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Coastal City and Ocean Renewable Energy:
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Coastal City and Ocean Renewable Energy: Pathway to an Eco-San Andres

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Coastal City and Ocean Renewable Energy: Pathway to an Eco-San Andres

Authors: **M I Cusano, Q Li, A Obisesan, J R Urrego-Blanco, T H Wong**

Series Editors: **R A Shenoi, P A Wilson, S S Bennett**

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Foreword

The Lloyd's Register Foundation (LRF) in collaboration with the University of Southampton instituted a research collegium in Southampton between 18 July and 11 September 2013.

The aim of the research collegium has been to provide an environment where people in their formative post-graduate years can learn and work in a small, mixed discipline group drawn from a global community to develop their skills whilst completing a project on a topic that represents a grand challenge to humankind. The project brief that initiates each project set challenging user requirements to encourage each team to develop an imaginative solution, using individual knowledge and experience, together with learning derived from teaching to form a common element of the early part of the programme.

The collegium format provided adequate time for the participants to enhance their knowledge through a structured programme of taught modules which focussed on the advanced technologies, emerging technologies and novel solutions, regulatory and commercial issues, design challenges (such as environmental performance and climate change mitigation and adaptation) and engineering systems integration. Lecturers were drawn from academic research and industry communities to provide a mind-broadening opportunity for participants, whatever their original specialisation.

The subject of the 2013 research collegium has been systems underpinning coastal eco-cities.

The project brief included: (a) quantification of the environmental challenge; (b) understanding of the geo-political legal-social context; (c) one integrated engineering system for a coastal eco-city; (d) economics and logistics challenges.

This volume presents the findings of one of the five groups.

R A Shenoi, P A Wilson, S S Bennett (University of Southampton)
M C Franklin, E Kinghan (Lloyd's Register Foundation)
2 September 2013

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We would like to express our deep gratitude to the Lloyd’s Register Foundation in the figures of Mr. Michael Franklin and Eileen Kingham. We would also like to thank Professor Ajit Shenoi, Professor Philip Wilson, Professor Vaughn Pomeroy and Dr. Sally Bennet for their constant encouragement and guidance.

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We would like to thank the entire group of LRF Collegium 2013 for your friendship, support, encouragement, patience and for making this experience unforgettable.

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Finally, we want to thank Albron Corpus-Robinson from the Special Unit of Public Services of San Andres (Colombia) for providing us valuable information about the energy and potable sector in the island.

Maria Ines Cusano . Qing Li . Abayomi Obisesan . Jorge Urrego Blanco . Tsz Hang Wong

Southampton, September 2013

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List of Abbreviations

AC	Alternating Current
AEP	Annual Electricity Production
CARES	the Scottish Government's Community and Renewable Energy Scheme
CC	Closed Cycle
CIURE	Inter-sectorial Commission for the Rational and Efficient Use of Energy and Non-conventional Energy Sources
COLCIENCIAS	Colombian Institute for the Development of Science and Technology
CRF	Capital Recovery Factor
DANE	Departamento Administrativo Nacional de Estadistica
DC	Direct Current
EEZ	Exclusive Economic Zone
ELF	Expenses Levelizing Factor
EU	European Union
FAO	Food and Agriculture Organization
HC	Hybrid Cycle
IDEAM	Institute of Hydrology, Meteorology, and Environmental Studies in Colombia
IEA	International Energy Agency
IMO	International Maritime Organization
IPSE	Institute of Planning and Promotion of Energy
IPSE	Institute for Planning and Promotion of Energy Solutions
IR	Inflation Rate
LCOE	Levelized Cost of Electricity
LEC	Levelized Expenses Cost
LIC	Levelized Investment Cost
NOAA	National Oceanographic and Atmospheric Administration
NODC	National Oceanographic Data Centre
NPD	National Planning Department

OC	Open Cycle
OECD	Organisation for Economic Co-operation and Development
OMR&R	Operation, Maintenance, Repair and Replacement
OTEC	Ocean Thermal Energy Conversion
OWC	Oscillating Water Column
PBW	Price of Bottle Water
PDW	Price of Domestic Water
PEM	Polymer Electrolyte Membrane
POE	Price of Electricity
POW	Price of Water
PV	Photovoltaic
PWF	Present Worth Factor
UNCLOS	United Nations Convention on the Law of the Sea
UNCSD	United Nations Conference on Sustainable Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNWTO	United Nations World Tourism Organisation
URE	Use of Energy
WEC	Wave Energy Converter
WTTC	World Travel and Tourism Council

Executive Summary

Proactively planning for sustainable coastal cities is increasingly important as climate change increases the frequency and intensity of extreme weather events. Scientific research indicates that greenhouse gas emissions, mainly induced by using non-renewable energy, are elevating temperatures and sea levels for coastal cities all around the world. Other issues that aggravate the challenge for coastal cities include: the continued growth of population on and around coastlines; the acute conflict between increasing energy demand and decreasing amount of natural energy resource. All evidences lead to one fundamental element for coastal eco cities: utilizing renewable energy from the ocean to make coastal cities more ecologically and economically sustainable.

The subject of this study is San Andres, a Colombian island in the Caribbean Sea that was declared as UNESCO Biosphere Reserve in 2000 for its well-preserved ecosystem and biodiversity. Regrettably, it is currently 100% dependent on imported fossil fuels and has a high level of greenhouse gas emission. The mono economy relying on tourism implicates financial incentives of various stakeholders to seek an eco solution. The system boundary of this study is drawn to transform San Andres into an oasis of sustainability for both inhabitants and tourists by using ocean renewable energy.

The pathway for such transformation starts with an intuitive thinking about the essences of coastal eco cities by conducting a SWOT analysis. A promising selection of ocean renewable energy has been investigated in-depth: solar, wave, wind and Ocean Thermal Energy Conversion (OTEC). After identifying the legal constraints, this study proposes an ocean renewable energy portfolio based on two scenarios comprehensively considering various investment scales and energy consumption: government-centred scenario and community-oriented scenario. It is shown that the production of clean energy under both scenarios has lower cost than the current generation cost based on fossil fuels. The implementation of the scenarios might positively affect other aspects of the city such as improving water supply, lowering the demand of electricity, increasing community involvement. Marketing scheme and transferability to other tropical island cities have been developed in the later parts.

1 Introduction

Several events in the last decades have demonstrated that there is no viable future for humanity without a healthy planet. Intensive use of natural resources, including fossil fuels, has the potential to significantly affect the earth system. Overpopulation, climate change and dependence on non-renewable resources are key element that make the current system unsustainable.

The year 2008 marked the first time in history that half of the population lived in urban areas. Even if we were to stabilize carbon emissions today, increases in temperature and the associated impacts will continue for many decades. In 1997 the Kyoto Protocol attempted to establish mechanisms to control greenhouse gas emissions. The treaty however, was never enforced and the commitments stated by the Protocol never complied. Therefore it is very unlikely carbon emissions will stabilize anytime soon.

To address these challenges, the current development model must be changed by a more sustainable one, particularly in urban centres where most of the world population is located. Since almost half of the world's population is living within 100 km of the coast, the importance of the coastal zone and related issues are paramount. The UN Population Division estimates that the number of people living on and around coastlines will increase to 3.1 billion people by 2025.

Coastal cities in the upcoming years will see their level of congestion, energy consumption, air pollution and waste production grow as a consequence of population increase and economic activities. An approach to turn existing coastal cities into coastal eco-cities may prove to be an adequate pathway to improve the sustainability in coastal communities.

This book is the result of six weeks interdisciplinary work aimed particularly at examining alternatives for a sustainable future of the island of San Andres (Colombia) with a focus on energy resources. The strategy has assessed the available and suitable renewable ocean technologies that would allow the island to become less dependent on fossil fuel. The ultimate goal is to develop solutions that would allow the production of clean energy from the sea.

The work started with a search for a common ground on what a cities, coastal cities and coastal eco cities are, and what the implications in terms of internal and external trade offs.

A preliminary analysis of five coastal cities (Genoa, Hong Kong, Lagos, New York and San Andres that are present in the Appendix) was carried out to assess their structural characteristics and understand what are their strengths, weaknesses, opportunities and threats. The development of the SWOT analysis allowed to highlight which are currently the most critical aspects in these cities. A a comparative chart is developed to identify energy as the most relevant issue for coastal cities and San Andres (Colombia) as the coastal city to be further studied in this research project.

Having chosen San Andres, a full description of the threats and weaknesses of the city was identified in order assess its characteristics and identify where long term sustainable solutions for the energy sector could be found. San Andres is an island with vast reservoir of ocean resources, therefore an assessment of the existing ocean renewable energy technologies was carried out to better understand which ones could be applied to the island. This topic was also analysed considering the existing legal boundaries and incentives at national and international level that would have to be considered to implement offshore sustainable energy solutions.

Efforts were then concentrated in the development of two different scenarios with two different approaches: one is the government-centred that aims at the installation of an offshore Ocean Thermal Energy Conversion system. The other is a community oriented because it implies the establishment of a renewable energy strategy that would be partially owned by the community. One step forward was made in order to assess the main aspects of these two scenarios that can be generalized or transferred to other coastal cities in their process of adopting sustainable energy solutions.

As San Andres is well known as a tourist destination in the Caribbean, tourism represents the main source of revenue. A new marketing strategy that would better fit the pathway towards a sustainable San Andres was therefore developed. While it is recognized that energy is only part of a much bigger problem that requires solution, it is expected that this research helps to guide the transition of San Andres from a coastal city into a coastal eco city.

1.1 Outline of the Report

The following paragraphs give a brief summary of the chapters within the book.

Chapter 1 this chaper

Chapter 2 presents an overview of what a cities, coastal cities and coastal eco cities means.

Chapter 3 provides the preliminary and SWOT analysis of five coastal cities.

Chapter 4 presents the full description of San Andres.

Chapter 5 indicates the existing legal boundaries and incentives with regards to San Andres.

Chapter 6 presents the assessment of the existing ocean renewable energy technologies applicable to San Andres.

Chapter 7 presents the two different scenarios for the establishment of a renewable energy strategies.

Chapter 8 provides the transferability of the renewable energy strategies to other coastal cities.

Chapter 9 presents the marketing strategies for the implementation of a sustainable San Andres.

Chapter 10 presents the conclusions, recommendations and final remarks.

2 Pathway to coastal eco-city: definition and implications

2.1 Overview

This chapter provides an intuitive thinking about what is a coastal eco city starting with comprehensive literature review on city definition. Three flow diagrams for city, coastal city and coastal eco city, reflecting original thoughts from this study, build up a common ground for later chapters.

2.2 City definition

The year 2008 marked the first time in history that half of the population lived in urban areas. The world urban population is expected to nearly double by 2050, increasing from 3.3 billion in 2007 to 6.4 billion in 2050 (World urbanization prospects, 2008). This means that many cities will be on the verge of collapse in most of the fundamental functionalities such as housing, transportation, health and food supply. In order to clearly identify the key issues for a more sustainable coastal city, this research put an effort to investigate what a city is and what its founding elements are.

This research first turned into the etymology of the word for different languages to see if there was a common ground in the definition of the main aspects of a city organization. In ancient Greece the city was defined as Polis that could also mean citizenship and body of citizens. In modern historiography "polis" is normally used to indicate the ancient Greek city-states, like Classical Athens and its contemporaries, so polis is often translated as "city-state". The main elements begin with the idea of the Polis being the ideal. According to Aristotle in Politics (written 350 B.C.E):

"A city exists for the sake

of a good life – not for

the sake of life only."

Aristotle

So for him, the city was the place where humans can achieve their highest aspirations and therefore the best form of social organization.

In the Greek and Latin, the city was not only a physical place with a specific set of rules and common interests, but also a community of people with shared values. For the Anglo Saxon languages, it implied a structure with a sense of security yet nothing is said regarding the inhabitants and whether there was a set of shared values or a feeling of community.

A review of the existing scientific and institutional literature consulting sources such as the United Nations, the World Bank, the Organisation for Economic Co-operation and Development (OECD) and the European Union (EU) has also been conducted. By doing so, it come to attention that there’s barely any universally accepted definition of what a city is. Yet, most of the definitions can be associated with one or more of the following criteria:

- administrative criteria or political boundaries (e.g., area within the jurisdiction of a municipality or town committee);
- number of inhabitants, for example for the EU a city comprises more than 50.000 inhabitants but this criteria is not applicable everywhere;
- economic function, in the past cities were industry-oriented while today most cities concentrate on the production and provision of services, as opposed to societies where the majority of the population is primarily engaged in agriculture.

Having assessed the existing literature, a definition of city was developed and this meaning will be intended throughout the project: A city is a permanent and highly organized centre of population that includes a series of complex systems for sanitation, utilities, land use, housing and transportation and that acts as a functional place of economic activities and social exchanges. Figure 2.1 illustrates this definition using a flow diagram: a city is considered as an integral entity comprised of various elements that serve its residents. The purple arrows above represent the inputs that a city needs to maintain its basic operations: energy, food and water. While the red arrows beneath present the outputs generated from a city they could be the waste and pollution as negative outputs from a city, or the service/products generated as positive externalities.

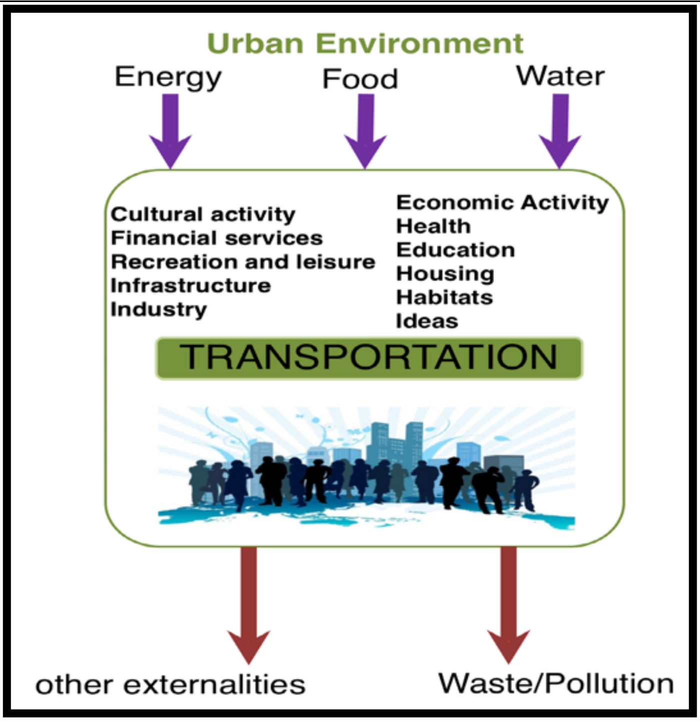

Figure 2.1 Flow diagram of city definition.

2.3 Coastal city definition

There are several definitions of coastal areas, whereas the simplest intends the land and sea areas bordering the shoreline. Meanwhile, coastal city has economic and geomorphic characteristics that are typically or exclusively coastal (seaport, deltaic, or estuarine setting).

For this study, a coastal city is defined as a conurbation of more than 50,000 people significantly oriented towards, and/or actually or potentially affected hydro dynamically by an extensive body of fresh or salt water. This could include cities at some distance from the water's edge, but which situation close to or below sea level subject them to coastal hazards. Also, for purposes of general discussion, this research also includes in the definition cities on major enclosed seas, estuaries, and rivers that are immediately emptying into larger bodies of water. As defined by the Food and Agriculture Organization (FAO) of the United Nations in "Integrated coastal area management and agriculture, forestry and fisheries" (1998), the term "coastal zone" would refer to the geographic area defined by the enabling legislation for coastal management, while "coastal area" would be used more broadly to refer to the geographic area along the coast that has not yet been defined as a zone for management purposes.

Figure 2.2 illustrates the definition of a coastal city based on the previous city definition. The major distinctive aspects are the coastal environment and the interactions between urban and coastal environment such as fishing, aquaculture and mineral mining activities. Meanwhile, climate change and population growth at coastal cities are identified as the two key issues that coastal cities need to address.

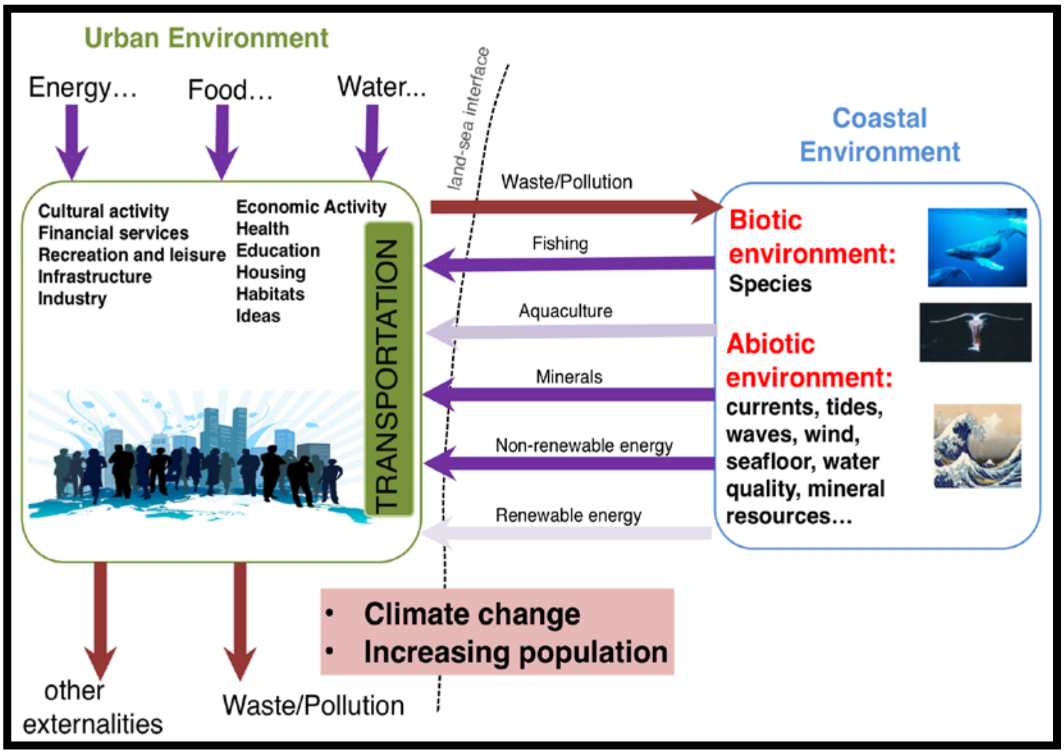

Figure 2.2 Flow diagram of coastal city.

2.4 Coastal eco city definition

An eco-city by its very appellation is place-specific, characteristically spatial in significance. It suggests an ecological approach to urban design, management and towards a new way of lifestyle. The advocacy is for the city to function in harmony with the natural environment. This implies that cities should be conceptualized as ecosystems where there is an inherent circularity of physical processes of resources, activities and residuals that must be managed effectively if the city's environmental quality is to be maintained. The term "eco-city" is widely traced to Richard Register's (Register, 1993) book, "Ecocity Berkeley: Building cities for a healthy future". Register's vision of the eco-city is a proposal for building the city like a living system with a land use pattern that supports the healthy anatomy of the whole city, enhances biodiversity, and makes the city's functions resonate with the patterns of evolution and sustainability.

As stated in "Eco-city planning: policies, practice and design" (Wong & Yuen, 2011), "Environmentally, eco-city development is used as a new environmental paradigm to counter global warming, ecological degradation and unsustainable resource exploitation. Within this paradigm, ideas of green urbanism, sustainable building design or architecture, promoting more compact cities to fight sprawling are subsumed". Economically, building eco-cities as a green infrastructure inevitably needs to be used as a form of new business opportunity serving the objectives of economic sustainability.

An interesting ecological approach to urban development, based on the existing literature, states that such a city requires a strategy combining:

1. Integrated water resources management
2. Energy management aim at reducing greenhouse gases emission
3. Waste minimization and integrated solid waste management
4. Integrated transport policies
5. A policy dealing with pollution issues
6. Anticipation of climate change
7. Housing policy
8. Objectives concerning justice, for example promoting an equal distribution of the benefits
9. Integration in the framework of sustainable urban management, while also managing urban risks.

Creating the eco-city, therefore, requires several mechanisms including careful management of local resources, long-term planning, establishment of an ecologically sound set of institutions, different land uses, environmental, social and economic policies (Robinson and Tinker, 1998).

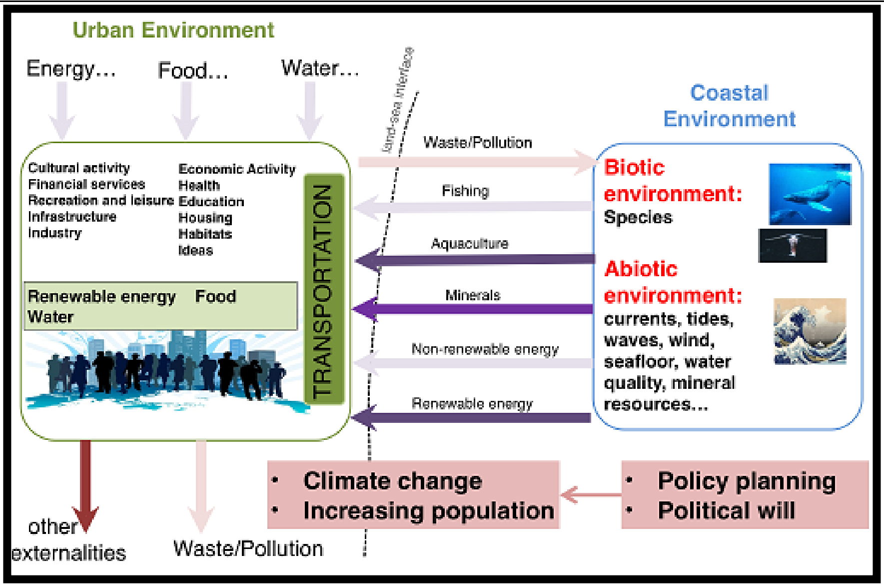

Figure 2.3 Flow diagram of coastal eco city.

From Figure 2.3 and Figure 2.2, the lightened colour arrows indicate a reduction of the flow while darken colours represent an increase of the flow. It is believed that a coastal eco city needs to reduce the dependence on external inputs such as energy and fresh water, as well as the waste and pollution it produces. At the same time, a coastal eco city should strengthen the interactions with the ocean by increasing the sustainable utilization of ocean resources. It is equally important for coastal eco cities to develop proactive policy and strategies to address the common challenges.

3 SWOT analysis of five coastal cities

3.1 Overview

In order to address the various concerns and issues analysed in Chapter 2, a SWOT analysis was adopted in this part of the work for five representative coastal cities: Genoa, Hong Kong, Lagos, New York and San Andres. The results and key conclusions from the SWOT analysis are also provided in this chapter while the city description for all of them is detailed in the Appendix.

3.2 Introduction to SWOT analysis

SWOT analysis, namely Strength, Weaknesses, Opportunity, and Threat, is a guide to develop a comprehensive strategic planning by identifying the positive and negative elements inside an organization (S-W) while also considering the external environment (O-T). A SWOT analysis is a structured planning method that helps to hand both ordinary and unusual situations while exploring both internal and external factors that may influence the outcome. It has been widely applied in the project and business adventure.

3.2.1 Strengths

Strengths describe the positive attributes, tangible and intangible, within an organization or situation. Strengths include the positive attributes of the people involved in the business/organization and it also includes the tangible assets such as available capital, infrastructures, etc. Strengths capture the internal positive aspects that add value or offer a competitive advantage.

3.2.2 Weaknesses

Weaknesses are factors that are within the organisation's control but detract it from its ability to obtain or maintain a competitive edge. They help identify the areas that might be improved. In this research weaknesses might include excessive bureaucracy, lack of expertise, limited resources, incapability to access technology, etc. These are factors that are usually under control, but they need to be improved to accomplish the goals. The more accurately the weaknesses are identified the more valuable the SWOT analysis will have.

3.2.3 Opportunities

Opportunities assess the external attractive factors that represent the reason for a business or an organization to exist and prosper and they can be found in the external environment. These opportunities reflect the potential that can be achieved through the implementation of appropriate strategies. Opportunities may be the result of market growth, change of mentality, tendency to adopt innovation, the ability to offer greater value, etc.

3.2.4 Threats

Threats include factors that are beyond control that could place an organization at risk. These are also external and cannot be controlled over, yet the organization may benefit by having contingency plans to address them if they should occur. A threat is a challenge created by an unfavourable situation or development that may lead to deteriorating the overall wellbeing. Competition – existing or potential – is always a threat. Other threats may include governmental regulation, potential natural disasters, economic downturns, devastating media or press coverage, etc.

3.2.5 Implications

The internal strengths and its weaknesses, compared to the external opportunities and threats, can offer additional insight into the condition and potential of any given situation. The challenging questions inspired by Figure 3.1 would be: How can the organization transform their weaknesses into strengths? How can they match their strengths to take advantage of the possible opportunities? Is there a way to transform the threats into opportunities? The true value of the SWOT analysis relies on the fact that it allows to bring all this information together to assess the most promising opportunities, and the most crucial issues.

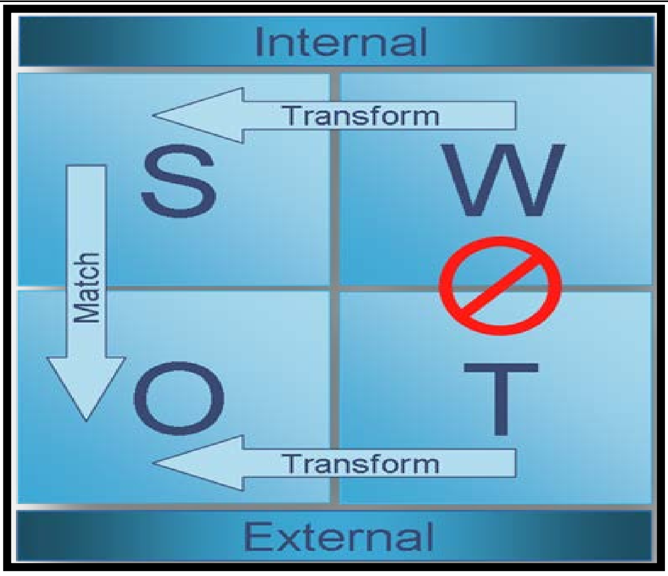

Figure 3.1 SWOT interpretation.

