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Beyond electricity: The potential of ocean thermal energy and ocean technology ecoparks in small tropical islands

Andrés F. Osorio [a,e], Jessica Arias-Gaviria [b,e,*], Andrea Devis-Morales [a], Diego Acevedo [c], Héctor Iván Velasquez [d,e], Santiago Arango-Aramburo [b,e]

[a] Grupo de Investigación en Oceanografía e Ingeniería Costera (OCEANICOS), Colombia
[b] Grupo de Investigación en Ciencias de la Decisión, Colombia
[c] Bluerise BV, Molengraaffsingel 12, 2696 JD Delft, The Netherlands
[d] Grupo de Investigación en Termodinámica Aplicada y Energías Alternativas (TAYEA), Colombia
[e] Universidad Nacional de Colombia sede Medellin, Facultad de Minas, Carrera 80 # 65-223, Medellin, Colombia

HIGHLIGHTS

- Small islands face problems such as development, energy, freshwater and food supply.
- Tropical islands with access to deep ocean water can use OTEC all year round.
- An Ocean Ecopark is proposed as an integral solution for San Andrés Island, Colombia.
- The Ecopark consists of OTEC, desalinization, SWAC, greenhouses, and R&D activities.
- This article discusses entrance barriers and presents a four-stage roadmap

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ABSTRACT

Small islands face difficult challenges to guarantee energy, freshwater and food supply, and sustainable development. The urge to meet their needs, together with the mitigation and adaptation plans to address climate change, have led them to develop renewable energy systems, with a special interest in Ocean Thermal Energy Conversion (OTEC) in tropical islands. Deep Ocean Water (DOW) is a resource that can provide electricity (through OTEC in combination with warm surface water), low temperatures for refrigeration, and nutrients for food production. In this paper we propose an Ocean Technology Ecopark (OTEP) as an integral solution for small islands that consists of an OTEC plant, other alternative uses of DOW, and a Research and Development (R&D) center. We present an application of OTEP to San Andres, a Colombian island that meets all the necessary conditions for the implementation of OTEC technology, water desalinization, and a business model for DOW. We present the main entrance barriers and a four-stage roadmap for the consolidation and sustainability of the OTEP.

1. Introduction

The Fifth Assessment Report on Climate Change (AR5) from the Intergovernmental Panel on Climate Change (IPCC) (2013) shows that the effect of climate change is increasing all over the planet, with evident changes in temperature, water cycles, sea level, extreme events, carbon and other biogeochemical cycles, among others. Such changes are the result of the emissions of anthropogenic greenhouse gases (GHG), which increased by more than 80% since 1970, mainly due to fossil fuels combustion for energy production (IPCC, 2014a). The effects of climate change on small islands are very strong and require both mitigation and adaptation measures. One of the main actions for climate change mitigation is the development of Renewable Energy (RE).

The ocean is the largest energy store on earth, and offers alternative forms of generation such as tidal, thermal gradient, saline gradient, off shore wind, and wave energy (Pelc and Fujita, 2002). However, ocean (or marine) RE technologies still have a minor share in the global energy mix, with only 530 MW installed from a total global capacity of about 5600 TW (IRENA, 2014b). Of particular interest, Ocean Thermal Energy Conversion (OTEC) is emerging as an option for supplying energy in tropical regions. Islands provide a starting point because of their large ocean

* Corresponding author.
E-mail addresses: jariasg@unal.edu.co (J. Arias-Gaviria), saarango@unal.edu.co (S. Arango-Aramburo).

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thermal potential. OTEC, along with different uses of Deep Ocean Water (DOW), could supply other basic needs. The properties of DOW can not only provide electricity, but also low temperatures for refrigeration and air-conditioning, and nutrients for food production. Additionally, small islands need to guarantee energy supply and food security, and promote sustainable development. Thus, if OTEC and other DOW technologies reach a technical maturity and competitive costs, they could emerge as an integral solution for current problems in small islands by using the resource in a cascade system, as proposed by (Nakasone and Akeda, 1998). However, it is required to reach the technical maturity at competitive costs.

OTEC technology uses the thermal gradient between warm surface water and cold DOW from 800 to 1000 m deep (IRENA, 2014c). This gradient is converted into electricity using a simple thermodynamic cycle. In addition to power generation, DOW can also be used directly in cooling systems, such as Sea Water Air Conditioning (SWAC), greenhouse conditioning, aquaculture and other nutrient-based industries (Yoza et al., 2010). Finally, DOW can also be used in the production of freshwater (IRENA, 2014c).

