

42. Press Information Bureau, Government of India. 2018. "21 IORA Countries adopt the Delhi Declaration on Renewable Energy; To Collaborate with ISA Member Countries," http://pib.nic.in/newsite/PrintRelease.aspx?relid=183973.
43. "IORA Action Plan 2017-2021," 2017. http://www.iora.int/media/1031/iora-action-plan-7-march-2017.pdf.
44. "JICA Assists to Transform Seawater into Drinking Water by Extending an ODA Loan of INR 1,800 crore to Project for Construction of Chennai Seawater Desalination Plant," 2018. *Japan International Cooperation Agency*. https://www.jica.go.jp/india/english/office/topics/press180402_02.html
45. Allows use of OTEC residual water to be used effectively for extracting resources such as Lithium from the sea-water as is being experimentally tried out by the Japanese. See http://www.xenesys.com/english/common/pdf/kumejima.pdf.
46. Gadonneix, Pierre, et al. 2010. "2010 Survey of Energy Resources," London: World Energy Council. p.593 http://www.wec-france.org/DocumentsPDF/Etudes_CME/Survey_of_Energy_Resources_2010_WEC.pdf.
47. "Investing in Ocean Thermal Energy Conversion is Financially Sound and Ecologically Responsible," 2018. *Ocean Thermal Energy* Corporation. http://otecorporation.com/2018/08/24/investing-in-ocean-thermal-energy-conversion-is-financially-sound-and-ecologically-responsible/
48. Gadonneix, Pierre, et al., *2010 Survey of Energy Resources* (London: World Energy Council, 2010), p.598 http://www.wec-france.org/DocumentsPDF/Etudes_CME/Survey_of_Energy_Resources_2010_WEC.pdf.

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