3.3 SWOT analysis for five coastal cities

Applying a SWOT analysis to a certain reality requires having certain knowledge on the topic. It is a fact that the assessment of the main characteristics of coastal cities in terms of their conformation and operation would later contribute to identify what are the critical issues in terms of sustainable development. In this sense, the research group realized that:

- The participants of this group this were born or are currently living in a coastal city.
- The five selected cities represent the five continents and belong both to developed and developing countries
- The sample comprises three mega-cities, one medium sized city and an island and therefore it is quite representative of the features of the coastal city family.

After carrying out a description of demographics, geographical characteristics, main economic activities, transportation network, energy sources, existing sustainable energy policies and level of emissions, the research group carried out a SWOT analysis for each case. Table 3.1 shows the summary of the SWOT analysis for the five cities. The full description for Genoa, Hong Kong, Lagos, New York and San Andres can be found in the Appendix.

Table 3.1 SWOT analysis results for five coastal cities.

	STRENGTH	WEAKNESS	OPPORTUNITY	THREAT
Genoa	Good geo position in the Mediterranean basin Good port performance and potential	Heavy bureaucracy Topographically constrained between sea and hills	Sustainable plan includes the city and the port Possibility of having public/private partnerships in sustainable energy projects	Undergoing economic crisis Sustainable policies rely in EU funding and might stop once the funding needs
Hong Kong	High percentage of public transport Energy stability (no blackouts)	High population density Urban heat due to high density of buildings	Use of electrical vehicles for public transport Regulation of building energy efficient policies	Heavy air pollution in the region Hurricanes
Lagos	High literacy rate (about 87%) 187 km of coastal line	Insufficient public transport and heavy congestion Rapid heavy pollutant Population growth	Potential solar energy development due to tropical weather Further development of maritime transportation (to reduce traffic congestion)	Highly prone to flooding due to its flat topography Annual rise in CO from wave arriving from the Sahara desert
New York	3rd largest port in US Key financial hub in the country	Vulnerable transportation infrasturcture Top energy sources are non-renewable	Political planning in renewable energy Innovative technology&financial benefits	Hurricane and flooding Rising temperature leads to power shortages;
San Andres	Best preserved ecosystem in the Caribbean Marine protected area	Relies entirely on external supply (fuel, food, etc) Mono economy based on tourism	Funding of renewable energy systems due to its status as marine protected environment Aquaculture	Increasing strength and frequency of hurricanes and coral bleaching Coastal erosion

3.4 Conclusions from SWOT analysis

Despite of the variety of geographic features, population densities and economic patterns of the selected five coastal cities, there are some noticeable common facts that these city are facing:

Internal perspective (Weaknesses):

- The energy supply of all five coastal cities relies almost entirely on external import, most of which are non-renewable energy such as natural gas, distillate fuel oil and coal.
- For coastal mega-cities like Hong Kong, Lagos and New York, challenges are posed by population growth and increasing traffic volume and reflect the conflict between an increasing demand of energy production and a shortage of energy supply.
- For smaller cities like San Andres, though with relatively smaller size of population and transportation, its mono-economy structure is highly depend on well-preserved natural scene for tourism which requires sustainable environmental policies.

External perspective (Threats):

- Rising temperature will leads to larger scale of power shortages.
- GHG emission from both industrial use and transportation are responsible for air pollution.

In general, energy, especially a sustainable and renewable system of energy supply would be the key solution for a coastal eco-city. After identifying sustainable energy supply as the key concern for coastal eco cities, seeking renewable ocean energy to the utmost extent as a supply for a coastal city should become a first priority. It is also well-recognized that the ocean is an incredible reservoir of resources and coastal cities have the possibility to make use of them. Having rights also imply having responsibilities and this means using these resources in a sustainable way that will allow future generations to do the same. Therefore, this study is focused on the assessment of ocean renewable energies that might be available for coastal cities. It was also decided that the most challenging case is represented by the island of San Andres in the Colombian Caribbean. The following chapter provides a full description of the motivations behind this decision and of the main interesting features of the case study.

4 Pathway to eco - San Andres

4.1 Overview

This chapter provides a brief description of the main features for and the main critical elements that San Andres is currently undergoing and will most likely have to face in the upcoming future.

4.2 Description of San Andres

San Andres is an island located at $12°35'N - 81°42'W$ which is part of the Archipelago of San Andres, Old Providence and Santa Catalina in the Colombian Caribbean. San Andres is the largest municipality and capital city of the Archipelago. The Archipelago has a total extension of $350{,}000\ km^2$, $27\ km^2$ of which correspond to San Andres Island, as shown in Figure 4.1. In 2000, the Archipelago was declared by UNESCO as Reserve of the Biosphere. The main economic activity in the island is tourism.

Table 4.1 shows the historical evolution of the population of the Archipelago of San Andres and Old Providence. Currently the population of San Andres is about 69,463 inhabitants which is more than 93% of the total population of the Archipelago. The number of tourists that visited the island rose from 341,293 in 2003 to 377,619 in 2012. The population density of San Andres is about 2,573 inhabitants per square kilometre and therefore is one of the most densely populated island in the Caribbean. This high density poses a serious demand for water, electricity, and building materials.

Figure 4.1 Location of San Andres in the Caribbean Sea.

Table 4.1 Historical evolution of the population in the Archipelago, Taken from (Gobernacion del Departamento de Archipielago de San Andres, 2013).

Year	San Andres	Providence	Total
1793	393	32	425
1835	644	342	986
1843	731	294	1025
1851	1275	640	1915
1870	-	-	3530
1912	3124	1924	5048
1918	3705	2300	5953
1938	4261	2267	6528

Historical evolution of the Archipelago population, Taken from (Gobernacion del Departamento de Archipielago de San Andres, 2013) (contd.).

1951	3653	1970	5675
1964	14413	2318	16731
1973	20359	2624	22983
1985	38069	3676	41745
1990	47921	4671	52592
1993	55111	5227	60338
1995	58652	5361	64013
1999	61943	5155	67098
2005	65627	4927	70554
2010	68283	5037	73320
2011	68868	5057	73925
2012	69463	5078	74541

According to DANE (Departamento Administrativo Nacional de Estadistica), 74% of the population in San Andres is located in the northern part of the Island, 12.6% in the central highlands, 0.3% in the Eastern part and 13.5% in the rural areas. Figure 4.2 shows the historical evolution of the urbanization in the island between 1944 and 2008.

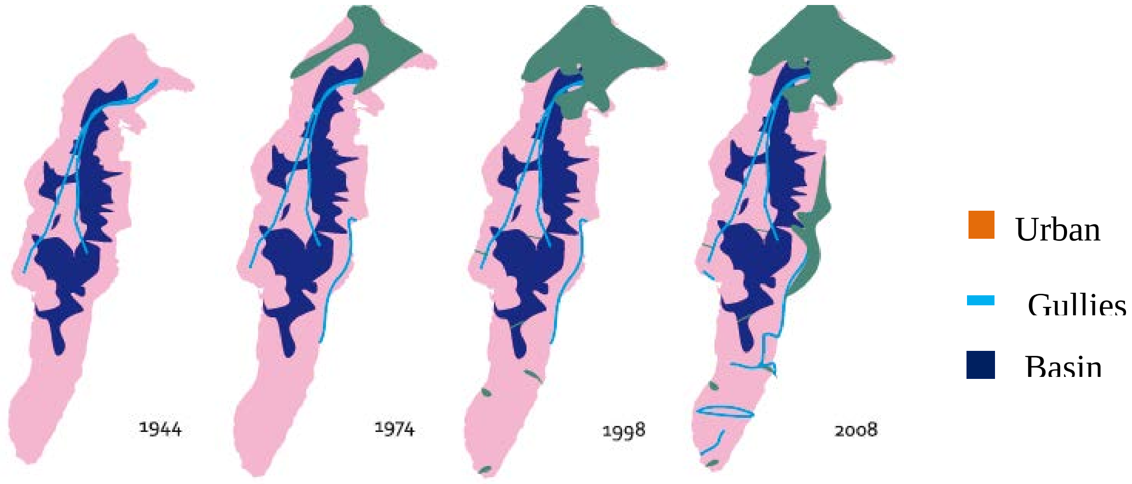

Figure 4.2 Historical evolution of urban areas in San Andres between 1944 – 2005, (Gobernacion del Departamento de Archipielago de San Andres, 2013).

Due to its location in the Caribbean Sea and the natural scenery, the main economic activity on San Andres is tourism and its related activities such as commerce and transportation. In 2010 the GDP was about $416 million which was about 0.1% of the Colombian GDP. In the last decade the economical annual GDP growth in the island has ranged between 2% and 6%. Figure 4.3 provides an overview of the economic activities, showing that the largest contribution to the GDP was commerce with 33% of the total, followed by hotels, restaurants and bars with 23%, public administration with 13% and transportation with 9% (Banco de la Republica-DANE, 2011).

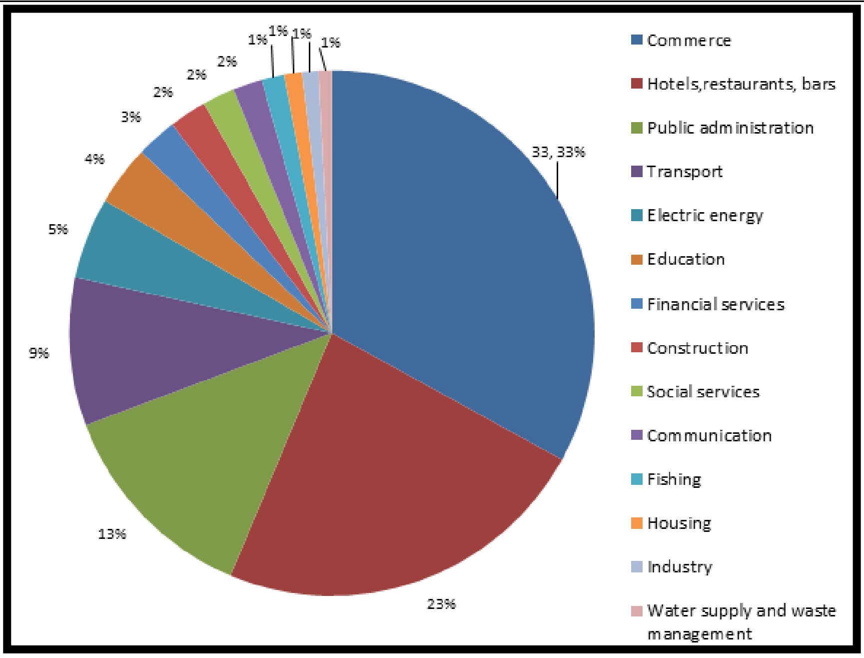

Figure 4.3 GDP participation by economic activity in San Andres in 2010 (Banco de la Republica-DANE, 2011).

The annual energy demand of the island is about 158 GWh which is generated from a power station that runs on diesel oil with a total capacity of $55MW$. The annual diesel consumption is about 40 million Litres. The generators in the power plant are divided in three units (A, B and C). The main unit is A and it meets 80% of the demand with a capacity of $20MW$. Unit B is composed of six motors with a total capacity of 17.1 MW and operates only on peak hours, covering 20% of the total energy demand. Unit C has eight motors with a total capacity of 17.1 MW. This unit is rarely used and accounts for only 1% of the total energy demand.

The energy supply system to the island is expensive, inefficient, vulnerable to natural hazards and logistics issues, and clearly not sustainable. The greenhouse gas emissions are high, but no detailed quantitative studies were found in the literature review. It is estimated that the annual emissions of CO_2 to the atmosphere are about 126,360 $tons$ (1.8 $ton/person$). An estimate made with the factor of 778 $gCO2/KWh$ calculated in the study by Sovacool (Sovacool, 2008) gives the annual quantity of CO_2 emitted to be 123,000 $tons$ for an annual energy consumption of 158 GWh.

The total number of vehicles in the island of San Andres is about 15,000. Private vehicles and boats with outboard motors consume approximately 1.2 million litres of gas while the public transport fleet and freight vehicles require approximately 491,000 litres of diesel. Propane gas is used in the island with a monthly overall consumption of almost 290,000 $litres$ of which around 73% is used in the residential sector.

San Andres Island is located in the Colombian Basin of the western Caribbean Sea. The Caribbean Sea has a variable bottom topography and remarkably irregular coastlines which affect significantly the physical processes at work in the region. The bathymetry near San Andres is presented in Figure 4.4.

The island has an elongated shape of about 13 km long and 2.5 km wide. The eastern side of the island has relatively shallow water depths and gentle slopes descending to 1000 m within about 10 km from the coast. On the eastern side the island is flanked by a coral reef barrier. The western side has steeper slopes and reaches depths of over 1000 m in less than 5 km from the coast.

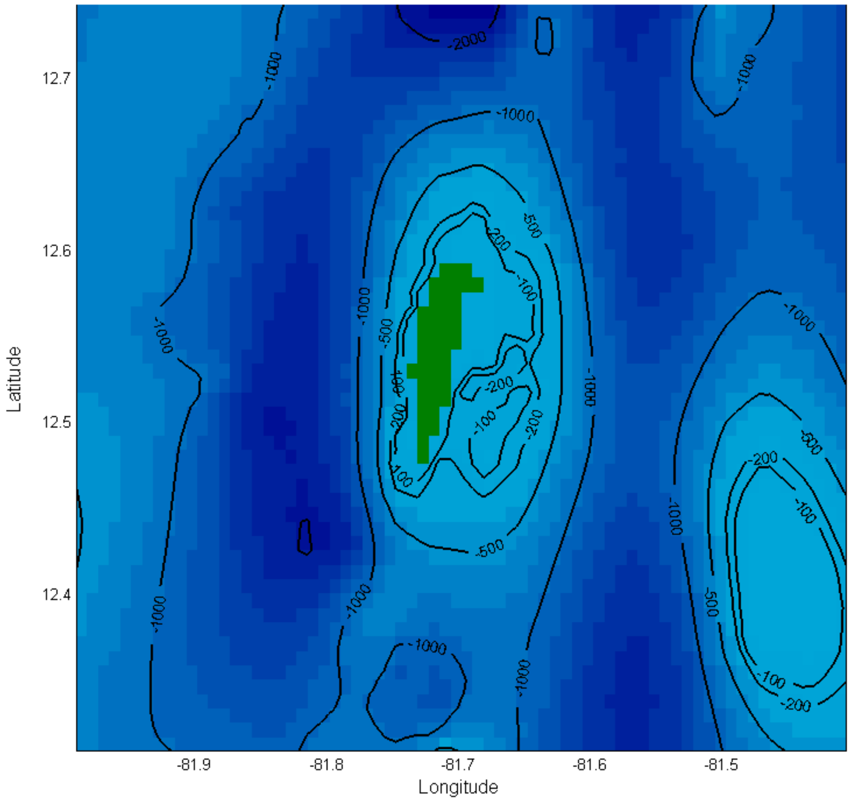

Figure 4.4 Schematics showing main bathymetric features near San Andres (British Oceanographic Data Center, 2010).

The island is affected by the westward flowing trade winds with average speeds between $3 - 6\ m/s$ at $10\ m$ above sea level (Figure 4.5), with maximum values between December and February and minimum values between September and November (Mesa, 2009). Easterly or north-easterly winds prevail over the region in winter and easterly or south-easterly winds prevail in summer (Sheng & Tang, 2003). The area is also frequently hit by hurricanes in summer and autumn. Winds in the Caribbean Sea result in wave heights of intermediate magnitude near San Andres, with significant wave heights of about $2\ m$ from December to February and $0.5\ m$ from March to May (Mesa, 2009).

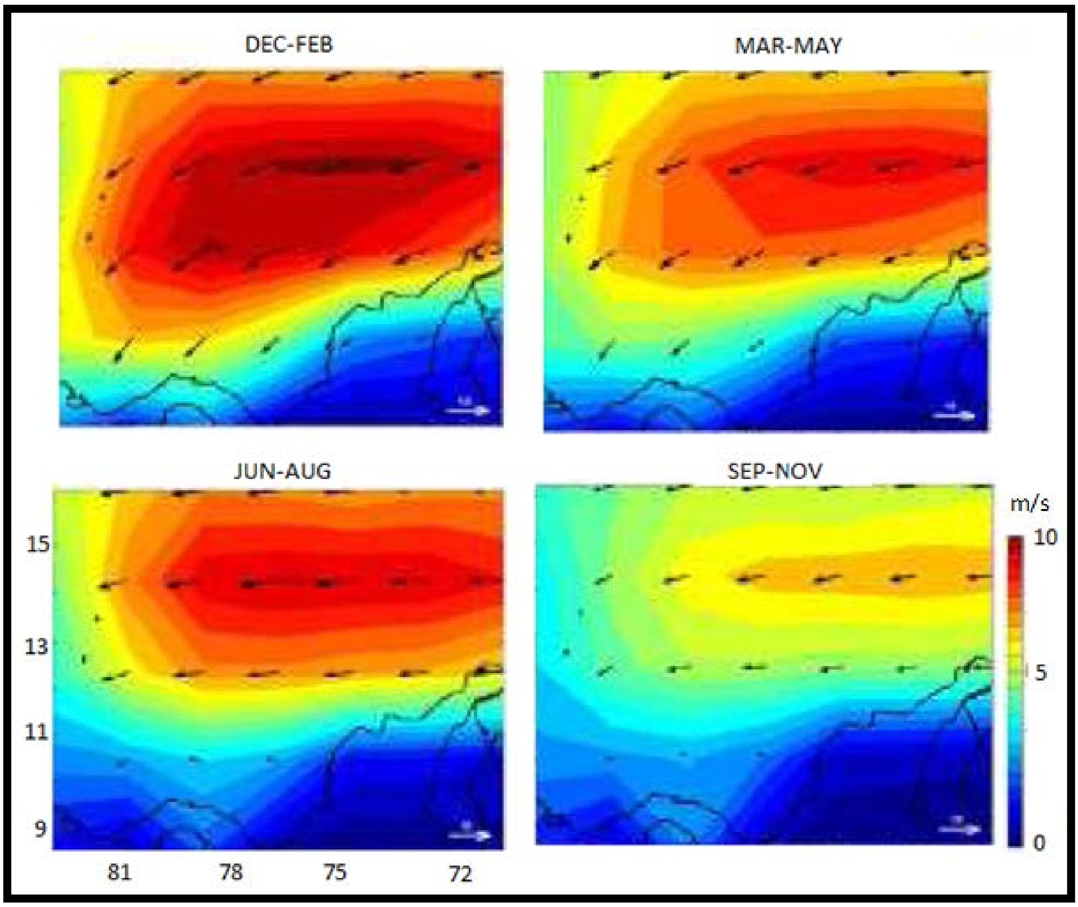

Figure 4.5 Seasonal-mean wind speed 10 m above sea level in the western Caribbean Sea (Mesa, 2009).

The surface ocean waters surrounding San Andres are relatively warm, with monthly mean maximum and minimum temperatures occurring in August ($\sim 28°$) and February ($\sim 26°$), respectively (Sheng & Tang, 2003). The ocean currents affecting the island are the westward flowing Caribbean Current (Figure 4.6) and the cyclonic (counter-clockwise) circulation of the Panama-Colombia Gyre (Sheng & Tang, 2003).

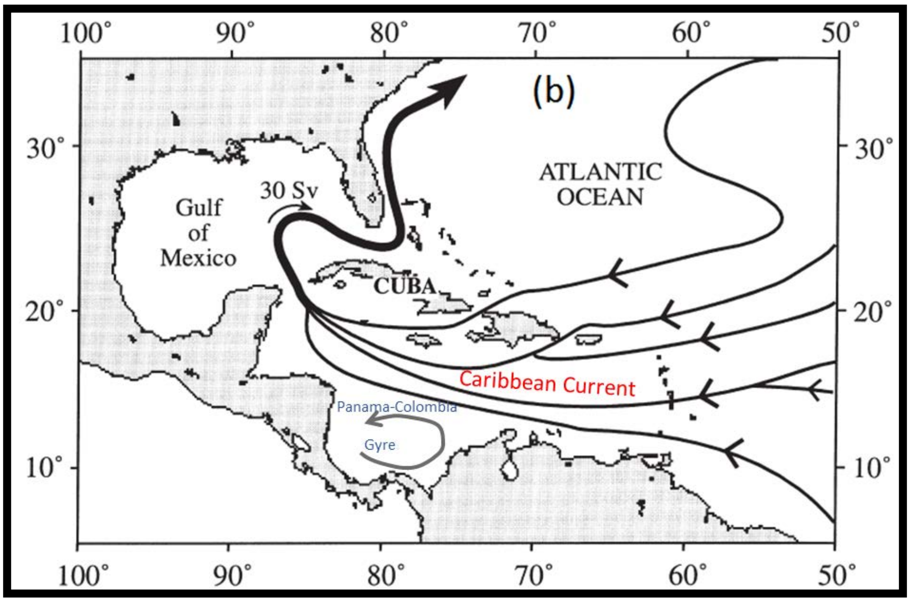

Figure 4.6 Main circulation features in the Caribbean Sea (Nof, 2000).

4.3 Weaknesses and threats of San Andres

San Andres has a series of problems that have been mentioned in the description of the city and also highlighted by the SWOT analysis (both in its individual version and the comparative chart). However, specifications that relate to the threats and weaknesses experienced on the island require further discussion. This is carried out in the following sub-sections.

4.3.1 Mono-economy:

A mono-product economy implies an economic system that is essentially based on the existence of only one major economic product. The implication is that the economic life and existence of that economic actor revolves around the relevance and currency of that product. That economy remains a potentially buoyant one only if such product does fine in the international market.

The free port designation given to San Andres in 1953 shifted the economic base from small-scale agriculture and fishing, beginning a process of economic and political marginalisation of native islanders. The uncontrolled influx of immigrants seeking work in the rapidly expanding tourism and commercial sectors, coupled with economic incentives that encouraged continental Colombians to settle in San Andres, led to impoverished social conditions, inequitable benefit distribution, divisive cultural tensions, and a decline in quality of life. This situation was exacerbated in the past decade by the economic and political crises affecting Colombia and by the collapse of the free port tourism model that was a result of loose national trade restrictions

The economy of San Andres is mainly focused on tourism and tourism related activities. The island receives several daily flights coming from different Colombian cities (and to a less extent from foreign cities) with passengers eager to relax and enjoy the beauty of the local beaches. These activities are complemented by agriculture and fishing for internal consumption that prove to be insufficient to supply the island and this is why San Andres needs external supply of food from the mainland on a regular basis both for inhabitants and visiting tourists. In the past the island exploited some agricultural resources commercially such as coconut, sugar cane, avocado, mango, oranges, ñame, noni and yuca.

The increasing urbanization of many areas driven by the touristic interest and infrastructure related development has generated soil damage that in the end has led to the decrease of the agricultural activities. Employment statistics indicate that tourism related employment accounts for 50% of total employment while direct employment in the fishing industry is less than 10% of the workforce. In San Andres fisheries account for less than 1% of local GDP and tourism directly accounts for over 40% of the local GDP. Every tourist visiting the island must buy a "Tourist card and contribution to the use of tourist infrastructures" with a price of 46,800 Colombian pesos or $US\$\,24.5$. Cities around the world are introducing the tourist tax as a source of revenue and San Andres is not an exception. With a number or tourists of around 400,000 the island is collecting $\$\,9.7M$. This shows the importance tourism has in the island's financial assets and as a consequence how vulnerable it is to the changes and fluctuations of the tourism market. San Andres caters almost exclusively to a domestic Colombian market. A large percentage of tourists come from relatively high income, by national standards, professional and managerial classes from the main Colombian cities.

The number of tourists that visits San Andres annually equals six times the local number of inhabitants. According to a study carried out in 2011(Sanchez Jabba, 2012), 76% of the tourists ranked the beauty of the beaches as the determining factor for their trip. The same study showed that should the surface of the beaches be reduced as a consequence of erosion, 60% of the tourists would not come back to the island. 68% of them replied that they would not pay the same amount of money for their trip and will be willing to spend only 56 % of what they have spent for their current trip. Considering this outcome and aware of the importance tourism has for the economy of San Andres, the economic impact of the above described scenario will reduce the local GDP drastically and damage the wellbeing of the system.

4.3.2 Dependency on external supplies (food and oil) shipped from the mainland

Regarding the food production, primary production closely linked to self-sufficiency on the island was replaced by the service sector in San Andres. Since food production decreased, import of canned goods and other products increased, contributing to the establishment of a new economy that would soon lead to narrowing the opportunities for survival of the native islanders.

Today almost all energy used on the island comes from imported liquid fossil fuels predominantly diesel for electricity generation and then kerosene and gasoline for air, ground and sea travel. Colombia possesses numerous fossil fuel and natural resources such as petroleum reserves, extensive coal reserves (the largest in South America), significant but largely untapped natural gas reserves, and extensive hydroelectric resources. A large amount of potentially productive oil and natural gas areas remain unexplored.

Demand for energy (petroleum, natural gas, and electricity) is expected to grow annually by 3.5% in the nearby future. San Andres completely relies on the supply of fossil fuels from the mainland. 630 GWh of imported fuel per year with the lion's share of that energy going to electricity production and ultimately air conditioning is the single largest electricity consumer on the island today and is provided predominantly by electric air coolers.