Recently, the interest in OTEC has increased in small islands with low energy resources because of its potential in tropical regions. Existing studies have focused on the potential and the market for this technology – which requires a minimum gradient of 20 °C to obtain net positive energy (Fujita et al., 2012) – and on the fact that tropical waters located between 25°N and 25°S meet this gradient condition (Fujita et al., 2012; IRENA, 2014c; Vega, 2003). Rajagopalan and Nihous (2013) have estimated the global large-scale potential of OTEC to a maximum of 12–14 TW considering geographic restrictions – the largest potential of all marine energy technologies. The literature states that 98 countries and territories could provide promising sites for OTEC installations, mostly on tropical islands (IRENA, 2014c). OTEC penetration is still limited due to high costs and the lack of experience in plant construction at an industrial scale – above 10 MW – (IRENA, 2014c); however if those barriers are overcome, it could be an alternative electricity solution for small islands.

Colombia has access to both the Atlantic and the Pacific Ocean, covering over 3000 km of coastline and almost 900,000 km^2 of marine area – nearly 50% of its national territory (INVEMAR, 2014). Osorio et al. (2016) present the Colombian potential for ocean RE such as OTEC, salinity gradients, and tidal energy, and state that OTEC has the highest potential. Devis-Morales et al. (2014) evaluated the potential for OTEC in Colombia based on the evaluation of temperature gradients, bathymetry and socio-economic features of the region. The results suggest that the Island of San Andres meets the technical conditions for the installation of an OTEC plant, given that there is an average thermal gradient of 22 °C at 2.3 km from the coastline throughout the year.

So far, OTEC studies have focused mainly on potential assessments, and, to our knowledge, there are no studies that analyze the combined effects of OTEC with alternative uses of DOW on the development of small tropical islands. In this paper, we aim to discuss that such integration could take place on an Ocean Technology Ecopark (OTEP) involving energy generation, freshwater production and use of DOW nutrients, among others, considering both Research and Development (R&D) activities and a business model for spin-offs. We apply the OTEP concept to the Colombian island of San Andres, as a case study. In Section 2, we present a discussion about the multiple challenges of small islands. Sections 3 and 4 present the proposal of OTEP and the application to San Andres, respectively. Finally, we conclude and discuss the policy implications in Section 5.

2. Not only energy supply: the problem of small islands

Islands are minor contributors to global GHG emissions. However, they have the highest levels of emissions per capita. For instance, the Caribbean Sea islands contributed only to 0.4% of global GHG emissions in 2011, but the emissions per capita reached almost 120 t/person, while the global average was 5 t/person (World Bank, 2015). These emissions mainly come from fossil fuel energy generation. This situation, combined with volatile fuel prices and high costs of fuel transport, is an incentive for the islands' stakeholders and communities to search for other energy alternatives (Weisser, 2004). Currently, a wide number of projects related to RE in islands are being developed (IRENA, 2014a).

Islands not only face the challenge of reducing emissions and guarantying energy supply, but also other important local development issues such as freshwater and food supply, and economic development. Moreover, insular areas are amongst the most vulnerable regions of the world. The Working Group II contribution to the AR5 shows that climate change poses many threats to small islands and requires numerous adaptation actions to change conditions such as shrinking freshwater resources due to rainfall variations, food security threats due to extreme climatic events, ecosystem variations, imports prices (also sensitive to climate change), economy and tourism due to extreme events; among others (IPCC, 2014b).

The sole implementation of RE only tackles the issue of power supply. Thus, we consider that an integral solution is preferable in order to guarantee proper development. One option is what we have called an OTEP involving the elements showed in Fig. 1: energy generation, freshwater production, DOW use for aquaculture, greenhouses, and nutrient-based industries, and R&D on all these aspects. The materialization of the proposed OTEP requires that technologies reach an economic feasibility status, however no development can be possible without the financing of initial R&D and innovative ideas. We develop this idea in detail in the next section.

3. Technological proposal

3.1. Ocean Ecoparks as an integral solution

In this section we discuss how the use of DOW could take place in an OTEP that involves energy generation, freshwater production, and use of DOW nutrients, among others. Such OTEP considers both R&D and a business model for spin-offs. The dynamic process and impacts of the OTEP are presented in Fig. 2. First, following the horizontal axis of Fig. 2, we expect the diffusion rate of the technology to be bell-shaped, given that on the first stages the technology faces low acceptance, high costs and low

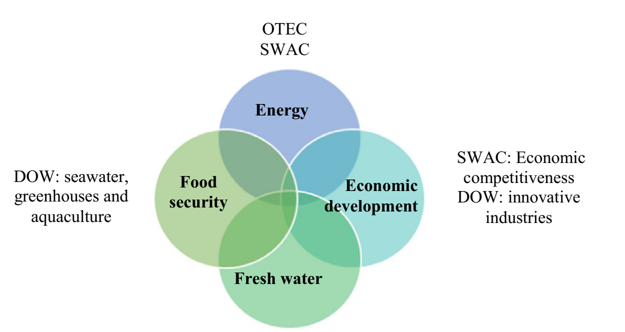

Fig. 1. Challenges for small islands and possible solutions offered by an Ocean Ecopark.

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