4.3.3 Scarcity of drinkable water resources

Poorly planned development and population growth have led to serious shortage of potable water. While demand is not the only factor, it remains the most relevant one. Since 1970 the population in the island has overcome the capacity of its ecosystem by 10 times. San Andres depends on two aquifer sources for human consumption that have been polluted with domestic waste with an increase of related illnesses and higher prices of imported bottled water as a consequence (Arjona, Molina, Castro, Castillo, Black-Arbeláez, 2002)

In 2012 the water supply was $1{,}900{,}000\ m^3$ per year but the losses in the system are high (approximately77%) as only $432{,}000\ m^3$ were actually used by the final consumers. This represents only a portion of the total estimated demand of drinking water in the island, as the total annual estimated demand is $4{,}471{,}250\ m^3$ (175 litres per capita daily). The annual cost of water supply is $\$\ 1.327M$ and it implies a cost of $3.00\ \$/m^3$. However, the final price paid by consumers is only a part of the actual cost of water as most of the public services are subsidized by the central government.

Due to the deficiency in water supply, inhabitants currently carry out their own water collection from other sources such as collection of rain water and wells built in their properties. Currently the overall demand for water is met by 80% from underground water, less than 20% from rain water collection and around 2% from private and commercial desalinization plants. According to a study carried out by University of Freiburg (Germany) and members of the Research team in Solar Energy from the National University of Colombia, only between 1% and $2\ \%$ of the existing water supply is drinkable and the average daily shortage is in a range between 5000 and $8000\ m^3$. The residential sector with almost $70{,}000$ permanent inhabitants represents the biggest water demand, however, it must be clarified that the fluctuating population per day (due to tourists) almost doubles that of the permanent dwellers. The estimation of the daily water consumption per capita of the island can be said to be about 93 litres.

The greater demand for water and the general lack of sustainable water use (both for locals and tourists) combined with a lack of awareness and good practices towards the use of water are the causes for the overexploitation of the aquifers and the pollution of groundwater and coastal waters. Salinization of aquifers due to sea level rise poses an additional threat to the freshwater resource of the island.

4.3.4 Land and water pollution:

Over the years, San Andres has experienced environmental degradation due to inadequate management of solid, liquid, and oily wastes combined with poor land use practices such as deforestation. Due to the inadequate disposal of residual waters, there has been a severe hydric pollution in San Andres. According to the local government, the coverage of the sewage system is significantly low reaching 22.7% in 2011 while the national coverage amounts for 72.3% (Banco de la Republica-DANE, 2011). This lack of sewage infrastructure and planning has led to the creation of septic tanks for water disposal (only 28% of which meet the basic technical requirements), and as they are not enough, the remaining water is directly thrown into the sea. The residual water thrown into the sea contribute to nutrients that are degraded by the bacteria living in the ecosystem. However, when the residual waste is excessive the ecosystem is not capable of degrading it all and this leads to a severe imbalance. Some studies that have analysed the quality of the water in San Andres establish that the proliferation of algae can be explained through the presence of nitrogen and phosphorous which is a clear indication of water pollution. This proliferation of algae can lead into a decrease of the beach quality that, as has been explained before can have a tremendous impact on the tourism sector and therefore on the economic structure of San Andres.

Due to scarcity of land, swamps have been filled up and replaced by infrastructures such as the island's airport. Coastal water from a nearby mangrove swamp was used to cool the machines that produced the electricity in an open cooling system. As a result, hot oil-polluted water which is a by-product of the cooling system was discharged into the enclosed mangrove swamp and destroyed almost 50% of the mangroves in Hooker Bight (Baine, Howard, Kerr, Edgar, Toral, 2007).

Human activities are poorly managed; additionally local governments do not have waste management systems put in place. The garbage production on San Andres is of approximately $100\ tons$ daily and the open air dump has reached its capacity. Another source of pollution that must be highlighted is the oil spills generated by the ships that transport supplies to the island and the thousands of fishing boats and touristic attraction boats that sail the island's waters.

5 Legal review on San Andres

5.1 Overview

The deployment of any project needs to take into account what are the existing legal boundaries and incentives both at national and international level for its fulfilment. The case of an offshore strategy to obtain ocean related energy for San Andres is no exception. This chapter examines what are the main existing legislations dealing with the development of offshore structures and renewable energy in the national and international scenario.

5.2 International legislation

In an international perspective, one of the first and founding elements in terms of environmental protection can be found in the Declaration of the United Nations for the Human Environment (1972) where Principle 13 states (UN, 1972)*: "In order to achieve a more rational management of resources and thus to improve the environment, States should adopt an integrated and coordinated approach to their development planning so as to ensure that development is compatible with the need to protect and improve environment for the benefit of their population"*.

Some years later another key document came into being. The third U.N. Conference on the Law of the Sea was convened in New York in December 1973. Attended by more than 3,000 delegates from 157 countries, it was the largest multilateral treaty-making conference in history. The conference lasted for a total of 585 days over a period of nine years with the scope of defining the rights and responsibilities of nations in their use of the world's oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources. The United Nations Convention on the Law of the Sea (UNCLOS) is the international agreement that resulted from the third United Nations Conference on the Law of the Sea (UNCLOS III). The Convention concluded in 1982 yet it came into force in 1994, a year after the 60th nation signed the treaty (UN, 1982). It should be noted that the United Nations has no direct operational role in the implementation of the Convention. There is, however, a role played by organizations such as the International Maritime Organization, the International Whaling Commission, and the International Seabed Authority (the latter being established by the UN Convention).

The convention introduced a number of important provisions, the most significant ones dealt with setting limits, navigation, archipelagic status and transit regimes, exclusive economic zones (EEZs), continental shelf jurisdiction, deep seabed mining, the exploitation regime, protection of the marine environment, scientific research, and settlement of disputes. The convention set the limit of various areas, measured from a carefully defined baseline (normally, a sea baseline follows the low-water line, but when the coastline is deeply indented, has fringing islands or is highly unstable, straight baselines may be used). UNCLOS convention provided several definitions regarding the sea related boundaries:

Territorial sea - the sovereignty of a coastal state extends beyond its land territory and internal waters to an adjacent belt of sea, described as the territorial sea in the UNCLOS (Part II); this sovereignty extends to the air space over the territorial sea as well as its underlying seabed and subsoil; every state has the right to establish the breadth of its territorial sea up to a limit not exceeding 12 nautical miles; the normal baseline for measuring the breadth of the territorial sea is the mean low-water line along the coast.

Contiguous zone - according to the UNCLOS (Article 33), this is a zone contiguous to a coastal state's territorial sea, over which it may exercise the control to: prevent infringement of its customs, immigration, or sanitary laws and regulations within its territory or territorial sea; punish infringement of the above laws and regulations committed within its territory or territorial sea; the contiguous zone may not extend beyond 24 nautical miles from the baselines from which the breadth of the territorial sea is measured.

Exclusive economic zone (EEZ) - the UNCLOS (Part V) defines the EEZ as a zone beyond and adjacent to the territorial sea in which a coastal state has: sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, of the waters super-adjacent to the seabed and of the seabed and its subsoil, and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents, and winds; jurisdiction with regard to the establishment and use of artificial islands, installations, and structures; marine scientific research; the protection and preservation of the marine environment; the outer limit of the exclusive economic zone shall not exceed 200 nautical miles from the baselines from which the breadth of the territorial sea is measured.

Continental shelf - the UNCLOS (Article 76) defines the continental shelf of a coastal state as comprising the seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baselines from which the breadth of the territorial sea is measured; wherever the continental margin extends beyond 200 nautical miles from the baseline, coastal states may extend their claim to a distance not to exceed 350 nautical miles from the baseline or 100 nautical miles from the 2500 meter isobaths, it does not include the deep ocean floor with its oceanic ridges or the subsoil.

The ocean boundaries discussed above are shown in Figure 5.1. The convention also established general obligations for safeguarding the marine environment and protecting freedom of scientific research on the high seas.

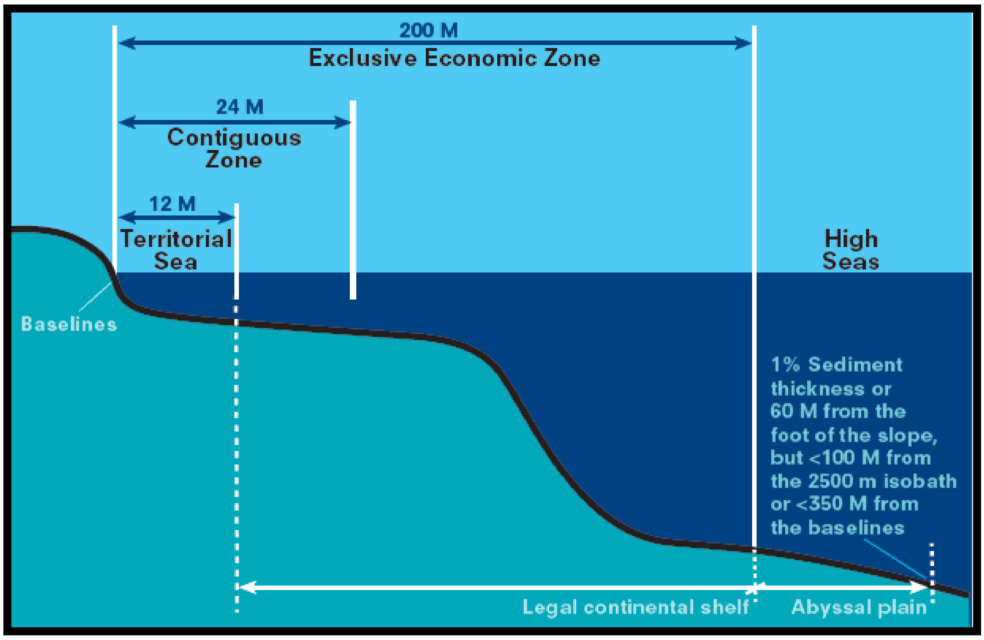

Figure 5.1 The ocean boundaries (UN, 1982).

Another aspect that needs to be taken into consideration when speaking about offshore structures is the situation regarding the use of submarine cables and pipelines in the continental shelf. These cables are the material link from the offshore production facility to the onshore storage and grid to be then distributed to the final users. Article 79 provides clarification on the layout of Submarine cables and pipelines on the continental shelf stating that:

1. All States are entitled to lay submarine cables and pipelines on the continental shelf.
2. They have to take reasonable measures for the exploration of the continental shelf, the exploitation of its natural resources and the prevention, reduction and control of pollution from pipelines, the coastal State may not impede the laying or maintenance of such cables or pipelines.
3. The delineation of the course for the laying of such pipelines on the continental shelf is subject to the consent of the coastal State.
4. Nothing in this Part affects the right of the coastal State to establish conditions for cables or pipelines entering its territory or territorial sea.
5. When laying submarine cables or pipelines, States shall have due regard to cables or pipelines already in position especially for its repairing and maintenance.

Many are the international treaties and laws with different environmental goals, apart from the ocean-centred Law of the Sea that has already been explained, that Colombia must take into consideration while dealing with environmental related aspects. The main ones are mentioned below.

Before the Earth Summit of Rio de Janeiro 1992:

- 1972 Declaration of the United Nations for the Human Environment.
- 1973 International Convention for the Prevention of Pollution from Ships (MARPOL).
- 1982 United Nations Convention on the Law of the Sea (UNCLOS).
- 1983 Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region.
- 1990 Protocol Concerning Specially Protected Areas and Wildlife in the Wider Caribbean Region.

Conventions and treaties related to the Earth Summit and beyond:

- 1992 Earth Summit – Agenda 21.
- 1992 Convention on Biological Diversity.

- 1992 United Nations Framework Convention on Climate Change.
- The 2001 Conference on Responsible Fisheries in the marine Ecosystem.
- 2002 World Summit on Sustainable Development.
- 2005 United Nations International Strategy for Disaster Reduction 2005-2015
- 2012 United Nations Conference on Sustainable Development (UNCSD), Rio+20.

5.3 National policy of ocean and coastal areas

Colombia defends its sovereign right to exploit its own resources pursuant to its environmental policy without prejudice to the provision of ratified international instruments with responsibility to ensure that activities are carried out within the jurisdiction or control, don't harm the environment of other states or areas beyond its natural jurisdiction.

The territorial waters, continental shelf and coastal areas on both the Caribbean and Pacific Ocean are areas within the country were different types of activities and processes such as tourism, fishing, shipping, exploration and mining, alternative energy generation, conservation and restoration of biological diversity take place.

The central government is convinced that it is necessary to contribute to the organization, development, strengthening and consolidation of science and technology of the Sea in Colombia in order to ensure that the country has strong scientific and technological basis to permit a comprehensive and adequate management of its maritime and coastal ecosystem areas and resources so as to achieve a balance between conservation and productive development (sustainable use) (National Ocean Policy, 2008).

Well aware of the fact that an integrated management is vital, the Colombian State created the Colombian Ocean Commission (Decree 347 of 2000) that is an intersectional advisory board that acts as a coordinating body of the government to carry out a Policy of National Oceanic and Coastal Areas. This policy focuses in the following different thematic areas (Comisión Colombiana del Océano, 2010):

- **Institutional development**: Naval power and maritime authority.
- **Economic development**: Ports and Port infrastructures, Maritime transport, Merchant marine and shipping industry, Fishing and aquaculture, Tourism

industry, Minerals, hydrocarbons and non-energy sources and renewable alternative (FENC) and alternative and renewable energy sources.

- **Territorial development**: Integrated Coastal Zone Management, Disaster attention and prevention and Marine and coastal protected areas.
- **Development of Oceanic and Coastal Environments**: Resource conservation and strategic ecosystems, Marine biodiversity, Marine environmental quality and Climate change.
- **Social and Cultural Development**: Marine culture, Maritime education and Cultural heritage

Regarding the development of alternative and renewable energy sources the National Policy of Ocean and Coastal Areas states:

- The State, encourages the use of non- conventional energy sources and conventional criteria of rational and efficient, including cogeneration systems both in the national grid as in non-interconnected areas, because of its impact on marine and coastal areas,
- The State, through the Ministry of Mines and Energy, ensures continuity of the studies developed under the Convention designed to identify potential energy from tidal and wave,
- The State, through the Ministry of Mines and Energy and the Institute for Promotion and Promotion and Planning Institute of Energy Solutions ensures increased service coverage by implementing programs and projects aimed at energy solutions in both the National Interconnected system as in non-interconnected areas, using non-conventional energy possibilities and expanding rural coastal routes,
- The State, through the Ministry of Mines and Energy, will lead the CIURE towards environmental proposals of tax incentives for science and technology for the development of coastal and marine projects.

The driving document is the National System for Integrated management of ocean and coastal zones that operates at different levels. Table 6.1 shows the different levels of execution and coordination of the coastal management strategy in Colombia.

Table 5.1 Levels of execution and coordination of coastal management strategy in Colombia.

Geographical scale	**Management level**	**Responsible bodies**	**Integration and coordination mechanism**
National	General policies and national plans of sectorial development. Law expeditions	Ministries (Environment, Housing and Territorial development, Transport, Mines and Energy, Commerce and Tourism, Foreign Relations), Colombian Ocean Commission, General Maritime Directorate	National Council of Economic Policy, National Committee for Integrated management of Ocean and coastal zones
Regional (Planning territorial units of the Pacific and Caribbean)	Regional Strategic plans Department of development plans	Governments Autonomous regional sustainable development corporations	Regional Committee for Integrated management of ocean and coastal zones

Levels of execution and coordination of coastal management strategy in Colombia (contd.).

Sub regional(environ -mental oceanic and coastal unities)	Integrated management of ocean and coastal zones plans Three-year action plans of the regional Autonomous corporations	Governments Autonomous regional sustainable development corporations Harbour masters General Maritime Directorate and related Research Centres	Regional Committee for Integrated management of ocean and coastal zones
Local (municipalities)	Municipal development plans Territorial order plans	Municipalities/city halls Harbour masters General Maritime Directorate Ethnic and community authorities	Coordination between municipalities Local Integrated management of ocean and coastal zones

At the technical level, the National Planning Department (NPD) is the entity in charge of defining and incentivising a strategic vision for the country in areas regarding social, environmental and economic development. This is done through the design, orientation and assessment of public investment as well as the definition of working frames for the private sector.

Another body that should be taken into consideration is the Institute of Planning and Promotion of Energy solutions for Non- Interconnected Zones (IPSE) such as the island of San Andres.

Regarding the national jurisprudence, several laws have been proclaimed to ensure that the different strategies can find a legal support framework. In October 2001 the Colombian authorities proclaimed the Law 697 for the Promotion of Rational and Efficient Use of Energy and Alternative Energies:

Article 1. To declare the Efficient and Rational Use of Energy (URE) as a matter of public, social and national interest to secure the full and opportune energy supply, the competitiveness of the Colombian economy, consumer protection and the promotion of the use of non-conventional energies in a sustainable way with the environment and the natural resources.

Article 9. To promote the use of non-conventional sources of energy. The Ministry of Mines and Energy will formulate the guidelines of policies, strategies and instruments for the promotion of non-conventional sources of energy, giving priority to non-interconnected zones.

Article 10. The National Government through the programmes that are being designed, will encourage and promote the companies that import or produce parts, heaters, solar panels, biogas generators, wind turbines, and/or any other technology or product that use as total or partial source non-conventional energies, according to the actual legal norms.

In December 2003, the Colombian government proclaimed the Decree 3683 which applies Law 697 and creates an Inter-sectorial Commission for the Rational and Efficient Use of Energy and Non-conventional Energy Sources (CIURE).

Decree 3683 of 2003

Article 1. The aim of the decree is to regulate the rational and efficient use of energy, in such a way that it will be possible to have the highest energy efficiency to assure the full and opportune energy supply, the competitiveness of the Colombian energy market, consumer protection and the promotion of non-conventional energy sources, in the framework of sustainable development, complying with the regulations in force with regard to the environment and renewable natural resources.

Law 99 of 1993 on the Environment

Article 5. Functions of the Ministry of Environment include (…), substitution programmes for non-renewable natural resources, and the development of energy generation technologies which are not polluting nor harmful.

Law 223 of 1995 on Tributary Reform

It offers exemption of VAT for equipment and elements for control systems and monitoring, which are necessary for the fulfilment of environmental regulations and standards. It is an instrument of the Ministry of Environment to promote clean production.

The Colombian Ministry of Mines and Energy has established a plan of financial aid for the development of energy solutions in Non- Interconnected areas (Law 633 of 2000, articles 81 to 83). This Financial Aid Fund for Energy solutions for Non- Interconnected areas aims at financing plans, programs and projects for the construction and installation of new energy infrastructures or for the restoration of the existing ones with the overall goal of enlarging the coverage and increase satisfy the demand of energy in these areas.

Decree 1140/1999 IPSE (Non-Interconnected Zones)

Article 3 The functions of the Institute for Planning and Promotion of Energy Solutions (IPSE) include the carrying out of the necessary studies that define the economic and technical characteristics of an integral energy solution that satisfies the needs of the zone in a self-sustainable, efficient and economical way.

Law 383 of 1997 on Tributary Reform

The Law offers an income tax deduction due to investments or donations for research, scientific or technological development projects. It responds to the National Science and Technology Policy whose technical secretary is the Colombian Institute for the Development of Science and Technology (COLCIENCIAS).

Law 488 of 1998 on Tributary Reform

The law stipulates that income tax or VAT is deducted to whom donates resources or equipment to “non-for-profit associations, corporations and foundations, whose social objective and activity are to develop technological and scientific research and environmental protection.”

Law 788 of 2002 on Tributary Reform

Article 18 establishes an exemption of income tax for fifteen years, to "the sale of energy based on wind resources, biomass or agricultural residues, only carried out by the generating companies".

Law 693 of 2001

This law establishes standards concerning the use of carburant alcohols and creates incentives for their production, commercialisation and consumption. In this regard, Law 788 of 2002 (articles 31 and 88) introduced exemption of VAT.

Even if much effort has been placed in the introduction of these laws, and considering they contemplate important aspects such as the stimulus to the education and the research in matter of renewable energy sources; it must be said that they do not have other fundamental aspects to impulse significantly the renewable energy strategy, for example (Ruiz, Rodrıguez-Padilla, 2006).

1. They do not propose a regulatory support system to encourage the investors,

2. They do not define a percentage quantitative share of renewables in the energy sector,

3. It is not clear how much of the available funding can be used for renewable sources within the funds for the development/restoration of energy infrastructures in the non-interconnected zones.

4. Indications are not given in terms of tributary incentive and it is not specified when such tributary exemption goes into force.

From what has been stated so far, considerations can be derived for offshore renewable energy case study. Colombia, well aware of its boundaries, is committed to pursue an integrated coastal and ocean policy that includes participation and coordination of stakeholders at different levels (from the national government to local municipalities). This aspect is very important, especially for territories that are far away from the capital (as in this case the island of San Andres) as decisions taken at central level that do not take into consideration local stakeholders have a higher tendency to fail. This strategy takes into consideration and respects the different international treaties and convention the country has signed and ratified along the years.

Having analysed the law of the sea, it can be stated that the installation of offshore renewable energy sources within the exclusive economic zone of San Andres is feasible from the legal point of view. However, another aspect that needs to be assessed is the impact these structures might have for the environment and human life and whether they comply with the existing regulations both at national and international level.

6 Ocean renewable technologies for San Andres

6.1 Overview

In this Chapter a review of the different offshore technologies available for recovering energy from the ocean is presented. These technologies include ocean thermal energy conversion (OTEC), offshore solar power, wave energy conversion, and wind energy conversion. The critical environmental parameters that determine the technical feasibility of the technology in a specific location are discussed and a preliminary assessment for San Andres is made. Tidal and salinity gradient energy recovery are not included since tidal amplitudes are very small in San Andres and there are not significant amounts of freshwater discharged by a river into the ocean.

6.2 Ocean thermal energy conversion (OTEC)

The ocean thermal energy conversion (OTEC) is a method for extracting energy from the ocean using the temperature difference between the warm surface waters and the cold deep waters in the ocean. The mechanism consists of evaporating a fluid and using the pressurized steam to drive a turbine to generate electric power (Heydt, 1993). The working fluid (usually ammonia) is evaporated by heat exchange with the warm surface waters of the ocean. Once power is generated, the vapour of the working fluid is condensed by heat exchange using cold water pumped from the deep ocean. The temperature difference must be greater than 20°C for net power generation.

The technical feasibility for OTEC production is mainly dictated by the vertical structure of the temperature distribution in the ocean. The ocean surface is directly warmed up by the incoming solar radiation and the stored heat is mixed by wind in the upper surface of the water column. The upper water column is relatively mixed and has near-homogeneous water temperatures. Deep waters in the ocean are usually cold because a large portion of them consist of water that have sunk in Polar Regions, and have filled the deep basins of the oceans. In the ocean, the temperature differences suitable for OTEC occur only in regions with relatively warm surface waters (inter-tropical regions) and deep waters (around 1,000 m). As a result OTEC is suited only to open ocean areas in inter-tropical regions (Fujita, et al., 2012) Figure 6.1 shows the time-mean temperature difference between the 20 and 1,000 m depths (Nihous, 2010). The figure shows that there are resources for OTEC over a large portion of the ocean between 25°S and 25°N. Regarding the site location for a particular project, more accurate studies using high resolution data to determine the spatial distribution of temperature and the temporal variability of the temperature must be considered.

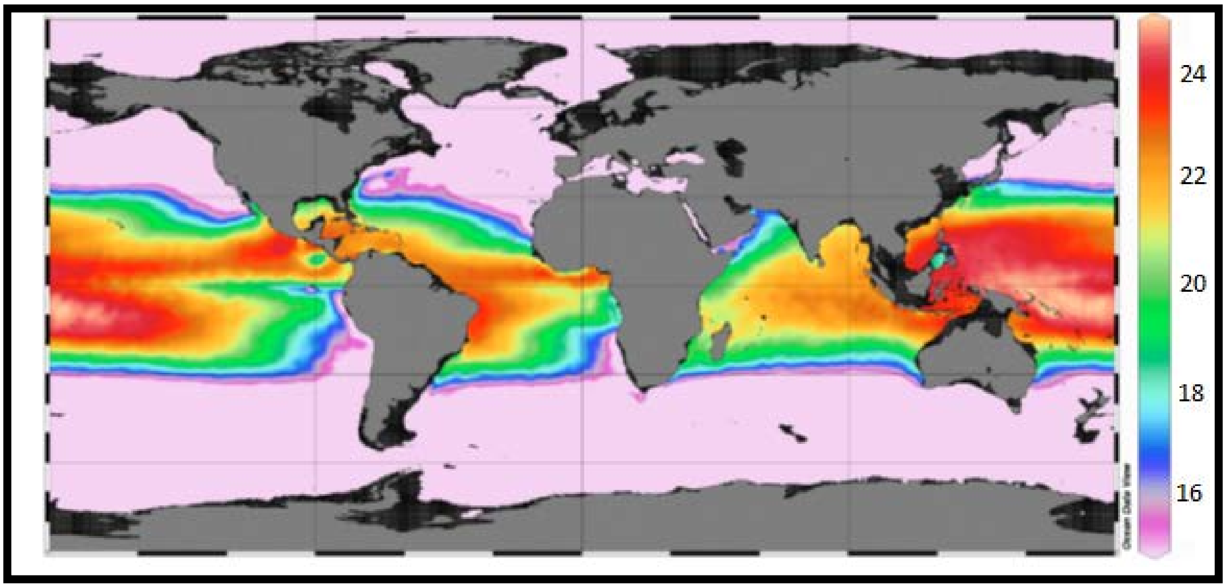

Figure 6.1 Time-mean average ocean temperature difference between 20 m and 1,000 m extracted from the World Ocean Atlas (2005) (Nihous, 2010).

For San Andres the availability of the resource can be observed in Figure 6.2. The Figure shows vertical profiles of monthly mean temperatures (Sheng & Tang, 2003) and root mean square values averaged over the western Caribbean Sea from oceanographic observations compiled by the National Oceanographic Data Centre (NODC). Winter and summer temperatures profiles show a warm upper layer of about 24°C and 28°C, respectively. The spatial variations, as indicated by the error bars (two standard deviations) are relatively small, particularly in summer. The temperature rapidly declines from about 100 m down to 1,000 m where temperatures are about 4°C. Below 1000 m the temperatures are relatively uniform and do not have much spatial variations within the Caribbean as the amplitudes of the error bars are very small. From these profiles it can be stated that the western Caribbean Sea is an appropriate area for the development of OTEC due to the availability of suitable temperature gradient that are maximum during the summer (24°C) and minimum during winter (20°C). The cold water depth which guarantee these gradients lies about 900-1,000 m water depth.

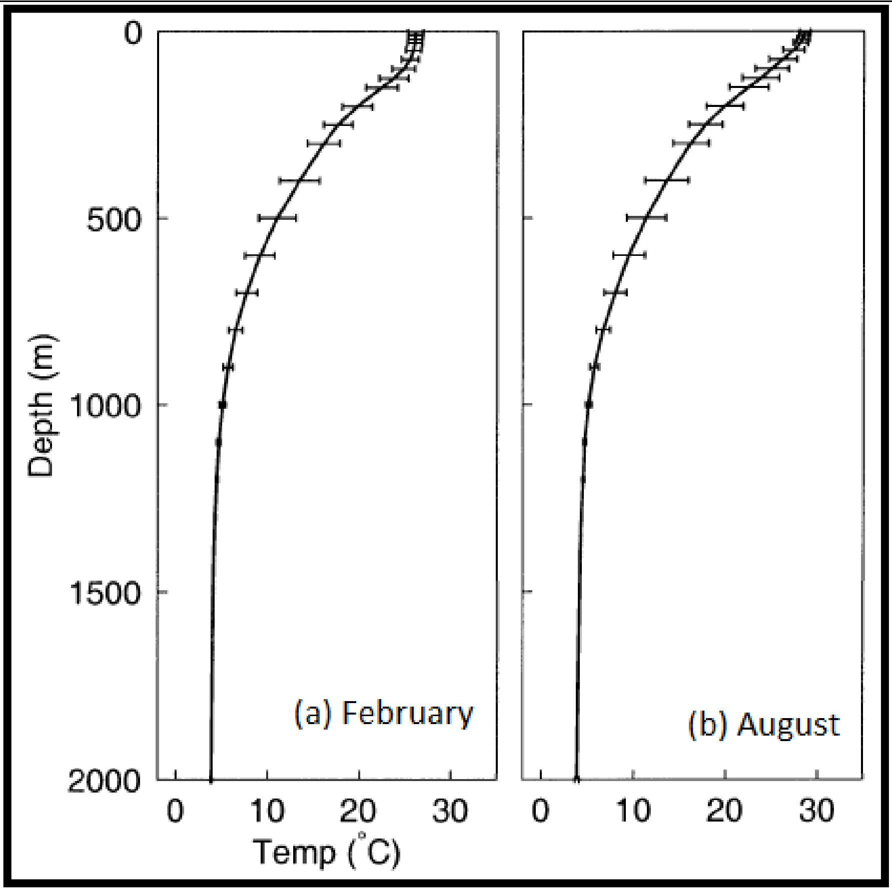

Figure 6.2 Vertical profiles of the climatological monthly mean temperature for the entire western Caribbean (Sheng & Tang, 2003).

6.2.1 Types of OTEC system

Different approaches have been developed which use the basic principles of OTEC: Open Cycle, Closed cycle and Hybrid cycle. Below an e explanation of the basics of these different methodologies is provided.

Closed Cycle OTEC (CC)

An OTEC closed cycle system uses a working fluid that can evaporate temperatures close to that of the warm sea surface water. As the working fluid evaporates the vapour expands making a turbine work and generate electricity (Figure 6.3). The working fluid is condensed by heat exchange with cold sea water pumped from the deep ocean and used again in a new closed cycle to generate electricity. The main components of a CC are: the heat exchangers for evaporation and condensation; the turbine and generator components; the pumps to drive the working fluid onto the evaporator and to drive deep cold water onto the condenser and the seawater supply system (pipes).

The success of the CC depends to a large extent on the selection of a working fluid that undergoes phase changes at the temperatures prescribed by the sea surface temperature. Other factors include the cost and availability of these working fluids, compatibilities with systems materials, toxicity, and environmental hazards (Masutani & Takahashi, 2001). Ammonia and some fluorocarbons have been proposed for these applications, but are hazardous substances if leaking occurs. Ammonia has some degree of toxicity and the depletion of atmospheric ozone by the fluorocarbons. These hazards can however be significantly reduced if proper system designs and operations are secured.

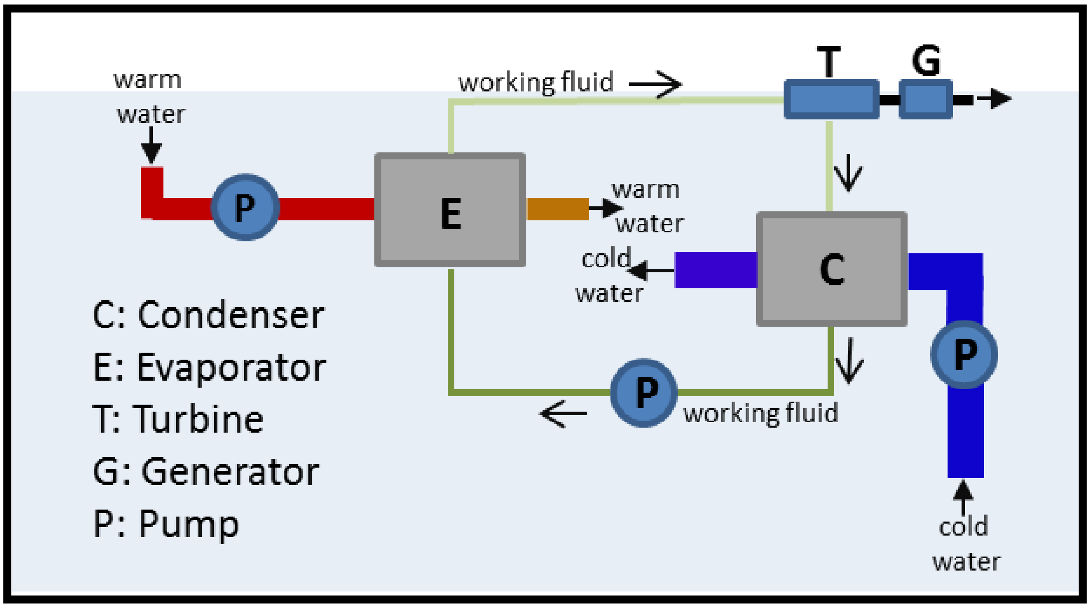

Figure 6.3 Schematic diagram of a Closed Cycle (CC) OTEC system.

Open Cycle OTEC (OC)

Ocean thermal energy conversion can be achieved also when the working fluid is sea water itself. In this case there is no recirculation of the working fluid because seawater is removed from the system after vapour generates electricity at the turbo-generator system. In an OC, warm surface water is flash evaporated (using a partial vacuum, 1-3% atmospheric pressure) then the vapour generates electricity as it passes through a turbo generator (Figure 6.4). In principle, there is no need for heat exchangers in the OC. The main advantage of the OC however, is that it can produce desalinated water. In this case heat exchangers are required so that water vapour is condensed by heat transfer to cold sea water (~4°C) that has been pumped from the deep ocean.

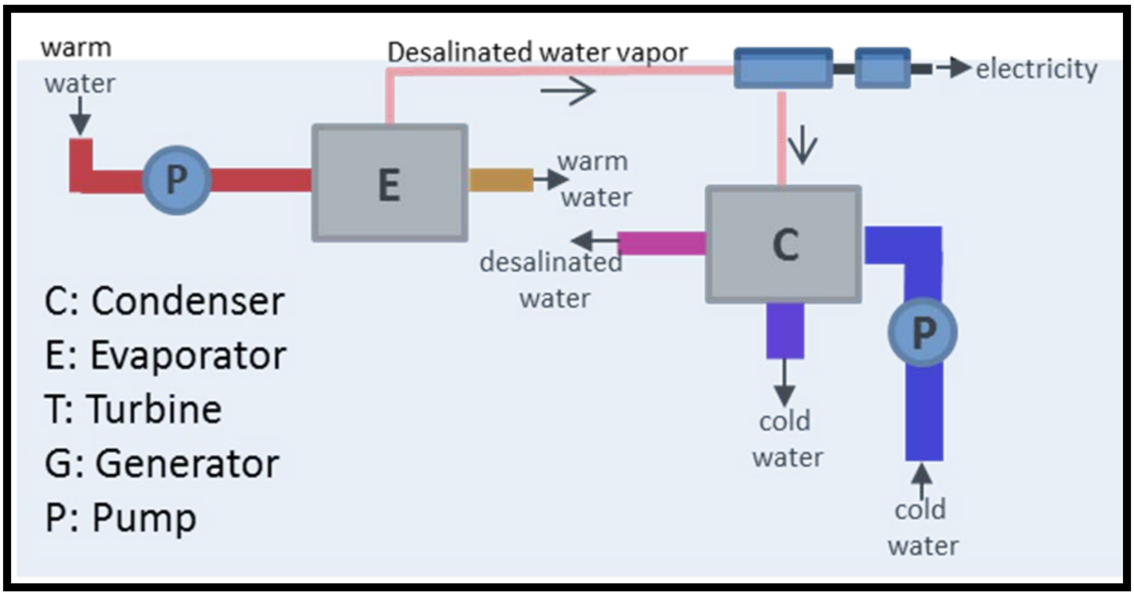

Figure 6.4 Schematic diagram of an Open Cycle (OC) OTEC system.

Some difficulties arise from the required low pressures used to evaporate the sea water. The most important is that the system is vulnerable to leakages of air and presence of non-condensable gases. To control this, the system has to use big amounts of energy to create the low pressures and this may be costly from an energy perspective.

Hybrid Cycle OTEC (HC)

Hybrid cycle (HC) OTEC plants use a closed cycle for power and heat exchangers similar to those of open cycle plants. Depressurized water is evaporated and then condensed on the outside of the boiler to heat the working fluid. The working fluid could be ammonia just as used in CC. Desalinated fresh water is produced during this process.

6.2.2 Additional uses derived from OTEC systems

Other products associated with OTEC can include:

Fresh water: Produced water from open cycle systems can be used as a drinking water or for irrigation. It was estimated that a 10MW plant could potentially produce some 35,000 m^3/day of fresh water (Seymour, 1992).

Refrigeration: The relatively large amounts of cold deep sea water used to condensate the working fluid in the OTEC system can be used to provide air conditioning and refrigeration. If used for refrigeration, only about 10 % of the energy required by conventional cooling would be required.

Hydrogen production: The relatively large amounts of cold deep sea water used to condensate the working fluid in the OTEC system can also be used to produce significant amounts of hydrogen. It has been reported that a 10MW OTEC plant can produce up to 834 Nm^3/h of gas hydrogen (Ikegami, Fukumiya, Okura, Jitsujara, & Uehara, 2002).

Water for use in aquaculture: The cold deep water used in OTEC is rich in nutrients and its high productivity is suitable to sustain fisheries and other sea food related activities.

6.2.3 Environmental challenges

Environmentally, OTEC is a very benign power production technology, since the handling of hazardous substances is limited to the working fluid, and no noxious by-products are generated. OTEC requires the pumping and return of various seawater masses, which, according to preliminary studies, can be accomplished with virtually no adverse impact. This argument should be very attractive, for pristine island. The visual impact of the plant is minimum. The largest units would occupy about 50x50 m, but would be located in substantial kilometres away from the coast. The major concern with closed cycle OTEC systems is that ammonia is used and could leak if pipes are damaged. There might also be some habitat disruption with the installation of the plant and the transmission cable, but in principle they are thought to be minimum yet detailed studies are needed.

Among specific impacts could be the biota attraction due to the platform presence, the organism entrainment due to withdrawal of surface and deep ocean waters, the nutrient, oxygen and salt redistribution due to discharge waters and the interference with marine life due to low-frequency sound production (National Oceanographic and Atmospheric Administration, 1981).

6.2.4 Components of OTEC plant ships

The capacity of OTEC power plants refers to the net power that an OTEC system can generate. Energy used to operate power plants can be of the order of 30% of the gross power produced by the plant. The main components of an OTEC plant can be seen in Figure 6.5 for the case of a CC OTEC. The schematic shows the pumps to bring warm water towards the inlet screens on the top. The warm water pipes transport the warm water from the upper part of the plant towards the bottom. The boilers in the bottom part evaporate the working fluid in the small-diameter pipes, and the turbo-generators produce the electricity. The pipe coming from the deep ocean has the largest diameter and transports cold water, which is used in the condensers to bring the working fluid back to liquid state. A brief description of the main components of an OTEC plant are presented below (National Oceanic and Atmospheric Administration, 2009).

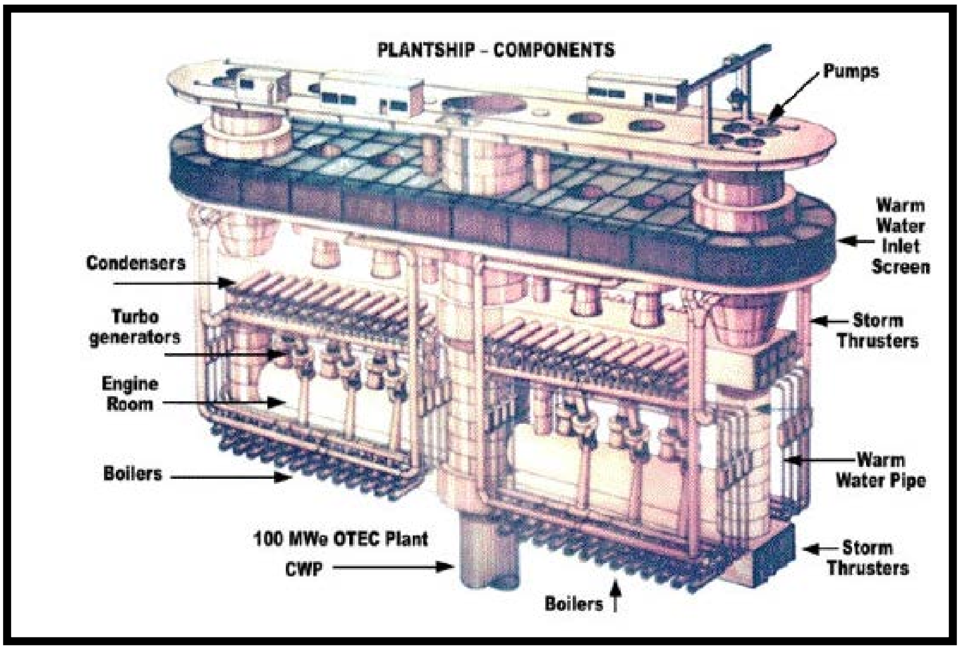

Figure 6.5 Main components in a CC OTEC plant designed by Sea Solar Power Inc. (Seasolar Inc., 2013).

6.2.5 OTEC plant for San Andres

Given the energy profile of San Andres with an average power demand of 18 MW, the existing OTEC technologies are feasible from a technical point of view. Currently a few 10 MW commercial plants are being built, which is expected to shed light onto the steps to build commercial plants of 100 MW (Meyer, Cooper, & Varley, 2011). Experts have suggested that floating OTEC systems of up to 10 MW are technically feasible using current design, manufacturing, deployment techniques and materials. A 20 MW OTEC might still be technically feasible, or be achievable by using a modular design of the 10 MW plant. With the current state of technology, San Andres would be a good proving ground for the application of OTEC in a small remote scenario. The plant would be located at about 5 km off the western side of San Andres because sufficient water depth can be achieved and there is no abundance of coral reef which could be damaged by the transmission cable.

Current designs of 10 MW OTEC feature a cold water pipe of 4 m diameter x 1000 m long, cold water flow 19 m^3/s, warm water flow 28 m^3/s, fresh water production 0.4 m^3/s (Lockheed Martin, 2013).

6.2.6 Cost of OTEC system

The levelized cost of electricity (LCOE) includes the capital costs (CC) and the operation, maintenance, reparation and replacement during the life cycle of the project. It is consideredthat the project is amortized within 15 years at an interest rate of 8% for a commercial loan, and with an inflation scenario of 3%.

The capital costs of OTEC facilities are high. Open cycle plants require higher capital investments (about 20%) than the closed cycle plants. It is generally accepted that OTEC capital cost ($/kW) is a strong function of plant capacity (Vega, 2010). A summary of the capital costs (price of 2010) of OTEC plants of different capacities is presented in Figure 6.6. The capital cost per kW decreases rapidly as the plant size increases. Then the capital cost per kW for plants larger than 30 MW decreases less rapidly than for smaller systems. The capital cost of a 10MW plant is about 20,000 $/kW. Experts speculate that future generation designs will reach cost reductions of as much as 30%.

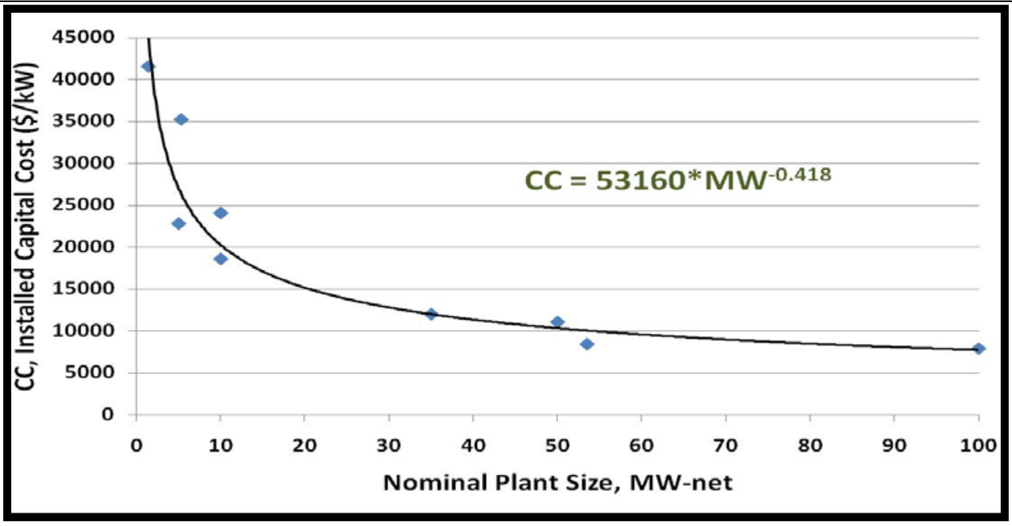

Figure 6.6 Capital costs estimated for first generation OTEC plants in US dollars of 2010 (Vega, 2010).

Table 6.1 shows the cost associated with closed cycle OTEC plants considering US prices of 2010. Operation and maintenance costs are relatively uniform across different plant sizes, which means that these costs per kWh are very high for small OTEC systems. The LCOE decreases as plant size increases, for example a 10 MW plant is about 0.44 cents per kWh.

Table 6.1 Levelized cost of electricity, Operation and maintenance (O&M) and repair and replacement (R&R) for closed cycle OTEC plants (Vega, 2010).

Plant size (MW)	Capital cost $/kw	O&M $M/year	R&R $M/year	COE $/kWh
1.35	41,562	2.0	1.0	0.94
5	22,812	2.0	3.5	0.50
10	18,600	3.4	7.7	0.44
53.5	8,430	3.4	20.1	0.19
100	7,900	3.4	36.5	0.18

Figure 6.7 shows a comparison of the levelized cost for closed and open cycle systems. For both systems the capital cost is the main component of the total cost. The O&M and R&R costs for both the open and closed cycle are very similar, however the capital costs are 20-25% higher in open cycle in comparison with the closed cycle. A 10 MW open OTEC system has a levelized cost of about 0.5 $/kWh of which about 70% corresponds to capital

cost. Going from 10 MW to 20 MW could imply a significant reduction in the levelized cost which could be of around 20%. Depending on the type of loan and interest rate, the levelized price could also be significantly different. If a government bond to be paid in 20 years at 4% interest rate is considered, the levelized cost could be also about 20% less (Vega, 2010).

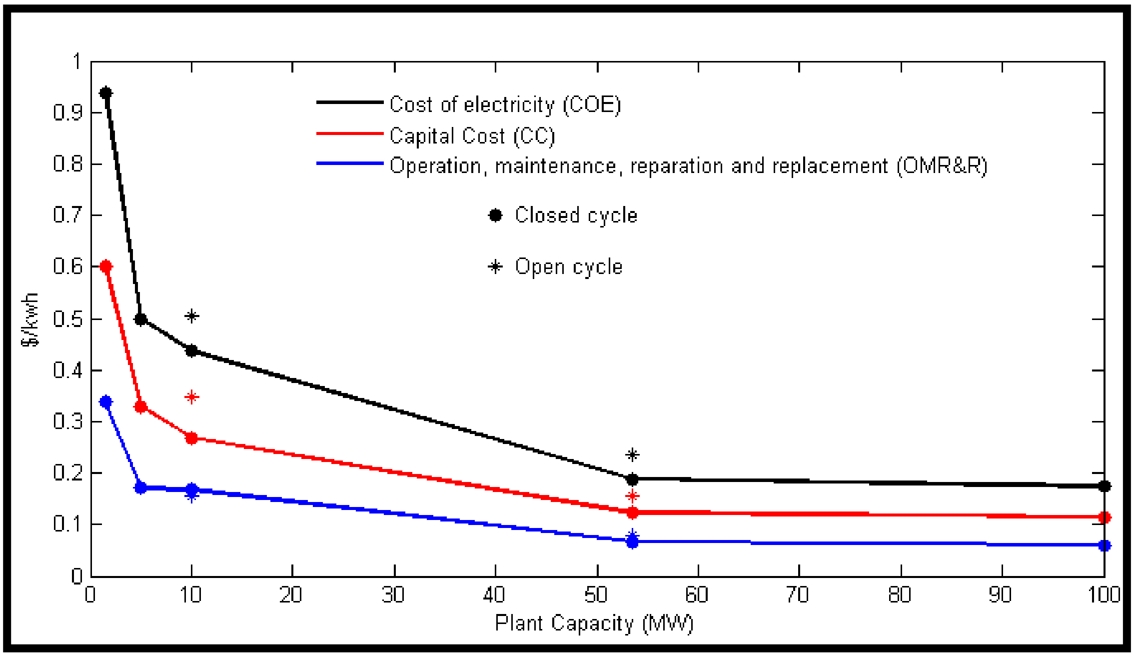

Figure 6.7 Levelized costs of electricity for closed and open cycle OTEC plants (Vega, 2010).

In any case, the levelized costs of OTEC systems are high and might not be competitive with other technologies. For OTEC to be financially feasible, it would be necessary to take advantage of other products associated with it. In particular, the production of fresh water could not only make the system more feasible but also improve the city as access to clean water resources is limited.

In order to be competitive with current diesel generation prices which are of about 0.16 $/kWh, a 10 MW plant producing 35,000 m^3/day would have to sell fresh water in order to offset high OTEC generation costs. A detailed examination of this aspect is presented in chapter 7.

6.3 Offshore solar energy

The sun is the planet's primary energy source and therefore has the potential to provide clean energy distributed around the globe. Solar power is the conversion of sunlight to electricity, either indirectly, using solar thermal, or directly, using photovoltaic (PV). A solar cell, also called PV cell, is an electrical device that utilises the photovoltaic effect, releasing electrons when exposed to sunlight, producing direct current (DC). This can be stored, or converted to alternating current (AC) with an inverter and fed into the utility grid or immediate local use. Usually, a PV system requires the following main components: Solar panels Solar cabling (DC cabling), inverter safety isolators, and generation meter.

Generally speaking, there are three common PV systems: monocrystalline (silicon) panels, polycrystalline (silicon) panels and thin film panels. Monocrystalline panels are the most efficient and expensive type with a typical efficiency of 15-17%. Polycrystalline cells are relatively cheaper and have slightly lower efficiencies of about 12-14% efficiency in comparison with monocrystalline cells. The less efficient and cheaper are the thin cell panels (Shah, Torres, Tscharner, Wyrsch, & Keppner, 1999). Thin cells however, can be implemented in schemes where flexibility is a requirement. This make thin cell the choice in offshore developments where continuous movement of the sea surface by the waves is critical in the operational phase of the project.

As the photovoltaic energy sector is rapidly growing and several emerging technological specifications for PV have been developed, these systems can be further categorized by the module types they adopt. Figure 6.8 uses a block diagram to illustrate prevailing modules on the market today. A detailed technological specification for modules is given in Table 6.2. As stated in the Table, non-silicon based thin film panels (CdTe and CIS) have an efficiency of 10% with a total of 10.5% of market share as of 2007.

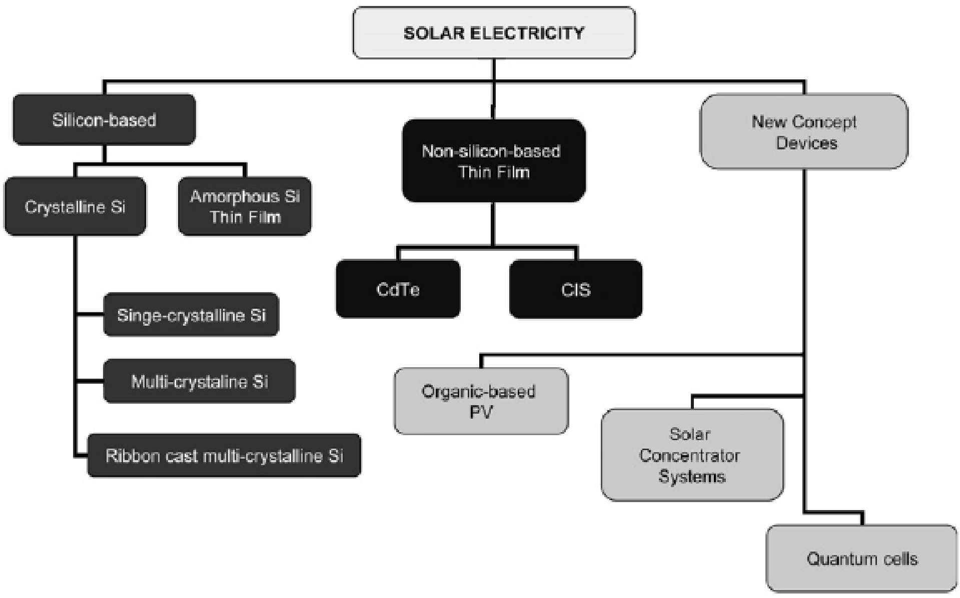

Figure 6.8 Classification of PV systems based on solar modules (Raugei et al., 2009).

Table 6.2 PV technology specification as of year 2007 (European Photovoltaic Industry Association/Greenpeace, 2008).

Cumulative installed capacity (GW)							
	Crystalline Si				**Thin films**		
	$Sc-Si$	$mc-Si$	Ribbon		$a-Si$	CIS	$CdTe$
Crystalline Si layer thickness	250	250	300		N/A	N/A	N/A
Module efficiency (%)	14	13	11		7	10	10
Module technical lifetime (years)	30	30	30		30	30	30
Share of market (%)	89.5	89.5	89.5		10.5	10.5	10.5

The pressure of urbanization in San Andres and its small size (10 x 1.5 km) are practical constraints to large-scale ground solar production in the island. Therefore, this study will introduce a conceptual model of offshore solar system using thin film panels that take advantage of the tremendous sea area with abundant solar resources in San Andres.

The critical environmental parameters for a solar power development are the number of sunshine hours and the radiance. San Andres has more than 2,600 hours light per year and a daily average solar radiance between 4.5-5.0 kWh (IGAC, 2005) which make it an ideal site for solar energy developments.

6.3.1 Conceptual model for offshore solar project

For coastal areas with a strong demand of electricity usage, a dynamic floating solar field concept might work better based on previous analyses. Dutch company DNV Kema introduced its innovative conceptual model known as SUNdy which was launched at the Singapore International Energy Week in November 2012 (DNV, 2011).

The core of SUNdy is a 2 MW hexagonal array using commercially matured thin-film panels that float on the sea surface. The scalable design can be deployed independently or linked together with others. They are flexible and lighter than the traditional rigid glass-based modules, allowing them to undulate with the ocean's surface. After briefly investigating the solar resources available in San Andres, a detailed model of SUNdy and information on how SUNdy can be implemented in San Andres will be expansively analysed in Chapter 7.

6.4 Wave energy conversion

Wave energy conversion makes use of the energy available in ocean surface waves for the generation of electric energy. The technologies available for wave energy conversion can be categorized into three classes: Oscillating water column, oscillating bodies and overtopping.

The oscillating water column (OWC) makes use of the ocean wave swell movement to act like a piston and cylinder as shown in Figure 6.9. As wave rises, water rushes into an opening in the column which is below the waterline. The level of water in the column increases thereby increasing the air pressure at the top of the column. The pressurized air is then forced out of the column to rotate a turbine for power generation. As wave falls, air is also drawn into the column from the other side of the turbine which also causes the turbine to rotate.

Oscillating water columns are mostly installed at the shoreline as a fixed structure or few distance offshore (near-shore) as a floating structure.

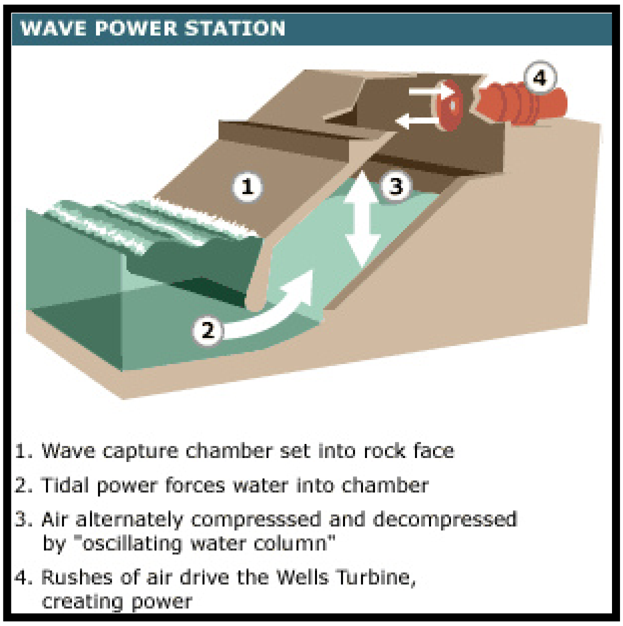

Figure 6.9 Representation of an oscillating water column wave energy converter (WEC), (Lemay, 2013).

Oscillating body technology utilizes hinge deflectors which are positioned perpendicularly to the wave direction. The movement of the deflector as it tries to resist wave surge is exploited to generate electrical energy. Oscillating body technologies can have fixed or floating structures. A schematic representation of a fixed structure is presented in Figure 6.10. A good example of floating oscillating body structures is the Pelamis installed off the coast of Portugal with power a rating of 750 kW which is the world's largest wave energy conversion development to date.

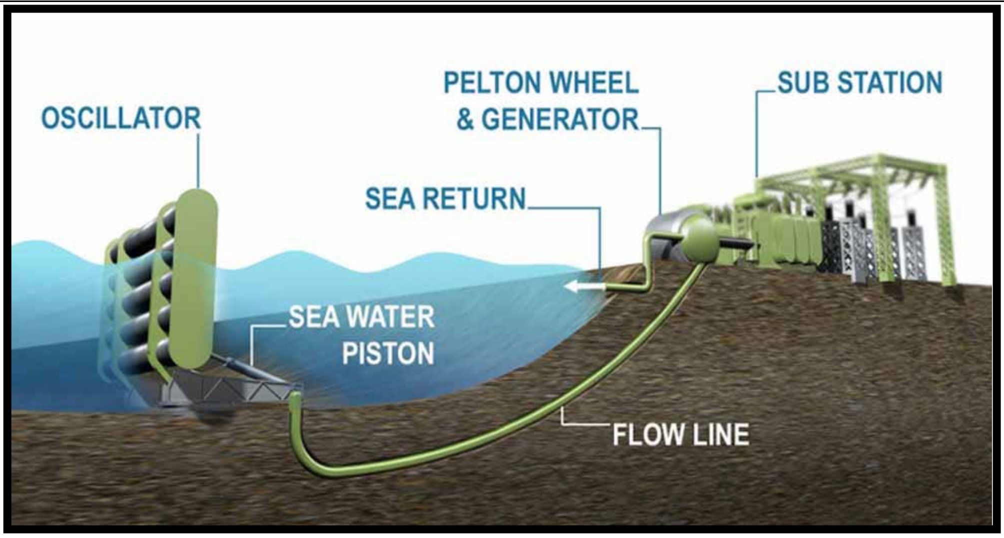

Figure 6.10 Representation of an oscillating body wave energy converter (Drew et al., 2009).

The overtopping technology captures the incident wave from the water surface. The water collected is directed to a central receiving part and then passed through a column with a turbine. The water turns the turbine and is then discharged back into the sea as shown in Figure 6.11. Overtopping technology is currently installed as either fixed or floating structure.

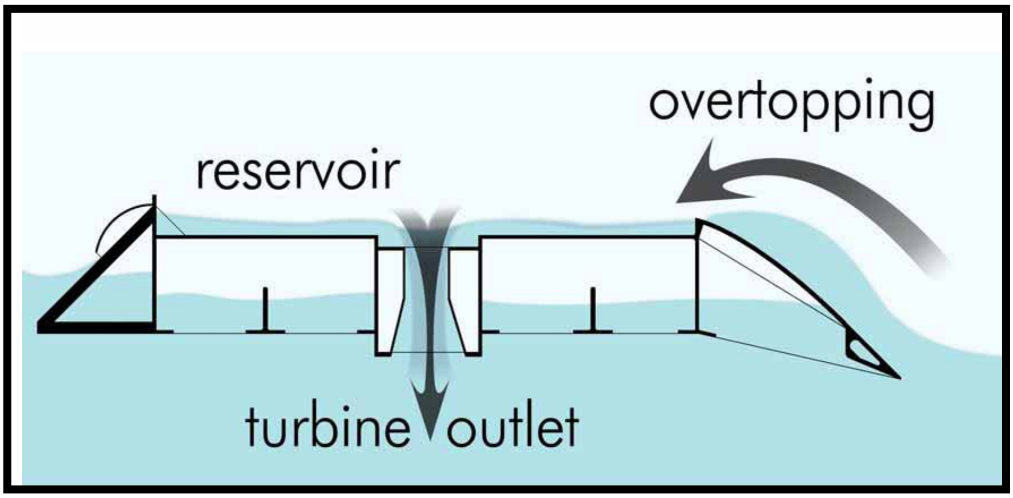

Figure 6.11 Representation of an overtopping wave energy converter (Dragon, 2013).

Although the concept of harnessing electricity from endless rolling waves provides a great alternative to conventional ways of electricity generation, wave device technology still needs to convince both venture capitalist and investors about its economic viability over other renewable energy sources. The technical factor that is considered before the installation of WEC is the wave condition of the location. The parameters that are looked out for are the wave height distribution, wave period, water depth and the yearly average energy in wave front of the area. These parameters are important for the decision making process on the size of WEC that would be required to produce sufficient energy output. These parameters therefore influence the net power production of the device.

The intensity of the wave front energy is also a major influence on the power production of the WEC. The study by Soerensen (Soerensen, 2006) showed a positive correlation between the wave front energy and the energy output of four units of Wave Dragon WEC (Figure 6.12).

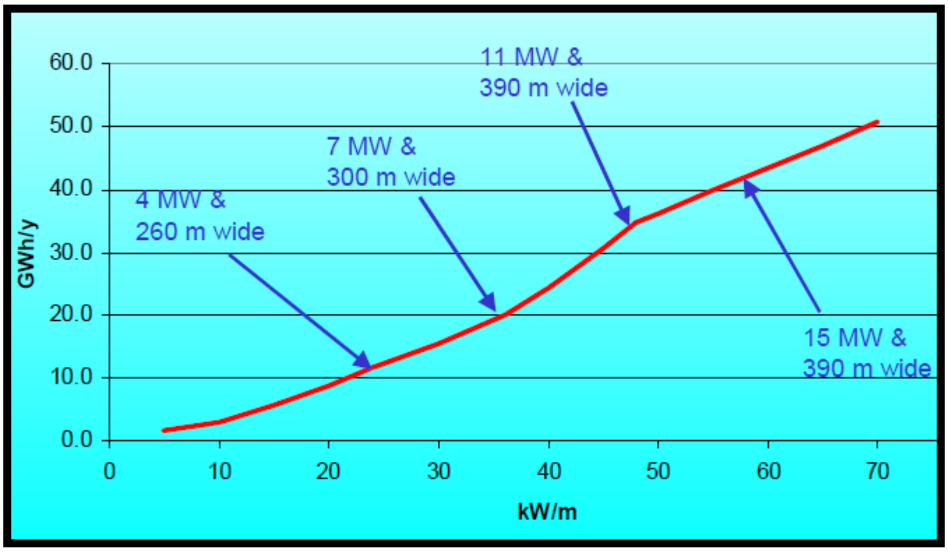

Figure 6.12 Relationship between the annual energy generation of WEC and energy in wave front (Soerensen, 2006).

As mentioned above, the availability of the wave resource is critical to the feasibility of a WEC development at a particular location. It is estimated that any area with an annual average over 15 kW/m is economically viable and has the potential to exploit wave energy at competitive prices if compared to other matured renewable energy technologies.

Figure 6.13 presents the distribution of the annual average wave front energy around the world in kW per meter wave crest. The Figure indicates that San Andres (enclosed in the red circle) has an annual wave front energy of about 5 - 10 kW/m. This means that the construction size of the WEC device that would be required for substantial power generation at San Andres may be approximately four times the device size used to generate the same amount of power in a 40 kW/m environment assuming that other technical factors are constant.

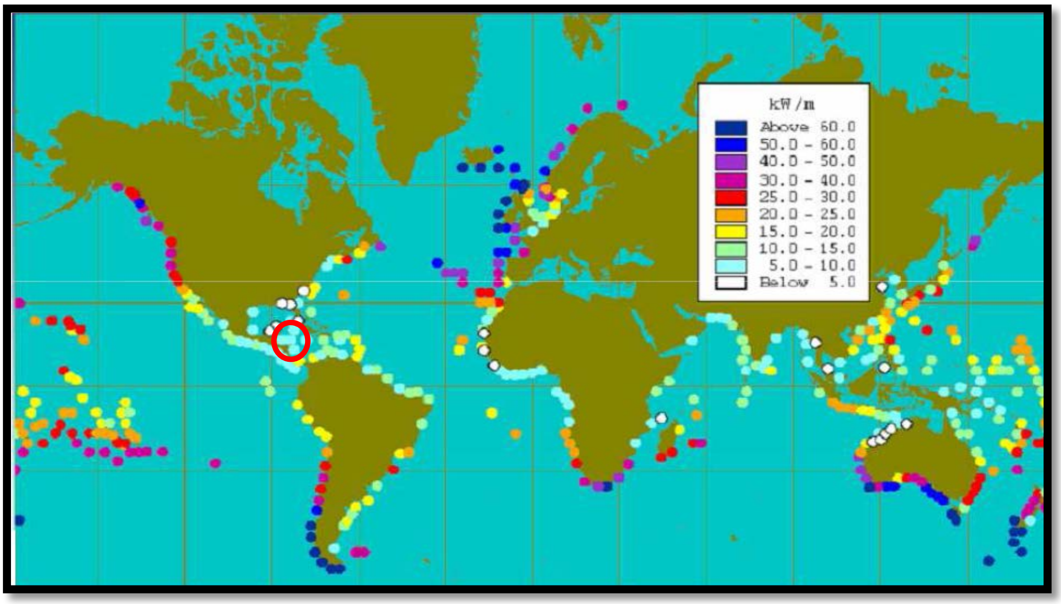

Figure 6.13 Global distribution of annual average wave front energy (Osorio, 2013).

6.4.1 Cost of WEC system

The capital and energy cost varies significantly between the three different WEC technologies. Most of the available WECs are prototypes which demonstrate the working knowledge of wave energy conversion. The available financial details for these prototypes in the literature are estimates of their potential cost. The financial implication of renewable energy technologies are quantified in terms of their capital cost and energy cost.

Soerensen (2006) demonstrated the economic viability of the overtopping WEC (Wave Dragon). His estimates are shown in Table 6.3 for the capital and energy cost of the device in three different wave front energy scenarios. The data in the Table shows a decline in both the expected energy cost and expected capital cost as the wave front energy increases.

Table 6.3 Energy cost and capital cost for different wave front energy, Adapted from (Soerensen, 2006).

Wave Front Energy (kW/m)	Energy Cost $(\$/kW)$	Capital Cost $(\$/kW)$
24	0.15	5,297.60
36	0.11	4,238.08

48	0.08	3,575.88

The Pelamis WEC device, which is a type of oscillating bodies floating technology, has a power rating of 750 kW and a single device is said to cost about $5.6 million. The capital cost for the device per one unit of the power output will then be $7,466/kW. It should be noted that the estimated capital cost only includes the cost of the equipment but does not include installation costs and other costs for offsite facilities. The capital cost for a near-shore installation of a 2.25 MW rated oscillating water column (OWC) device was estimated to be $7.14 million. The capital cost for the device per one unit of the power output will then be $3,172.08/kW.

6.4.2 Environmental challenges

It is estimated that the environmental impact of WEC devices shall be low when they are installed at water depth between 50 and 80 meters (Wave Energy Centre, 2013). However, there might be possible impacts on fishing activities as the presence of the device may become an artificial reef for marine animals. The components of the device may also disrupt movement of large marine animals or migration of fishes in the ocean. It is therefore important that the location of wave energy devices should be a prohibited zone for navigation and fishing purposes. The installation of a WEC should be located in an area that is less sensitive to biosphere reserves, such as the coral reefs in San Andres.

The process of harnessing energy from wave may direct fish migration to the direction of the turbine which may lead to their death in large quantity. There are investigations currently going on to assess the impact of noise from offshore installations on the behaviour of dolphins and whales. The hydraulic fluid used in WEC devices poses environmental concern. For example, the Pelamis uses a biodegradable transformer fluid. It is important to ensure that hydraulic fluids are well contained in order to avoid water ingress which could lead to escape of fluid to the sea environment. There is the need to develop hydraulic systems that are environment friendly and are well compatible with the device and seals used for containing the fluid.

6.5 Offshore wind energy

Offshore wind power has seen a significant growth in recent years driven mainly by the policy in Europe which has devoted much attention to it (European Comission, 2007). In general, offshore wind energy technology is less mature than the onshore technology. Offshore developments require higher investments as the construction, operation and maintenance works are more complex (Wang et. al, 2009). In comparison with onshore wind energy, offshore wind energy has some advantages such as (IPCC, 2012):

- More availability of wind resource as the wind profile is less damped in the open ocean than inland.
- Less conflicts with other land uses.
- Better economies of scale for building a larger wind farm with a higher number of wind turbines

Typically, energy is extracted from the wind by using turbines that start rotating at speeds of about 3-4 m/s. The rated power level of wind turbines usually corresponds to wind speeds between 11-15 m/s. Most of wind turbines are of the horizontal axis type and consist of three blades attached to a hub and main shaft, from which power is transferred to a generator (Kaldellis, 2012).

Control systems limit power output to prevent overloading the wind turbine at higher wind speeds (Burton et al, 2001). Most turbines stop operating at wind speeds of approximately 20 to 25 m/s (cut-out speed) to limit loads on the rotor and prevent damage to the turbine's structural components.

Offshore wind technology developments are mainly focused on the type of platforms use to place the wind turbines. Fixed offshore foundations are the most common type of structures used on wind energy projects and referr to commercial substructures that are limited to 40 to 50 m maximum depths. Floating platform foundations on the other hand, are based on the experience of the offshore oil and gas industry and therefore typical structural systems include a tension leg platform, a spar buoy, and semi-submesible. During the next decade it is expected that major effort will be made in developing offshore wind projects at water depths of over 50 m to the advantage of the market and its economic potential.

6.5.1 Cost of offshore wind power

The establishment of an Offshore wind farm is more expensive than the onshore farm due to the relative immaturity of this techonology in dealing with harsh weather conditions in the open ocean. This implies high costs of the foundations, installation, electrical connections and operation and maintenance (O&M) costs (Sun, 2012). A summary of investment costs for different offshore wind farms operating in Europe is given in Table 6.4. Although offshore wind is currently expensive, cost reduction can be expected over the long-term due to economies of scale (Junginger, 2005), learning effects (Blanco, 2009) and R&D efforts. The expected trends in capital costs for onshore and offshore wind projects can be found in Table 6.5. As revealed by the Table, offshore energy is expected to remain about 50% more expensive than onshore energy.

Table 6.4 Summary of investment costs for some offshore wind farms in Europe (Nikolaos, 2004; EWEA, 2009).

Offshore wind farm	**Number of turbines**	**Turbine size (MW)**	**Capacity (MW)**	**Water depth, (m)**	**Distance to shore (km)**	**Investment costs (€ M)**
Middelgrunden (Denmark)	20	2	40	5-10	2-3	47
Horns Rev I (Demark)	80	2	160	6-14	14-17	272
Samsø (Demark)	10	2.3	23	11-18	3.5km	30
North Hoyle (UK)	30	2	60	5-12	7.5	121
Nysted (Demark)	72	2.3	165	6-10	6-10	248
Scroby Sands (UK)	30	2	60	2-10	3	121
Kentich Flats (UK)	30	3	90	5	8.5	159
Barrow (UK)	30	3	90	15	7	NA
Lillgrunden (Sweden)	48	2.3	110	2.5-9	10	197
Burbo Bank (UK)	25	3.6	90	10	5.2	181

Table 6.5 Capital cost prediction for offshore and onshore wind turbine technology (Blanco, 2009).

	€/kW in 2020	€/kW in 2030	€/kW in 2040	€/kW in 2050
Onshore wind	826	788	770	762
Offshore wind	1,274	1,206	1,175	1,161
% difference comparing to onshore	54.2%	53.0%	52.6%	52.4%

6.5.2 Environmental impact of offshore wind farm

Offshore wind farms have less environmental impact comparing to the onshore farm in terms of visual and noise impact to people during the operation phase. However, the offshore wind farm may have an impact for the marine ecology and birds during the construction and operation phase.

Marine ecology – marine life, water quality and fisheries

Water quality may be affected due to following construction activities related to offshore wind farm operation (HKE, 2006):

- Change in hydrodynamics due to addition of foundation arrays in the wind farm site.
- Sediment plume dispersion due to piling.
- Sediment plume dispersion due to cable burying.
- Sediment plume dispersion due to excavation work near the cable landing point.

In addition, the noise emitted during construction and operation phase may affect marine mammals over a long distance causing temporary or permanent hearing impairment, behavioral disturbance and possible stress. (Richardson, 1997). Artifical electromagetic fields induced by underwater cables may also affect some fish species which are sensitive to magnetic fields such as sharks, rays and skates (Petersen et. al, 2006).

Impacts to birds

Wild birds collision with wind turbines are both site and species specific depending the flight path of migrant birds (HKE, 2006). Offshore wind farms can affect birds through collisions resulting in injuries or fatalities and in habitat loss or damage due to the operation of the turbines. These disturbances can lead directly to expulsion and thus loss of territory for certain species of birds (Petersen et. al, 2004).

6.6 Summary

A review of promising offshore renewable energy technologies for San Andres was made. The basic physical principles of energy conversion processes, potentiality of energy resource in San Andres, possible environmental issues and costs estimates were outlined for OTEC, solar energy, wave and wind energy technologies. The revision of these aspects led to narrowing down alternatives for San Andres to OTEC, solar and wind energies. Moderate availability of wave power makes the wave energy conversion less attractive in comparison with the availability of energy resource for the other technologies. OTEC was identified as a promising alternative which requires significant capital investments and has the advantage of producing freshwater. Wind and solar energies were shown to be promising from the point of view of resource availability and cost, however some constraints regarding fluctuations of the energy resource need to be taken into account. The next chapter will provide a detailed description of two approaches for energy solutions for San Andres. One is based on OTEC while the other one is a combination of offshore wind and solar energy conversion.

7 Approaches for an eco San Andres

7.1 Overview

Participation of the authorities and communities are important factors that need to be considered for the transformation of a coastal city to a coastal eco-city. Two different approaches of changing the energy profile of San Andres to be renewables are proposed in this chapter based on the technologies outlined in chapter 5. The first alternative is the implementation of an OTEC system, which because of high capital investment costs, would require a strong funding scheme from the central government (government-centred). The second alternative is the implementation of a system based on offshore wind and solar systems which has lower requirements of investments and therefore could be more easily funded by a cooperative scheme (community oriented). Detailed analysis for the two approaches has been carried out in the following section, including estimates in US dollars of the levelized cost of energy (LCOE) which comprises the initial capital cost and the operation and maintenance cost throughout the system life cycle.

7.2 Government-centred approach (OTEC alternative)

The first scenario is focused on the government driven approach which involves the installation of a 10 MW open cycle OTEC plant. This section shows how an OTEC system for San Andres could recover the capital investment within a considerable period of time. Besides the costs associated with the implementation of the open cycle PTEC system, this analysis takes into account the current price of electricity (diesel-based) and domestic water in San Andres. The feasibility of the OTEC system is given by the potential for reducing the current costs of these utilities in San Andres.

<u>Estimated costs of a 10 MW OTEC system</u>

The study considers a 10 MW OTEC plant whose capital, operation, maintenance, repair and replacement costs are provided in Table 6.1 which are prices for the United States in 2010. To account for disparities in the purchase power in different countries, the estimated costs given in the table have to take into account a purchase parity index (Big Mac Index). The index for Colombia relative to the US has fluctuated between $+/- 20\%$ between 2004 and 2013 (theconomist.com) with an average value about 0%. Therefore 0% is adopted as the value for the purchase parity index and thus no correction is applied for international parity. The price Since prices found in the literature often refer to values in the United States (US), these have to be updated to present value (year 2013) by applying an average inflation rate in the US of 2.2% (correction factor 1.07) over the last four years.

The cost of implementing a 10MW OTEC system in Colombia, including capital, operation and maintenance (O&M), and repair and replacement costs in 2013 is given in Table 7.1

Table 7.1 Estimated costs of a 10 MW OTEC system updated to 2013 values.

Plant size (MW)	Capital cost $\$/kw$	O&M $\$M/year$	R&R $\$M/year$
10	19,902	3.638	8.239

<u>Existing cost of electricity and potable water in Andres</u>

The cost of electricity in San Andres from the diesel-based generation plant in 2013 is to be 0.23 $/kWh in 2013 considering an inflation rate of 4% with reference to the price in 2005 which is 0.17 $/kWh in 2005.

The current cost of potable water in San Andres is 3.00 $\$/m^3$ which is subsidized by the central government. The high cost is due to the losses in the distribution system of around 77% as mentioned in chapter 4. The government aims at reducing the losses experienced in water distribution by 55% where the actual amount of water that would be available for the final users would be increased from 432,000 m^3 to1, 045,000 m^3 per year. This improvement in the network efficiency will most likely generate a reduction in the prices reaching a price of approximately 1.2 $\$/m^3$ (Unidad Administrativa Especial de Servicios Públicos, 2013).

7.2.1 Levelized cost of electricity produced by the proposed OTEC system for San Andres

In order to update the levelized cost of electricity (LCOE) for the 10 MW OTEC plant, a detailed description and evaluation of the main variables need to be carried out. It is assumed that the 10MW power output is generated through different production units each with a downtime of 4 weeks. The availability of the OTEC system can be calculated as 92.3% after considering the downtime periods. Since the OTEC resource is always available unlike other renewable sources, the annual average capacity factor of 100% was used. As a consequence the annual electricity production (AEP) will be:

Equation 7.1: $AEP = OTEC\ output\ rating\ \times System\ Availability\ \times 365\ days\ \times 24\ hours,$

from Table 7.1 it can be seen that the capital cost per kW for the 10 MW plant is \$ $19{,}902$, so the total installed cost would be derived from:

Equation 7.2: $Total\ installed\ cost = \ OTEC\ output\ rating\ \times System\ Availability\ \times Capital\ Cost,$

An interest rate (i) of 4% was assumed for the study as well as amortization period of $20\ years\ (N)$ (Table 7.2**)** This would permit the calculation of the capital recovery factor (CRF) from the following expression:

Equation 7.3 $CRF\ = \frac{[i\times(1+i)^N]}{[(1+i)^N-1]},$

applying the assumed interest rates and the amortization period, the capital recovery factor would be derived as 7.36 %. The levelized investment cost (LIC), which is the product of the CRF and the total installed cost, was derived as \$ $13.52M$. Therefore the cost of electricity as a result of the capital cost was obtained by dividing the LIC by the AEP which would give $0.1672\ \$/kWh$.

The cost of electricity would be influenced by the operation, maintenance, repair and replacement (OMR&R) across the lifetime of the OTEC plant and this needs to be put into consideration. From Table 7.2 the OMR&R cost per year would be the sum of operation and maintenance costs and repairs and replacements costs which would be $11.9\ M$ \$/year. In order to achieve this, the present worth factor (PWF) for the plant based on the amortization period, the inflation rate (IF) and interest rate (i) would be calculated. The value for the PWF can be determined from:

Equation 7.4 $PWF = [(1+IF)/(i-IF)] \times [1-[(1+IF)/(1+i)]^N],$

using the equation above, PWF was calculated to be $18.1\ years$. The product of the PWF and the CRF would then produce the Expenses Levelizing Factor (ELF) which was calculated to be 1.33216. The Levelized Expenses Cost (LEC) would be the product of the OMR&R costs per year and the ELF. This was calculated to be $15.8M\ \$/year$. Therefore the cost of electricity as a result of the OMR&R cost would be obtained by dividing the LEC by the AEP which would provide a value of $0.195\ \$\ /kWh$.

The sum of the cost of electricity from the capital cost and that from the OMR&R cost would give the total levelized cost of electricity (LCOE) that would be $0.36\ \$/kWh$. The values derived for the variables described above are provided in Table 7.2.

According to the information provided by the Office of Public Services and Infrastructures of San Andres, the current Levelized cost of electricity (LCOE) which is generated from the use of diesel is $0.16\ \$/kWh$. If this value is compared with the calculated LCOE for a 10 MW OTEC plant, it would be observed that the LCOE of the study is higher. A way of ensuring that the OTEC plant is economically viable for San Andres is to account for the difference between the two LCOE values, i.e., $0.20\ \$/kWh$. To achieve this, possible income of other connected benefits from OTEC plant needs to be considered. One of the OTEC derivatives which could account for the difference in the two LCOE values is the supply of drinking water to San Andres which is discussed in the following section. Aside from ensuring that OTEC is economically viable, the supply of drinking water from a clean energy would avoid its production with the use of non-renewable source which would in turn reduce carbon dioxide emission in San Andres.

Table 7.2 Variable values for the derivation of LCOE for a 10 MW OTEC plant.

Capital Cost	
OTEC output rating	10 MW
System availability	92.3 %
Site annual average capacity factor	100 %
Annual electricity production (AEP)	80,855 MWh
Installed cost	19,902 $ $/kW$
Interest rate (i)	4 %
Amortization period (N)	20 $years$
Inflation rate (IF)	3 %
Capital recovery factor (CRF)	7.36 %
Levelised investment cost (LIC)	$ 13.519 M
Levelised cost of electricity, for investment	0.1672 $\$/kWh$
Operation, Maintenance, Repair and Replacement costs	
Annual O,M, R, R Cost (OMR&R)	$ 11.9 M
Present worth factor (PWF)	18.1 $years$
Expenses levelizing factor (ELF)	1.33216
Levelized expenses cost (LEC)	$ 15.8 M
Levelised cost of electricity, for expenses	0.195 $\$/ kWh$
Total levelized cost of electricity	0.36 $\$/kWh$

7.2.2 Water production from OTEC

Using the freshwater produced by the OTEC system not only will improve the economic feasibility of the scheme but contribute to a more sustainable future and community's wellbeing. .

A 10 MW open cycle plant would produce around 12,775,000 m^3 of drinkable water per year (Q). The current water supply per year in San Andres is 4,471,250 m^3. However if the improvement in water distribution (55% losses in distribution) is put in consideration, the amount of water needed to meet the demand in San Andres (175 Lt/person/day for 70,000 people) will be about 10 $million\ m^3/year$.

The OTEC system would be more economically feasible if the price could be offset by the price of another OTEC derivative, fresh water. The calculated LCOE from the OTEC plant from previous section is 0.36 $\$/kWh$ and the current price of electricity in San Andres is 0.16 $\$/kWh$. Therefore there is an unaccounted difference of 0.20 $\$/kWh$. The breakdown of LCOE into price of fresh water (POW) and price of electricity (POE) is illustrated in Figure 7.1. Two different approaches for selling the fresh water have been identified, one would be the supply in the form of domestic water and the other is the commercializing the fresh water as bottled water on the island. The quantification of these two approaches are illustrated in the Figure 7.1 as PDW and PBW, respectively.

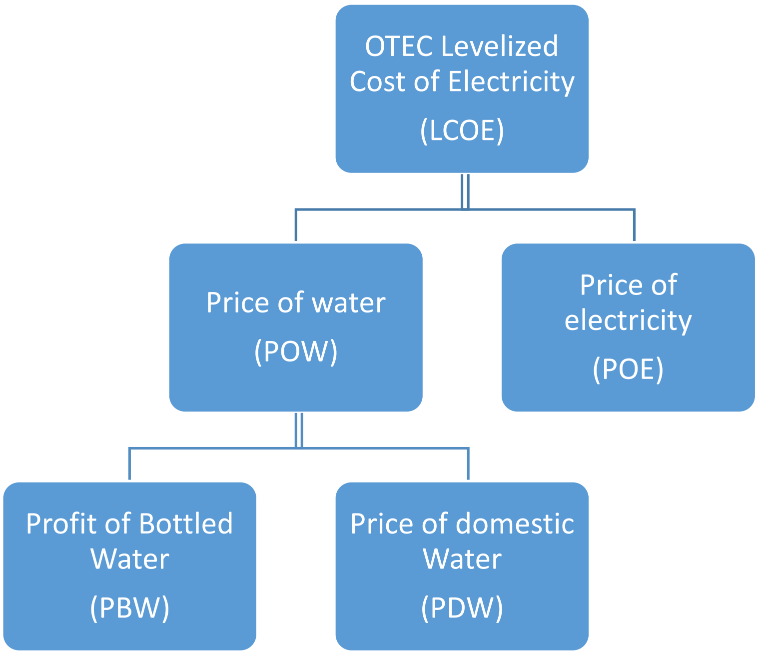

Figure 7.1 Breakdown of the levelized cost of electricity (LCOE).

With the possible demand of fresh water reaching $10\ million\ m^3$ per year in San Andres and the possible fresh water production of $12{,}775{,}000\ m^3$ from the OTEC plant, the quantity of fresh water per energy unit (Q_E) would be $0.16\ m^3$ per kWh implying that the POW should be $1.25\ \$/m^3$. This is slightly higher than the expected cost in the scenario of higher efficiency that San Andres aims to achieve in the next few years ($1.2\ \$/m^3$).

In the course of breaking down the amounts of water for domestic use and for production of bottled water, the priority goes to the supply of domestic market ($10\ million\ m^3$ per year) and the remaining $2{,}775{,}000\ m^3$ from OTEC produced fresh water would be available for the bottled water strategy. This would greatly contribute to the diversification of the economy of the Island.

The primary target market for bottled water would be Colombia where the total annual consumption of this product is $700{,}000\ m^3$. By considering the competition from other bottled water producers in Colombia, it is assumed that 15% of the national market would purchase the bottled water and this would result in the sale of around $105{,}000\ m^3$ of the fresh water from OTEC per year. Neighbouring countries in Central America and the Caribbean can be targeted as potential buyers of this bottled water, with an additional $45{,}000\ m^3$ is aimed to be sold per year. It is also assumed that the price for each unit m^3 of bottled water would be $ 1,000 (i.e. $1/Lt).

The domestic water and the bottled water would need to be given different price value due to the consideration of current price of domestic fresh water in San Andres. If Q is used to represent the fresh water produced by OTEC, q_d is the volume of water supplied for domestic use and q_b is the volume of water used for bottled water production, one could express a weighted POW as:

Equation 7.5: $POW_w = \frac{q_d \times PDW + q_b \times PBW}{Q}$,

The weighted POW can also be expressed as a function of POW and the production of fresh water per energy unit (Q_E) as:

Equation 7.6: $POW_w = \frac{POW}{Q_E}$,

Equation 7.5 can be rewritten as:

Equation 7.7: $\frac{LCOE-POE}{Q_E} = \frac{q_d \times PDW + q_b \times PBW}{Q}$,

and can be solved for POE, PDW and PBW. For the PBW, it was considered that the profit per m^3 of bottled water ranges between $5-12\%$ of the sale price of $1000\,\$/m^3$. The solution to Eq. 7.9 for different values of POE and PBW is shown in Figure 7.2. The contour of the current cost of fresh water of $1.2\ \$/m^3$ is also illustrated in the Figure 7.2 along with a line representing the current cost of electricity ($0.16\ \$/kWh$). At any point within the coloured region the combination of POE, PBW and PDW balance the LCOE and no profit is made. At the boundary of the coloured region, PDW would be zero. Above this boundary, PDW would be negative implying positive profit, therefore no data would be plotted in that region.

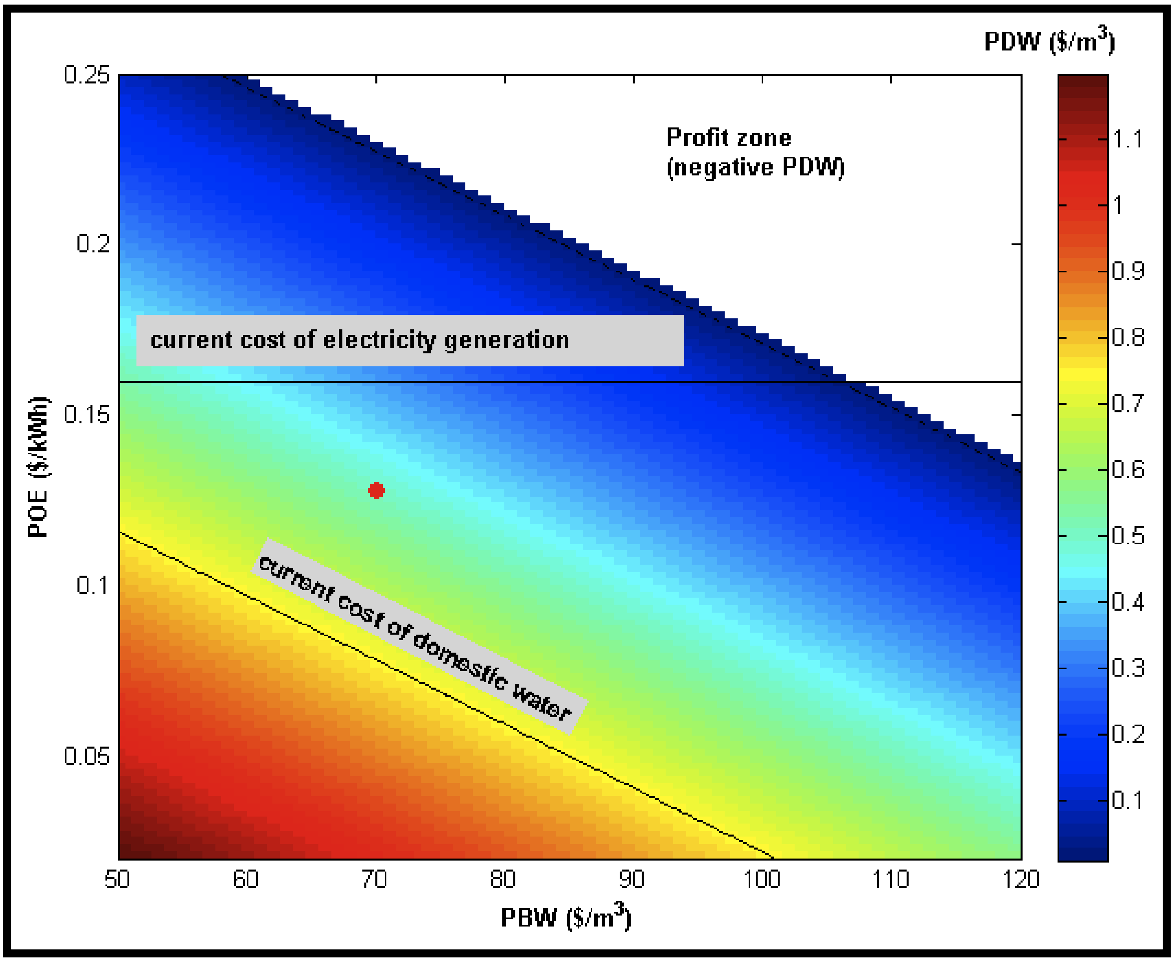

Figure 7.2 Combinations of domestic water, electricity and bottled water costs with zero profit.

The current goal is to seek for a combination of prices (POE, PBW, and PDW) that would be ideal and also make up for the total cost of electricity ($0.36\ \$/kWh$). A major constraint to be considered is that the prices should not be higher than the current corresponding production costs (0.16 $\$/kWh$ and 1.2 $\$/m^3$ of electricity and domestic water, respectively). In addition it is assumed that no net profit would be made from the selling prices. The region in Figure 7.2 that suits the above condition and assumption is the coloured area bounded by the 'current cost of electricity generation' and the 'current cost of potable water'.

Suitable values is chosen for the price of electricity and the profit of bottled water to reduce the overall cost for an OTEC plant. The price of electricity chosen is $0.13\$/kWh$ which is about 23% lesser than the current price of electricity in San Andres. The profit from bottled is chosen as 7% (i.e. 70 $\$/m^3$). Once the price of electricity and profit from bottled water are determined, the required price of domestic water can be determined. The value of 0.8 $\$/m^3$ is chosen as the price of domestic water, as indicated by the marked red spot in Figure 7.2. This value is about 33% lesser than the current cost of potable water in San Andres. The comparison of the current costs of electricity, potable water and the profit of bottled water with the new scenario of generating these utilities from OTEC reveal that the installation of a 10 MW OTEC plant in San Andres would bring a reduction in the current prices, as shown in Table 7.3.

Table 7.3 Comparison between price of OTEC derivatives and current prices in San Andres.

	Current Cost	New Scenario	Relative Change
Cost of Electricity	0.16 $\$/kWh$	$0.128\$/kWh$	Cheaper
Price of Domestic Water (PDW)	1.2 $\$/m3$	0.8 $\$/m3$	Cheaper
Price of Bottled Water (PBW)		70 $\$/m3$	

The breakdown of the LCOE into the different products of OTEC is carried out and illustrated in Figure 7.3. Both electricity and water should contribute to the recovery of the investment made in the OTEC project. The electricity is expected to account for 0.128 $\$/kWh$ of the LCOE of 0.36 $\$/kWh$ and water is expected to contribute with 0.232 $\$/kWh$ which correspond to 36% and 74% of the LCOE, respectively. Bottled water would account for 57% of the price of water while domestic water accounts for the remaining 43%.

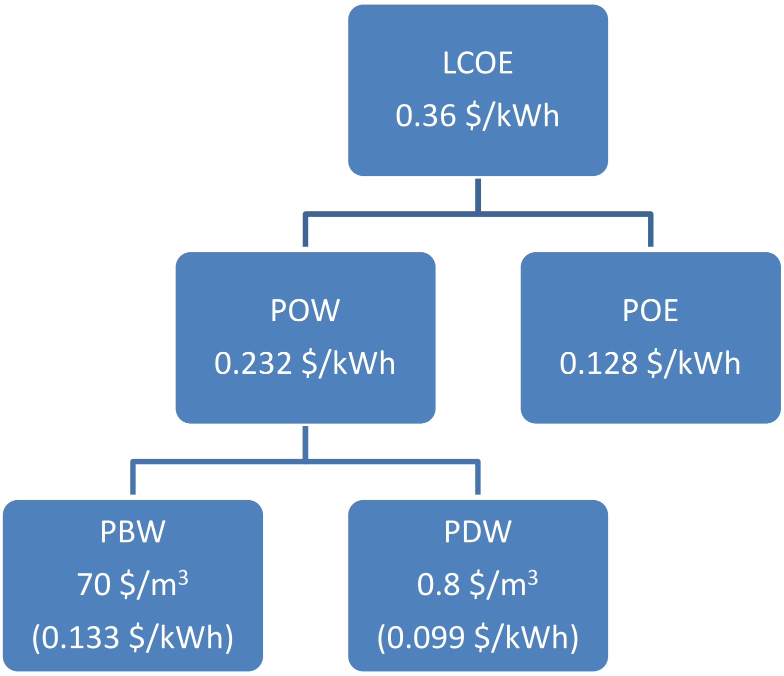

Figure 7.3 Breakdown of the levelized cost of electricity (LCOE) per kWh of electricity generation.

7.2.3 Introduction of cold seawater for cooling systems

The large amounts of cold sea water ($\sim 6°C$) produced by OTEC systems could be used in seawater cooling systems to replace conventional air conditioning within the city. Energy consumption for cooling in offices, homes and building account for about 35% of the total energy consumption.

The use of cold sea water from OTEC systems uses only about 10% of the energy consumed by electrical cooling. This means a total reductions of about 32% in the energy consumption might be expected if cold sea water for cooling. For San Andres, the power demand may drop from 18 MW to about 12.5 MW. With the current generation costs of $0.13 kW/h$ of the diesel power plant, the potential gross annual savings would be about $ 6.2 $million$.

The proposed sea water cooling is illustrated in Figure 7.4. Cold sea water being brought to the surface by the OTEC system has to be pumped to a cooling station located onshore. Seawater is transported through fibre glass pipes. At the cooling station, heat exchangers are used to cool down freshwater that circulates in a closed loop. The chilled fresh water is transmitted through an underground pipeline network that connects to the final users (homes, offices, buildings). Once the freshwater is warmed up at individual air conditioning systems, it is returned to the cooling station to repeat the iterative cooling cycle.

It is noted that the discharge of sea water in the cooling cycle might cause disturbance to the ocean due to the entrainment of relatively cold waters into warmer superficial water. The disturbance could be mitigated by installing a buffering reservoir in the system so that sea water leaving the heat exchangers has time to be warmed up before being discharged back into the ocean.

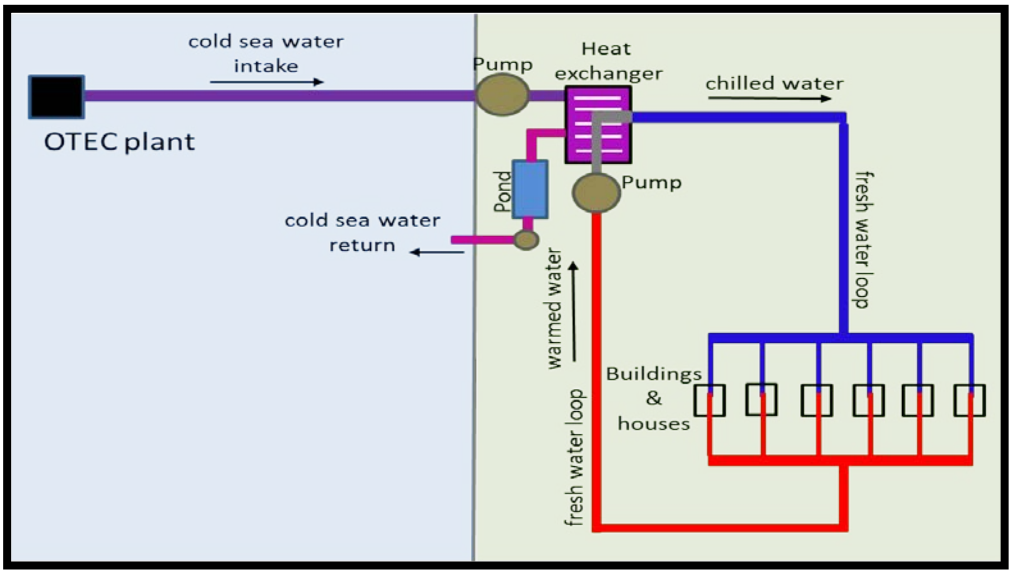

Figure 7.4 Seawater cooling system proposed for San Andres as part of the OTEC development project.

An analysis for the cost of the seawater cooling system in San Andres should include the cost of the seawater supply system including cold water pipe, associated ballast, anchoring and seawater pump. The capital cost of the system depends heavily on the length and diameter of the cold water pipe. The cost of the cooling plant is mainly contributed by the cost of the heat exchanger, and the cost of the fresh water cooling loop which is highly dependent upon the cost of installation of pipelines within the city.

Table 7.4 summarizes the main benefits of implementing cold seawater from the OTEC system, and a list of the main components of the cooling system.

Table 7.4 Main components and benefits of implementing a seawater cooling system for San Andres as part of an OTEC project.

Impacts of using OTEC seawater in San Andres:	Main components of seawater cooling system:
1. Reduction of 32% in the total demand of electricity in the island. From 18MW to 12 MW. 2. Annual savings of $6.2 million in electricity costs. **3.** Possibility to re-use chilled water in other subsystems: coral bleaching control or aquaculture.	1. Large diameter cold water supply pipe (fiberglass), about 5 km length. 2. Heat exchanger used to cool down freshwater with cold seawater exchangers must be resistant to corrosion by seawater. 3. Network of distribution pipes within the city containing freshwater. 4. Possible secondary use of cold seawater (coral bleaching control). 5. Pond to receive effluent from cooling station. **6.** Return line of seawater into the ocean

7.2.4 Use of chilling water to reverse coral bleaching

It is well documented that global warming is a major threat for corals. The Caribbean Sea is one the regions of the world's ocean where rising ocean temperatures pose enormous stress on corals, with massive mortality events occurring in previous years (Eakin, Morgan, Heron , Smith, & Liu, 2010). Coral bleaching in San Andres might have devastating effects not only for the ecosystems, but also for the food security (10 tons of food per year per km^2) and the tourism industry of the island. Therefore it is very important for San Andres to adopt measurements to mitigate coral bleaching. These should include adaptive strategies for extreme weather events such as monitoring of coastal waters to provide early warning alerts of bleaching (Lorde, Gomes, Alleyne, & Phillips, 2013). It could be one of the solutions to use the cold seawater to cool down water temperature in coral areas (Figure 7.5) where anomalously high temperatures are being monitored or forecasted.

The sea water temperatures could be lowered by pumping cold water produced by OTEC plant to the area with coral reef. This would require a flexible pumping system readily deployable which would involve a floating pipeline sending water to the reef area to a floating platform. At this platform cold water would be redistributed over different points in the reef area and discharged onto the corals by diffusors. This is a conceptual system for coral reef conservation, however, technical and economic feasibility has to be further examined.

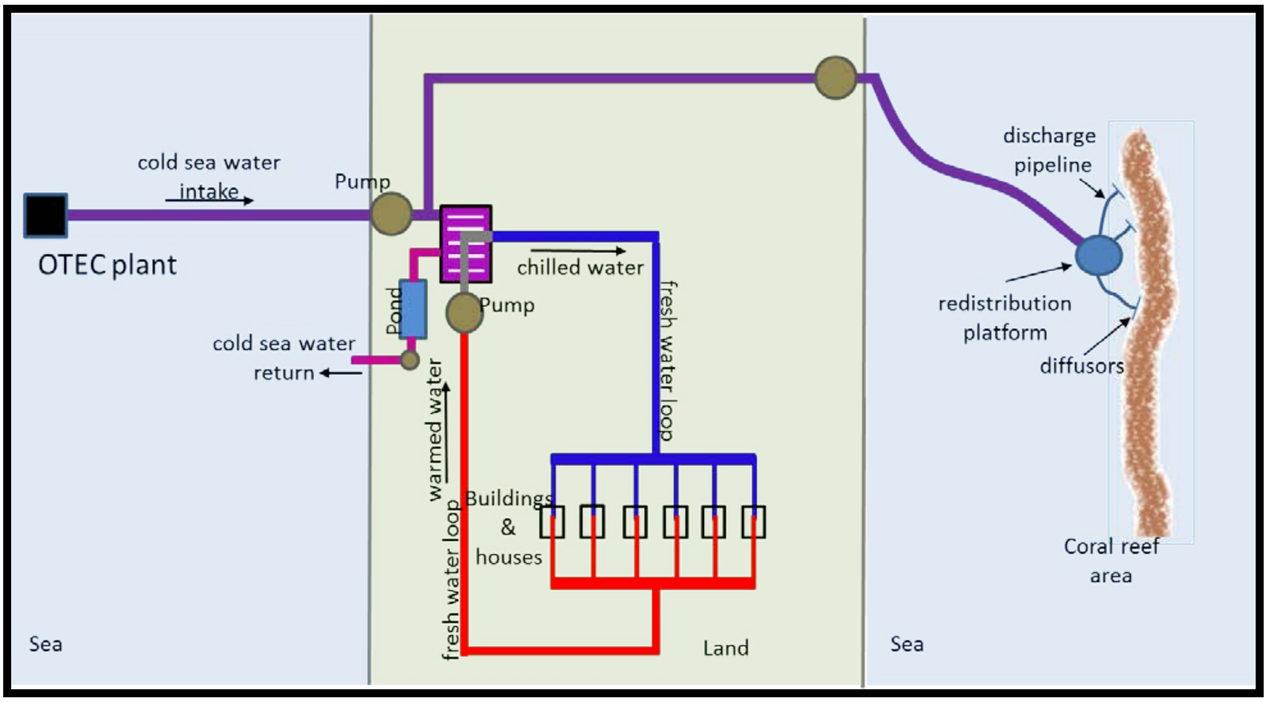

Figure 7.5 Sketch of a system for reversing coral bleaching.

7.2.5 The use of OTEC derivatives for hydrogen production

The OTEC power system could be used for produce hydrogen as the secondary output apart from the primary function of producing electricity. The electric energy from an OTEC power system can be used alongside for hydrogen production as shown in Figure 7.6. Comparing to a traditional hydrogen plant, this electrolysis process does not involve the use of electricity by fossil foil which could reduce a significant amount of greenhouse gases. The hydrogen can be used in a secure and efficient manner in the form of fuel cells for further utilizations.

The three dominant electrolysis methods in the industry include solid oxide electrolysis, alkaline electrolysis and polymer electrolyte membrane (PEM) electrolyser. The first two methods requires very high temperatures in the range of 200^{0}C and 800^{0}C for hydrogen production. The PEM operates at the lowest temperature, at approximately 80^{0}C. This means that PEM would demand the least energy from OTEC to operate and it is the most suitable for the production of Hydrogen from renewable energy technologies. Other advantages of PEM electrolyser is its simplicity and its ability to accept variability in voltage inputs which makes it ideal for Hydrogen generation from renewable energy sources (Ogden, 1995). There have been recent efforts applied to the successful development of PEM electrolyser with high efficiency and security for large-scale hydrogen production that can compete with the cost of producing from conventional methods (Kazim, 2005).

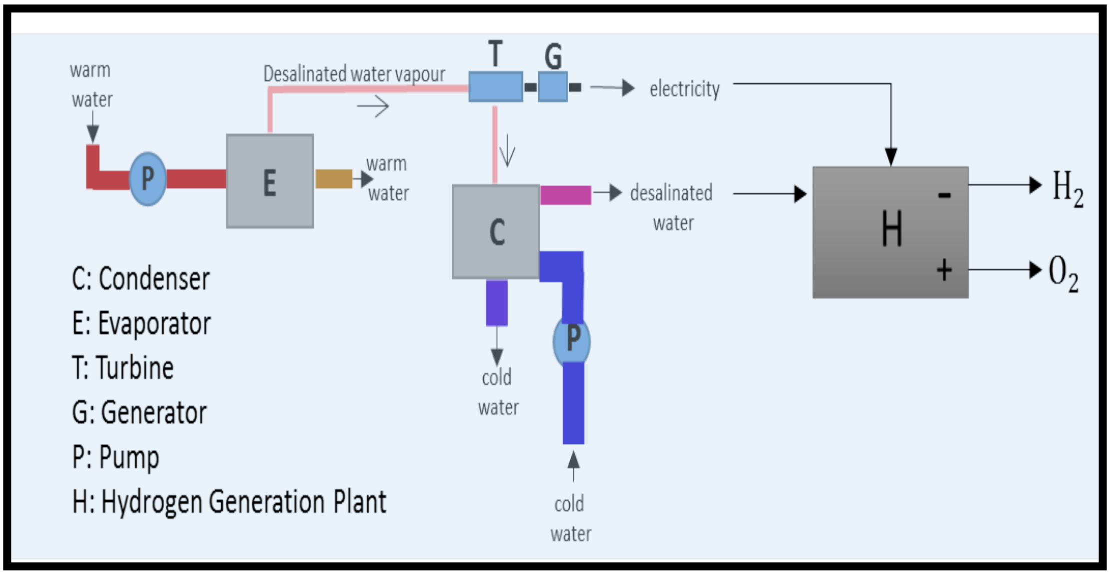

Figure 7.6 Hydrogen generation from OTEC plant.

The quantity of hydrogen that can be provided from an OTEC plant is dependent on the performance of the electrolyser, the energy production from the OTEC plant, the quantity and quality of fresh water produced from the plant. It is important that the water used for the electrolysis process is fresh water rather than sea water because high salinity could be harmful to the PEM electrolyser.

The PEM electrolyser developed by the Japanese WE-NET project is acclaimed to be the most efficient with the capacity of producing Hydrogen and Oxygen at maximum rates of $3000\ Nm^3/h$ and 15 respectively (Ikegami et al, 2002) (Kazim, 2005). The energy required for the electrolyser to function is $4.3\ kWh$ per unit of Hydrogen, with a unit of hydrogen measured in Nm^3. The quantity of fresh water required is measured per unit of Hydrogen produced, and $0.81/Nm^3$ of Hydrogen is required.

If San Andres is put into perspective as regards to the usage of hydrogen, the likely sector that hydrogen production from OTEC could be of benefit would be transportation. This is however subjected to certain factors such as the economic viability of hydrogen production from OTEC and the perception of the residents to the replacement of fossil fuel cars with hydrogen fuel cell cars. However, the current production of hydrogen is done using processes that require hydrocarbons as the fuel. The use of hydrocarbon contradicts the great cause to adopt clean energy as approximately 2.5 tonnes of carbon dioxide are released for each tonne of hydrogen produced from hydrocarbons (Abbasi and Abbasi, 2011). Despite the advancement in different renewable energy technologies, the cost effectiveness of producing hydrogen from these technologies has to be further examined.

7.3 Community oriented approach

In comparison with the government-centred approach, a presumably cheaper and ready-to-use alternative for energy production in San Andres would be a system based on wind and solar energy. This approach would be oriented towards a community-owned system rather than relying on investments only from the central government. This approach demonstrate not only the of use renewable energy as the source of electricity, but also a way to generate their own income for a more sustainable future. Two case studies of successful renewable energy community projects are presented in the following chapter.

7.3.1 Review of community oriented renewable energy projects

<u>CARES –Scotland, UK</u>

The Scottish Government's Community and Renewable Energy Scheme (CARES) has been established in April 2009 with a total of £13.7m grant by the Scottish Government to encourage and maximize local and community ownership of renewable energy generation projects across Scotland. Scottish government strongly believes that there are lots of benefits renewable energy can offer to local communities rather than energy and financial benefits. The cohesion and confidence among local residents, for instance, may get increased by building up the community level renewable energy solutions.

CARES provides a new scheme to offer loans towards the high risk, pre-planning consent stages of renewable energy projects– whether for the benefit of own rural business or local community which have significant community engagement and benefit. The scheme is managed on behalf of Scottish Ministers by Community Energy Scotland Ltd through a one-stop shop of renewable energy projects from support, technical advice, financial assistance and Feed-In-Tariffs scheme development.

CARES funding has resulted in 21GWh of energy generation, saving 6200 tonnes of carbon in 2009-2011. A survey conducted by Community Energy Scotland also demonstrate that "83% of community representatives who have been involved in an energy project said their knowledge and understanding of renewable energy issues has increased; 44% of groups are financially more sustainable and feel empowered"(CARES, 2011).

Samsø - Denmark

In 1997, a small Danish island, Samsø, won the contest to be "Denmark's Renewable Energy Island" and become a model renewable energy community (Jørgensen, 2007). At the time Samsø was entirely dependent on imported oil and coal. The project proposed that Samsø would be expected to convert all its energy supply to 100% renewable energy within 10 years by:

- Cuts in consumption and increased efficiency in terms of heat, electricity and transport; Expansion of the district heating supply systems combined with utilization of local biomass resources;
- Expansion of individual heating systems using heat pumps, solar heating, biomass-plants and other means;
- Construction of land-based and offshore wind power plants to cover electricity production.

The programme was very ambitious since it tried to change the entire cycle of energy production and consumption for the whole island within a decade. Before the project started, Samsø didn't have any conventional energy resources of its own. All fossil fuel had to be transported by tankers, and electricity by connecting to the mainland grids.

Various stakeholders are considered for this project since it involves in a large network of different actors to support the project: private citizens of Samsø, Samsø municipality, Danish Government, and local and external business took part in the project. PlanEnergi, an independent consultancy firm which specializes in renewable energy has investigated available resources at Samsø and made a rough time schedule for the project. The plan was used as a guideline through the project.

Saastamoinen (Saastamoinen, 2009) mentioned that this project's results had reached most of the goals that were set. The primary objective, 100% self-dependency with renewable energy using local resources, has been achieved in 8 years, rather than 10 years. Some major constructions include three new district heating plants, 10 offshore and 11 onshore wind turbines within the area. The project was less successful in the transportation sector and in behavioural changes that the project aimed at.

The case of Samsø is considered as the most successful practice by now, along with adequate technical consideration on feasible ocean renewable energy resource at San Andres in Chapter 5, the proposed approach will suggest a community-owned offshore power plant that utilize both offshore solar island and wind turbine.

7.3.2 Key takeaway and motivation for the success of a renewable Samsø

The success of the "Samsø Renewable Energy Island" relies on a number of prerequisite prior to the implementation of the programme. These factor would be briefly discussed as follows:

- Small community
- Decentralized institutional structure
- Local cooperation
- High household electricity
- Supporting energy policy

Small community

The demography and the economic activities of Samsø Island favour the implementation of the programme. The Samsø Island has a population of around 4,000 inhabitants and covers 114 km². Two of the main economic activities include farming and tourism where lots of vegetables and fruit are exported from the island and million guests stay overnight annually. (Jørgensen, Hermansen el at., 2007). With a small population and limited economic activities, it is expected to be easier to convince all people about the business benefit of the project as well as to encourage and invite the participation in work groups for the planning and development work.

Decentralized institutional structure

The energy sector in Denmark has a fairly decentralized structure and a high degree of cooperative and municipal ownership. For example, the central government as well as the municipalities participate in the decisions on fuel choices, waste incineration and surveys on renewable energy sources. In addition, a numbers of district heating and co-generation companies are owned by cooperatives or municipalities. (IEA 2011)

Local cooperation

Denmark has a longstanding tradition of community ownership and civic engagement in renewable energy (Saastamoinen, 2009). For example, it is estimated that approximately 150,000 families have an ownership stake in wind energy projects. (Sorensen, et al., 2002). A higher acceptance of renewable energy is expected with the culture of community ownership.

High household electricity

Denmark has the highest household electricity prices in the Europe (EEP, 2013). The high energy taxes had been introduced for the purpose of reducing dependence on imported fossil fuels since the oil crisis in mid 70s. The tax income primarily contributed by energy consumers provides the budget for Danish government to finance the transition to fossil fuel independence.

Supporting energy policy

Denmark has an energy policy that aims to save energy and support the use of renewable energy. For example, the government issued “Energy Strategy 2025” in 2005 focusing on initiatives for energy saving and renewable energy, climate change, energy markets and technology. A more long term policy “Energy Strategy 2050” published in February 2011 details the recommendations that help transform Denmark to a country of 100% independent of reliance on fossil fuels.

7.3.3 Offshore solar panel suggestions for San Andres

Due to the land scarcity and abundant solar radiance at San Andres as stated in previous chapters, a floating offshore solar island (DNV KEMA, 2012) is recommended to build as a community-owned offshore solar plant in San Andres.

The key element of this offshore solar island concept is a hexagonal array (Figure 7.7) of SUNdy floating on the sea surface which would be manufactured as a pre-wired unit. This may significantly reduce the number of electrical connections while minimizing the need for offshore assembly as well. Unlike the traditional glass-based rigid modules, SUNdy modules use thin-film PV that are dynamic to yield to the sea water movement. The thin-film panel has an efficiency of around 8% to convert radiation exposure. Though with relatively low efficiency compared with crystalline solar panels (See in Chapter 6) and other renewable energies, the cost is much cheaper for thin-film panel.

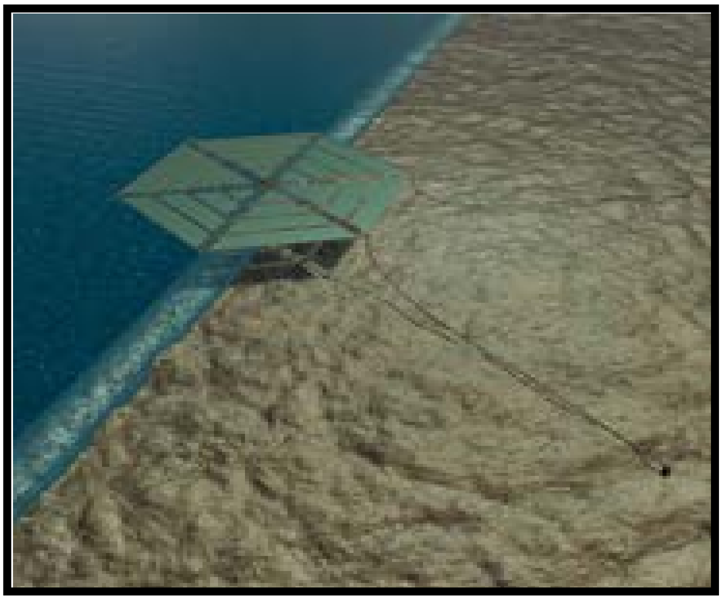

Figure 7.7 SUNdy solar panel array (Brewer, 2012).

SUNdy System installation requirements and system requirement (see Table 7.5) are outlined as follows:

- Solar island would ideally be located in waters with depth range of 20 – 100m;
- Solar island would ideally be located within approximately five miles from shore and from shipping lanes;

Table 7.5 System specification for SUNdy system.

Unit power rating	560W per array
Unit size	2.5 m^2 per array
Number of units	4200 arrays
System power rating	2.3 MW
System size	108,000 m^2

The Island of San Andres has tremendous solar resource: the annual sunshine hour of San Andres is more than 2600 hrs and daily average solar radiance is 4.5-5.0 kWh/m^2 (Colombian country study: Part C,2006). Therefore, "SUNdy" annual capacity for San Andres can be roughly estimated by:

Equation 7.8: $Annual\ Capacity\ =\ annual\ sun\ hours\ for\ the\ region \times system\ size\ \times performance\ ratio$

= 2600hr X 560 W X 8% X 4200

= 489 MWh/ year

After identifying that most resort zone, coral reef preservation area and diving zone for tourists are located on the east side of the beach, the suggested SUNdy solar island would be recommended to place at the west side of San Andres. Since SUNdy installation requires depth of 20-100meters in the water, it can be observed that there are plenty area fits into the criteria on the west side.

7.3.4 Feasibility of using offshore wind power in San Andres

Wind profile in San Andres

As stated before, the wind intensity is around 3m/s to 6m/s. A more detailed wind speed profile measured at San Andres is presented in Table 7.6 (Jiménez, 2012). The data was obtained each hour at 10 m of altitude during the 1987/2001 period by the Institute of Hydrology, Meteorology, and Environmental Studies in Colombia (IDEAM). The annual mean wind speed is 4.99m/s at a height of 10m which would be used to assess the feasibility of using wind power in San Andres.

The dominant wind direction is ENE. Wind direction information is referred to another statistics based on observations taken daily between Feb 2008 to July 2013. Figure 7.8 illustrates that the dominant wind direction is ENE (Windfinder, 2013)

Table 7.6 Location and annual wind speed for San Andres.

Location	**Meteorological station name**	**Coordinates**	**Annual mean wind speed (m/s) at a height of 10m**
San Andres Island	Sesquicentenario Airport	Latitude – 12º35' Longitude - 81º43'	4.99

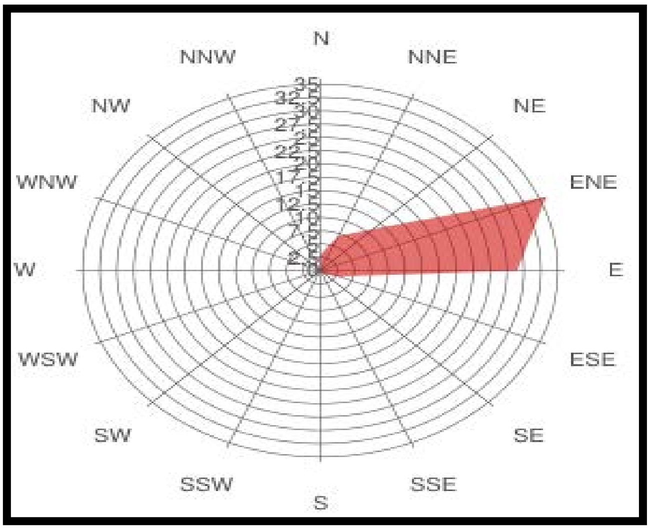

Figure 7.8 Wind direction distribution in San Andres all year (Windfinder, 2013).

<u>Sea water depth</u>

It should be noted the investment cost for offshore wind farm increase due to the tremendous cost increase in foundation and installation. In order to reduce the initial investment cost, the location of the wind turbine should consider the wind profile in conjunction with the water depth.

Table 7.7 The variation in investment cost of offshore wind power at different water depth (Bilgili et al., 2012).

Different components (€/kW, appro. % of total cost)	**Water depth (m)**			
	10-20	20-30	30-40	40-50
Turbine	772 , 43%	772 , 40%	772 , 35%	772 , 31%
Foundation	352 , 20%	466 , 24%	625 , 28%	900 , 36%
Installation	465 , 26%	465 , 24%	605 , 27%	605 , 24%
Grid connection	133 , 7%	133 , 7%	133 , 6%	133 , 5%
Others	79 , 4%	85 , 4%	92 , 4%	105 , 4%
Total cost	1800	1920	2227	2514

Potential electricity production

The balance between environmental impact, amount of electricity production by the wind turbine and electricity consumption in San Andres should be considered in order to determine the scale of the offshore wind farm. Six different wind turbines rated from 300kw to 2750kw are used to model the electricity production with wind speed being extrapolated to a different height as shown in Figure 7.9. It is noted that a wind turbine with larger hub height and higher power rating can produce more electricity per year (Jiménez, 2012).

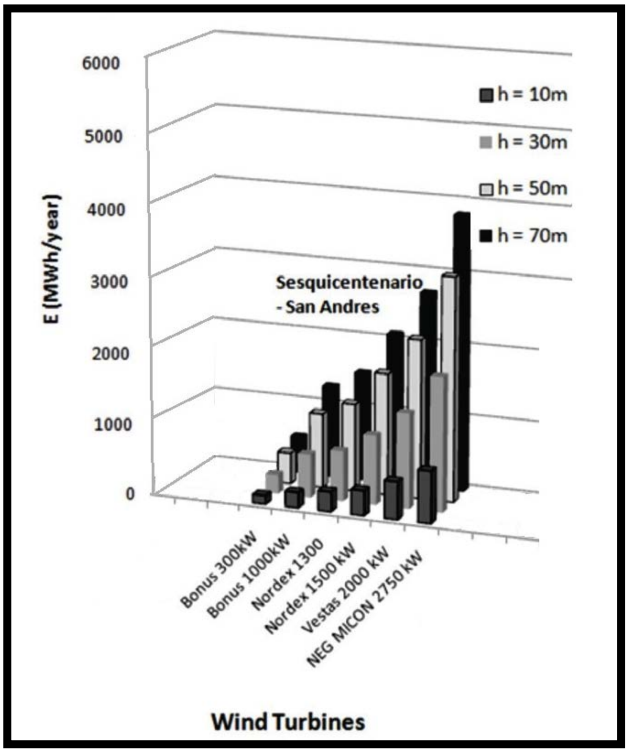

Figure 7.9 Annual mean energy generated at San Andres (Jiménez, 2012).

Cost of offshore wind based electricity

In Europe, the initial investment cost ranged from 1480-2640 $/kW (see Table 6.4) and the levelized cost of energy (LCOE) ranged from 0.079-0.12 $/kWh (EWEA, 2009) depending on the scales and location of the wind farm. The cost of initial investment as well as the LCOE should be calculated considering the condition in San Andres. Table 7.8 presents the cost of offshore wind turbine using the same methodology as for an OTEC plant in Section 7.2. The following assumptions are made for the preliminary calculation in this section:

- The price of wind turbine (Jiménez, 2012) for calculating the installed cost is adjusted to the price in 2013 with an inflation rate of 3%.
- Figure 7.9 is referred for the annual energy production per wind turbine at a hub height of 70m. The annual energy production of the wind farm is the multiple of an individual production in a year.
- The annual maintenance and operation cost is calculated as 25% of the annual cost of the turbine divided by the life time of the turbine, where the life time is assumed to be 20 years for all wind turbines (Jiménez, 2012).
- The cost of investment, maintaining and operating a multi-wind turbine wind farm is proportional to the cost for individual wind turbine.
- The cost of electricity for offshore wind farm is about 50% (without taking into the account of different water depth) more than the on-shore option, see Table 6.4. This factor is applied when calculating the levelized cost of energy
- Other assumptions applied for the OTEC alternative in Section 7.2 (i.e. interest rate, inflation rate, amortization period).

The result in Table 7.8 shows that wind model Nordex s70 (rated 1,500MW) and Vestas v80 (rated, 2,000MW) give the lowest LCOE as well as the lowest initial capital (installed cost) among other options.

Table 7.8 Levelized cost of electricity for offshore wind.

	Wind turbine model					
	AN Bonus	AN Bonus	Nordex N60	Nordex s70	Vestas v80	NEG Micon
Turbine output						
Rated power put (kW)	300	1000	1300	1500	2000	2750
Annual Energy Production at kWh	400,000	1,200,000	1,400,000	2,050,000	2,800,000	3,700,000
Investment cost						
Installed cost $/kW	4,609	1,771	1,686	1,349	1,349	1,840
Interest rate, i	4%					
Amortization period (year)	20					
Inflation rate, IF	3%					
Capital Recover Factor, CRF	7.36%					
Levelized Investment Cost (LIC), $	101752	130293	161315	148906	198541	372265
Cost of electricity (captial cost), $/kWh	0.2544	0.1086	0.1152	0.0726	0.0709	0.1006

Levelized cost of electricity for offshore wind (contd.).

	Wind turbine model					
	AN Bonus	AN Bonus	Nordex N60	Nordex s70	Vestas v80	NEG Micon
Operating and maintenance cost						
Annual cost of operation maintenance, repair and replace $, (OMR&R)	14,405	18,445	22,837	21,080	28,107	52,700
Present Worth Factor (PWF)	18.10					
Expenses Levelizing Factor (ELF)	1.33					
Levelized Expenses Cost (LEC), $	19183	24564	30412	28073	37430	70182
Cost of electricity (OMR&R), $/kWh	0.0480	0.0205	0.0217	0.0137	0.0134	0.0190
Total COE for offshore option USD/kWh	0.4686	0.2000	0.2123	0.1338	0.1306	0.1853

System specification for wind farm in San Andres

The scale of the wind farm should consider electricity consumption statistic of San Andres as well as a low initial cost where the citizens could take part in funding the wind farm with a significant share of ownership. In the case of Samsø, local citizen take part in the funding for both onshore and offshore wind farm project. Regarding the offshore wind farm of 10 turbines, the Municipality of Samsø financed five turbines, local citizens financed three, and the last two were financed by approximately 1,500 shareholders from two separate companies. The local citizens have an even higher percentage of ownership for the onshore wind project where 9 out of 11 land-based wind turbines are owned by local citizens. (EDIN, 2011). A 10MW wind farm with 20% of the investment cost funded by the local citizen is considered as feasible where the rest of the investment cost would be funded by government and company.

The offshore wind turbine should be the wind profile and the sea water depth in order to maximize the harnessing wind energy and minimize the investment cost. Hence, the best location of the offshore wind farm should be located at north or northeast of San Andres where the coral reef is located at the east side of the island. A comprehensive environmental impact assessment shall be undertaken to evaluable the influences of the wind farm during construction stage as well as the long term ecology system of the carol reef.

A preliminary system specification and financing planning for offshore wind farm is summarized in Table 7.9.

Table 7.9 System specification of an offshore wind farm for San Andres.

System specification	
Number of turbine	5 (Vestas v80)
Total power output	10MW
Location of the wind turbine	Upwind at the north or north east of San Andres
Foundation	Fixed foundation with water depth at 10-20m
Grid connection	To be connected to transmission grid
Storage system	NA. The existing diesel plants in Andres will supplement and balance the daily electricity consumption.

Finalizing planning	
Total investment cost (for 5 turbines)	Million$13.5
20% of the shares (investment cost) of local citizens	Million $2.7
Individual shares (investment cost) from 1,000 local citizen	$2,700

7.3.5 Summary of community oriented approach for San Andres

The successful of a community oriented project are collaboration with the community and sharing of the economic benefits with the landowners, neighbours and the local government and company. The planning and development process of the project shall take into the account of the needs of the community.

The proposed community-driven approach, an offshore power plant combining both offshore solar island and wind turbine is suggested for the Island of San Andres. Due to the diversified stakeholders involved in the development of offshore power plants, this approach would also cover the following:

Municipality of San Andres

- Should develop general guiding principles and outreach for possible national and international public/private funding for offshore power plant;
- Should develop detailed local Feed-In-Tariff policies for using offshore solar and wind energies;
- Should organize work groups for planning and development work of the offshore power plant;
- Should effectively liaison between national/international agencies, financial institutions, independent consultancy firms, local business and residents;
- Should supervise owner committee (comprised of local business and residents) on daily operations and maintenance of the offshore power plant.

Small businesses (restaurants, hotels, shops, etc.)

- Should participate work groups for planning and development work of the offshore power plant;
- Should be advised by professional independent consultancy firm to make sustainable financial plans for business continuity;
- Should invest and take partial ownership of the offshore power plant;
- Should actively involve in education program for tourists to demonstrate the process and benefits of ocean renewable energies.

Local residents

- Should participate work groups for planning and development work of the community offshore power plant;
- Should be given information about the costs, payback time, technological advantages and disadvantages for offshore wind and solar island;
- Should be advised on possible financial loan and investment scheme, Feed-In-Tariff scheme and energy savings;
- Should invest and take partial ownership of the offshore power plant;
- Should promote education programs of ocean renewable energy knowledge and experience to general public.

8 Transferability

8.1 Overview

Transferability refers to the degree to which the results of a qualitative research can be generalized or transferred to other contexts or settings. It can be achieved by doing a thorough job in describing the research context and the assumptions that were central to the research. The outcome would then be a detailed portfolio of the research which can be applied to areas with similar characteristics.

The transferability of the research will be attempted in this chapter for the two scenarios presented in chapter 7 as they represent two different approaches aiming at providing ocean energy related solutions.

8.2 Transferability of the OTEC proposal

In the process of assessing the application of OTEC plants in San Andres, the main aspects for transferring the use of OTEC plant to other coastal cities have been recognized as follows:

1. The OTEC plant must be located in a tropical zone: this would allow to reach the necessary 20^0 C difference between the warm surface water and the cold deep water. This generally occurs in tropical regions around the world, as indicated in Figure 6.1. Even in a scenario of global warming this difference will still be ascribable to tropical areas and might be suitable to sub-tropical areas of the world provided that the temperature gradient of 20^0 C is available.
2. The OTEC solution is feasible for coastal cities or islands: A key element for OTEC technology is the accessibility to the ocean and this can only be achieved if the city is an island in the ocean or positioned at the coast. Islands, and to a higher extent island states, are usually very vulnerable in terms of energy supply due to their remote location and lack of energy autonomy. Therefore OTEC can be a good solution to overcome this situation and island states can be suitable to operate as pilot cases.
3. Appropriate depth to reach cold deep water should be reached within short distance from the coast: This concern is mainly due to the cost related to the length of the necessary sea cables to connect the offshore plant to the power station onshore. As stated in chapter 6, the OTEC offshore plant should be positioned within the

country's Exclusive Economic Zone (EEZ) and it would actually be advisable to install within the territorial sea, which is within 12 nautical miles from the coast. If the required temperature gradient is achieved outside the EEZ this could lead to boundary dispute and increase the complexity of the project.

Table 8.1 indicates the countries in Africa, Latin America and the Caribbean that might be suitable for introducing OTEC. It provides information regarding the water temperature gradient and the distance from the shore that is necessary to achieve that gradient. The OTEC plant can be applied to coastal cities near tropical region. In general, the case of island cities the necessary distance is much lower than in the case of coastal cities and therefore they might represent the best option in terms of transferability of the San Andres energy portfolio proposal.

Table 8.1 Countries in Africa, Latin America and the Caribbean with adequate ocean thermal resources (Myers et al, 1986).

African Nations	ΔT (°C) **0-1000 m**	**Distance from resource to shore (km)**	**Latin American and Caribbean Nations**	ΔT (°C) **0-1000 m**	**Distance from resource to shore (km)**
Angola	18-22	65	Bahamas	20-22	15
Benin	22-24	50	Barbados	22	1-10
Congo	20-22	50	Belize	22	50
Gabon	20-22	50	Brazil	20-24	75
Ghana	22-24	50	Cost Rica	21-22	50
Guinea	20-22	80	Cuba	22-24	1
Guinea Bissau	18-19	60	Dominica	22	1-10
Ivory Coast	22-24	30	Dominican Republic	21-24	1

Countries in Africa, Latin America and the Caribbean with adequate ocean thermal resources (contd.)

Kenya	20-21	25	Ecuador	18-20	50
Liberia	22-24	65	El-Salvador	22	65
Madagascar	18-21	65	Grenada	27	1-10
Mozambique	18-21	25	Guatemala	22	65
Nigeria	20-24	30	Haiti	21-24	1
Sao Tome and Principe	22	1-10	Honduras	22	65
Senegal	18	50	Jamaica	22	1-10
Sierra Leone	20-22	100	Mexico	20-22	32
Somalia	18-20	25	Nicaragua	22	65
Togo	22-24	50	Panama	21-22	50
Cameroon	22-24	65	Trinidad and Tobago	22-24	10
Tanzania	20-22	25	Venezuela	22-24	50

4. OTEC solution can be a solution for cities with a need of water supply: As described in chapter 5 and chapter 7, OTEC can supply drinkable water for human consumption apart from producing clean energy. It is well noted that many countries are currently suffering from water shortages or will most likely suffer in the upcoming future due to climate change. OTEC is assessed as a possible solution for coastal cities that require both energy (especially for the cooling systems needed to cope with the high temperatures) and drinkable water.

5. Availability of funding options and/or political to support the substantial cost of the project: OTEC is apparently considered as a high cost options for renewable energy and might not be a financially feasible options for many countries. As shown in Table 8.1, most of the countries in the tropical area are developing countries and therefore their economic performance might not allow them to adopt a strategy which is capital intensive. However,

these countries could make the OTEC strategy feasible by accessing international loans. The political commitment is a key element as financing this project requires many years (20 years in this case study) and there is a need of political stability to cope with the debt.

8.3 Transferability of the community oriented approach

In the case of the community oriented approach, the aim should be that of transferring the consensus building strategy to other small sized communities interested in becoming sustainable and energetically independent. In the case of San Andres and connected to the experiences carried out in Scotland and Denmark that have been described in chapter 7, the strategy should be that of carrying out pilot experiences in particular areas with a reduced level of political power (most likely districts with representatives in the municipal and regional boards) which would allow community participation in carrying out the institutional/bureaucratic aspects of the initiative. The core concept in the community oriented approach is the creation of a sense of community and shared future both economically and environmentally.

As a community oriented project aims at partial community ownership of the renewable plants, it should easier for the inhabitants to be convinced of the benefits that would be derived from the strategy. The project planning process may be shortened because of the involvement of local community in decision making. Citizen would have a more throughout understanding on the efforts to be made for mitigating the environmental threat by engaging the project and community. Hence, it is expected to have less resistance for implementing a project that may change the existing environment (for example visual and noise impact from a wind farm) and lifestyle.

The transferability in this sense would imply some recommendations to reach the necessary mind-set to carry out shared initiatives at community level than guidelines for the achievement of results, as shown in Figure 8.1. It is worth considering this approach because the policies that are carried out in cities should aim at maximizing the sustainability and well-being of citizens. The creation of civic engagement strategies in vital aspects within society can definitely contribute to assure a sustainable path as illustrated below:

1) Involvement of local stakeholders at all levels (residents, shop owners, hotel managers, politicians, etc.) from the beginning and in all the fundamental aspects of the project planning while establishing open communication and a cooperative environment. This is a key aspect as it will settle the basis for a long lasting commitment.
2) The identification of the right community to carry out the pilot project is vital. Some sectors of the community are more open to innovation while others might not be willing to participate in this kind change. For example, communities with high levels of young couples with kids might be more open to the introduction of innovation than those with a high degree of elders. The process of carrying out survey studies would be a useful tool to identify the right place to implement the approach.
3) Work towards building consensus and awareness regarding the importance of changing energy production and consumption patterns in order to achieve more sustainable living standards for the involved communities. If the inhabitants do not see something as a problem, they may not be willing to change their status quo. This is where local authorities and different groups (such as the local branches of the System for Integrated management of ocean and coastal zones in the case of San Andres) need to show their commitment and leadership. It would be advisable to create integrated educational and informative plans for all sectors of the community (kids, adults and elders).

Figure 8.1 Example of community building strategy.

9 Marketing strategy for eco-San Andres

9.1 Overview

The pathway for an Eco San Andres needs to be assisted by an adequate tourism marketing campaign that introduces the island to new target markets with specific characteristics. This strategy will be coupled with the existing one for some time and therefore the island can aim her target to two different market sectors. This would bring about the increase in potential attraction of San Andres by diversifying its appeal while contributing to the island wealth in a broader sense.

9.2 Tourism sector in perspective

The World Tourism Organization defines a destination as "a physical space in which visitors spend at least one night and is made up of tourism products such as support services and attractions, and tourism resources with physical and administrative boundaries that define its management, images/ perceptions of market competitiveness" (UNWTO, 2013).

As discussed in Chapter 4, tourism contributes to almost 40% of the GDP and accounts for a high rate of occupation both formally and informally in the case of San Andres. Looking beyond the current economic turmoil, the World Travel and Tourism Council (WTTC) forecasts an average growth rate of 4.4% for the tourism industry between 2009 and 2018. This growth rate would translate to the representation of 10.5% of the global GDP and supporting 297 million jobs (Croes, 2006).

The attempts to increase the price of tourism products is intertwined with efforts of making a tourist destination more competitive. Tourism destinations need to do better than their rivals to satisfy customers and attract potential tourists. It is well known that the competition in the Caribbean is quite fierce with regards to the tourism sector. Seen in this light, destination competitiveness is becoming increasingly important, especially if more economies are relying on tourism.

Ritchie and Crouch (2003) define competitiveness as: "…the ability to increase tourism expenditure, attract visitors while providing them with satisfying, memorable experiences and this is done in a profitable way, while enhancing the well-being of residents and preserving the natural capital of the destination for future generations."

The more a destination is able to meet the needs of the tourists, the more it is perceived to be attractive and the more the destination is likely to be chosen. Very simple, yet very complex to achieve especially in the light of the changing trends

9.3 Marketing Strategy for Sustainable Tourism

Sustainable tourism can be defined as one that takes into consideration its current and future economic, social and environmental impacts, addressing the needs of visitors, the environment and the host communities. According to the World Tourism Organization, sustainable tourism should:

1) Make optimal use of environmental resources that constitute a key element in tourism development, maintaining essential ecological processes and helping to conserve natural heritage and biodiversity.

2) Respect the socio-cultural authenticity of host communities, conserve their built and living cultural heritage and traditional values, and contribute to inter-cultural understanding and tolerance.

3) Ensure viable, long-term economic operations, providing socio-economic benefits to all stakeholders that are fairly distributed, including stable employment and income-earning opportunities and social services to host communities, and contributing to poverty alleviation.

Figure 9.1 shows a conceptual framework of economic, ecological and social factors in the development of an eco-tourism status. One key element related to sustainable tourism is that it requires the informed participation of all relevant stakeholders and a strong political leadership to enhance participation and consensus building because this process needs constant monitoring of impacts (UNWTO, 2005). The whole idea is to achieve both the satisfaction of the local inhabitants while maintaining a high level of tourist satisfaction by ensuring a meaningful experience.

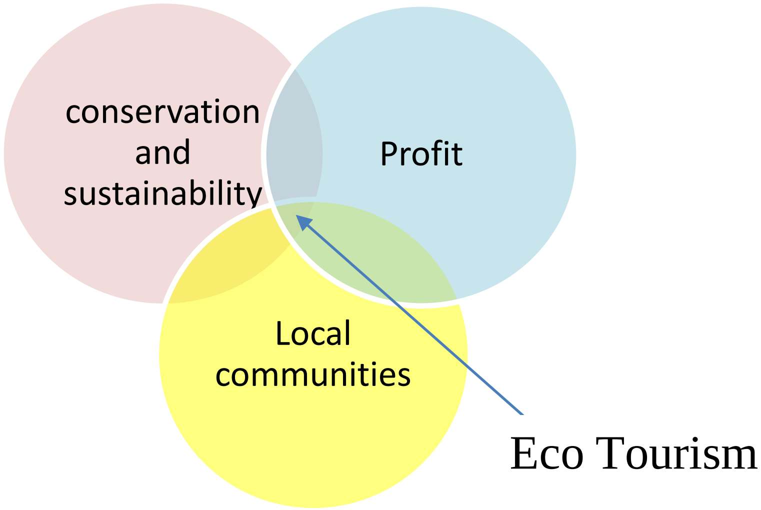

Figure 9.1 Conceptual map of economic, ecological, and social factors of ecotourism (Patterson, et al., 2004).

9.4 Sustainable tourism approach for San Andres

In the case of San Andres the current fact is that the highest share of tourists comes from the domestic market, have high spending capacity for Colombian standards (yet not that high in comparison to American and European tourists) and choose the all-inclusive formula. During the last years the amount of foreign tourists with higher spending capacity has reduced by 25%. This is probably due to the poor basic infrastructures on the island compared with other islands of the Caribbean. Another aspect that has reduced the number of foreign tourists is related to the deterioration of the sea water quality in the island to practise scuba diving in the coral reef (Arjona, Molina, Castro, Castillo, Black-Arbeláez, 2002).

Based on the reasons above, it is believed that a new tourism marketing strategy is needed in a scenario where consistent efforts are carried out to improve the sustainability of the island. If it is assumed that at parity of price for some structures and domestic tourism will keep the same values, the strategy should be that of positioning San Andres as a destination for those international travellers that aim at having a genuine experience and enjoying the characteristics of an eco-holiday. This target market is still a niche section in spite of its continuous growth and therefore the marketing efforts should be communicated through the right channels. Some of the characteristics of the targeted market: Experienced travellers, mainly European and American; age 35 to 65 with higher education; high income and willingness to pay more for an eco-vacation; They don’t aspire to luxury but they want quality and authenticity.

Most of the existing infrastructures might not suit this kind of tourist because they are not interested in big anonymous hotels but in having a special experience and therefore they will more likely choose little ‘bed and breakfasts’ built in the traditional way and decorated in the traditional style of the island instead of in the globalized manner. Figure 9.2 shows representations of different possible accommodation solutions that better suit the eco-tourist in San Andres. This is mainly because they do not have a big impact on the surrounding and they actually blend quite nicely with nature.

Figure 9.2 Possible accommodations for eco-tourism, Taken from (Costa Rica Star, Colombia travel, homeaway.com, sumtravel.com).

The eco-tourists want to enjoy the uncontaminated nature, culture and overall atmosphere. In a way, eco-tourism positions itself as the opposite of a globalized experience. Natural attractions such as the coral reef, the beautiful “seven colours sea”, the blowing hole, Captain Morgan’s cave altogether with local food are the aspects that most likely appeal to tourists and therefore there is a need to preserve them. Pictures of the natural attractions expected in San Andres is shown in Figure 9.3. San Andres has to work in that direction, offering excursions and services that can only be associated with the idea of an eco-destination and concentrating on those aspects that make the island attractive while differing from other destinations in the area.

Figure 9.3 Natural attractions offered in San Andres.

"Colombia, Magical Realism" is the new slogan for the national campaign to promote tourism abroad, as shown in Figure 9.4. It was conceived to raise foreign tourist's interest in having "different", "magic", "unique" and "surprising" experiences. This slogan also consolidates previous campaigns which have changed people's perceptions and shown the charms of Colombian tourist destinations. This new campaign is in trend with the proposed strategy as it also aims at attracting foreign tourists and offering them with unique experiences.

"Do you want to live in a place where all the colours of the sea emerge to the surface? Come."

Figure 9.4 National campaign for tourism promotion, Taken from Colombia Official travel guide.

Even if the pathway to an Eco San Andres being assessed deals with the introduction of ocean energy related solutions, it is believed that this should only be the starting point of an integrated strategy towards a sustainable future. It is also believed that this effort could position the island as a pilot case in the region and this might interest not only government in neighbouring countries but also specialists in the sector that might be willing to visit the island to study how the OTEC system works. This green trend needs to spread throughout other sectors such as waste management, transport, buildings and this will improve the overall environment and quality of life in San Andres.

10 Conclusions

An examination of alternatives to transform the current island city of San Andres (Colombia) into a coastal eco-city was made by focusing on schemes to provide renewable energies from the ocean. From the definition of the term coastal-eco city, it was clear that the energy profile in coastal cities is fundamental because the economic as well as the environmental aspects determine their future sustainability to a large extent. In the case of San Andres, the total dependency upon imports of fossil fuels to generate electricity pose a major problem for sustainable development. Other problems such as overpopulation, lack of potable water, deficient waste management, poorly diversified economy, or threats arising from climate change (e.g. salinization of aquifers, coastal erosion, increased frequency and strength of hurricanes, coral bleaching) were also identified, however, the solutions to them were not the scope of this research.

By considering the ocean energy resource availability in San Andres, the most promising technologies to produce clean energy were identified: 1) ocean thermal energy conversion (OTEC), 2) offshore wind energy and 3) offshore solar energy. The main advantage of OTEC is the steady generation of electricity all year round with production of fresh water and cold seawater which can be used in a number of applications in coastal communities. The main drawback of OTEC is the required high capital investment and the lack of existing developments at a commercial scale. The main advantage of wind energy was identified to be the technological maturity and relatively low capital investments. For the solar energy is the relatively low required investments, however this technology has not seen offshore applications at a large scale and requires considerable spaces to produce significant amounts of electricity. Both wind and solar energy generation can have significant fluctuations due to the variability in wind intensity and the impossibility to produce energy during night time, respectively.

Based on the above, two scenarios were proposed to supply the 18 MW energy demand for San Andres, one requiring high capital investments, the other with a less capital intensive nature. The first scenario considered OTEC as the power system (10 MW) to be implemented. The project in this scenario needs strong support from the central government.

The second scenario is based on an offshore wind farm development which involves the community ownership.

In comparison with the current levelized cost of electricity in San Andres (0.16 $/kWh), the levelized cost of electricity in the first scenario is significantly higher (0.36 $/kWh) assuming an amortization period of the entire OTEC project of 20 years and 4% interest rate. However, it was found that commercializing the fresh water produced by OTEC plant makes the project economically feasible.

The fresh water production of OTEC (about 13 million m^3/year) is enough to satisfy a potable water demand (10 million m^3/year) that currently is not met by the existing water supply system (about 5 million m^3/year). It was proposed to provide 10 million m^3 of fresh water from OTEC to the domestic use of the island and to have a bottle water factory to commercialize bottle water (150,000 m^3/year) which can generate revenue and create jobs in the community. The domestic water from OTEC would be priced at 0.8 $/m^3$ which is cheaper that the current cost of potable water in the island (1.2 $/m^3$). In that case, the levelized cost of electricity would be about 0.13 $/kWh (cheaper than the current 0.16 $/kWh). It is also proposed to implement an air conditioning system based on the cold seawater from OTEC, which may bring the energy demand of the island from 18 MW down to about 12MW, representing an annual saving of about $6million. Using chilling water from OTEC to prevent coral bleaching and therefore mitigate effect of climate change. OTEC based hydrogen production was identified as a promising activity generating additional revenue.

To summarize, OTEC is an appealing system that could bring several benefits to San Andres. It is indicated that OTEC system can be economically feasible as well. OTEC system is technologically ready-to-install and operate at San Andres, however, might not be installed at immediate use because the technology is still at an early stage of commercialization.

The community-oriented scenario is shown to be a ready-to-use approach for San Andres. The maturity in wind and solar gives relatively lower investment cost which is easier for people in the community to be part of the shareholders. Taking wind power as an example, the levelized cost of electricity in this scheme is low (0.13 $kWh) and is very competitive with the current cost of electricity (0.16 $/kWh). The level of investments required in this solution suggested that the project could be partially owned by the community (20% as proposed) and rest by the central government and company. The partial ownership by the community is sustainable because it diversifies the existing mono-economy while at the same time it encourages more efficient use and operation of the system.

Both of the alternatives proposed for San Andres represent a big step towards an eco-city and they improve the energetic sovereignty of the island by using the ocean resources. The production of 10 MW of clean energy would imply reductions of 115,000 ton/year and 72,000 tons/year of CO_2 in the OTEC and wind energy alternatives, respectively. It is strongly recommended that if implemented, the projects should be registered as a Clean Development Mechanism that provides incentives for reductions of CO_2 emissions into the atmosphere.

The renewable energy oriented solutions proposed in this work are only a piece of the path to an eco-San Andres. By considering both government-centred and community oriented approaches as the core concept in strategic sustainable policy, many other elements should come into play such as a more sustainable tourism in the island, waste management, water supply, transportation and adaptation to climate change Moving the current paradigm of coastal communities to models of coastal eco-cities is a necessary step towards a more sustainable world.

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A Appendix

A.1 Genoa, Italy

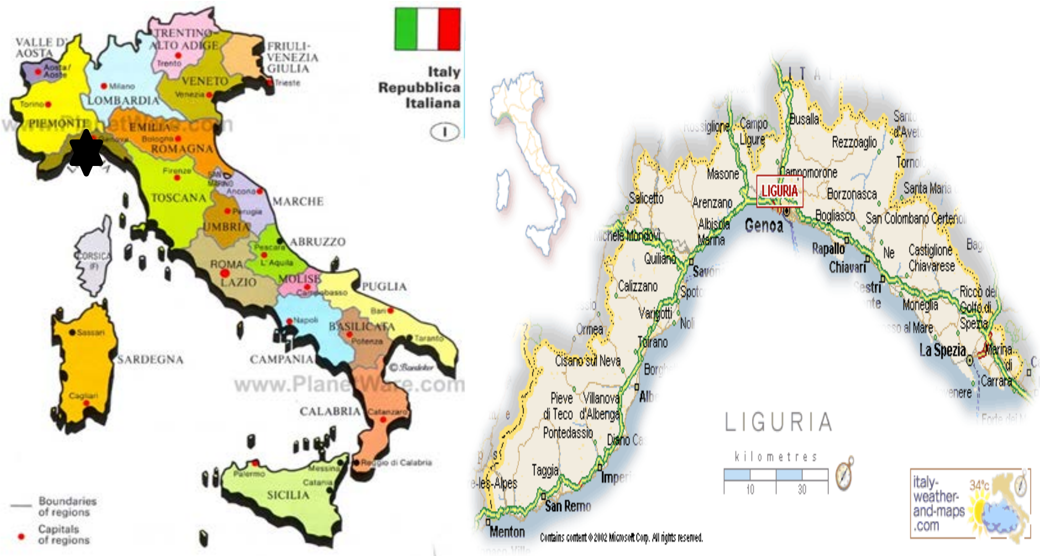

Figure A.1 Map of Italy and Liguria showing Genoa

1) Demographics: 584.644 inhabitants. During the last ten years the city lost almost 25.000 inhabitants and this trend will most likely increase as a consequence of low birth rates.
2) Geographical aspects: Genoa is the capital of the Liguria region in Italy's north-west and is located between the sea and the mountains with a comparatively long and narrow coastline stretching from east to west. Despite a city area of 243 square km, the urban core covers just 28 square km with a density of 2.406,3 inhabitants per square km.
3) Economic activities: In the past Genoa hosted massive shipyards and steelworks, however the city has experienced a progressive deindustrialization-process. The service sector has become increasingly important in activities connected to the port such as freight forwarders, shipping agents, etc. Naval reparations, refitting and conversion of vessels mostly through family run businesses are quite important. The Port of Genoa is the major Italian seaport in its range with a trade volume of 51.6 million tons, being the busiest in Italy by cargo tonnage and the second busiest with a trade volume of more than 2 million TEUs handled in 2012.

4) Transportation network: Genoa has an extensive and capillary bus network of around 900 km with 2.500 bus stops, several funiculars and elevators connecting different points along the hills with the centre. It also has a 7-km tube with 8 stations and a ferry service that connects the western border of the city with the Old Harbour. The city has a Car Sharing service that counts a fleet of 76 vehicles and 52 dedicated parking spots around the city.
5) Energy sources: The city energy consumption relies heavily upon non-renewable sources, however, the Municipality and other institutional bodies are currently working to incentivize the use of renewable sources in public buildings through different initiatives.
6) Current sustainable energy policies: Genova Smart City is a Municipality driven project that aims at sustainable economic development based on research, innovation and technology guided by local leadership using a logic of integrated planning. It counts four different macro areas of work: efficient buildings, sustainable mobility, energy and the port. In connection with the Smart City project, the Port Authority has developed a Port Energy Environmental Plan (PEEP) with the scope of stimulating and developing the activities linked to the production of energy from renewable sources aimed at the containment of consumption in its own territory.
7) Emissions in the city (CO2, NOx, SOx, pm10)

Type of Emissions	Amount	Measure Unit
CO_2	5.653.683	t/year
NO_x	15.482	t/year
SO_x	12.845	t/year
PM10	1.150	t/year

Source: Liguria Region statistics for 2005.

Table A.1 SWOT analysis for the city of Genoa.

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STRENGHTS

- Port performance and potential
- Good position in the Mediterranean basin
- Existence of a capillary urban transport system

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WEAKNESSES

- Decreasing and ageing population
- Topographically constrained between the sea and the hills (doesn’t allow expansion)
- Unclear regulations (at local, national and EU level) on the renewable energy field

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OPPORTUNITIES

- Political support of local government to foster innovative sustainable solutions
- Private investors are currently exploring the possibility to invest in renewable sources of energy in the city

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THREATS

- If the port grows the existing transport infrastructures will not be enough and therefore there will be more congestion
- Lack of adequate infrastructures will make the port less appealing
- Continuous economic crisis might stop sustainable initiatives once the EU funding is over
- Heavy pollution

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A.2 Hong Kong, China

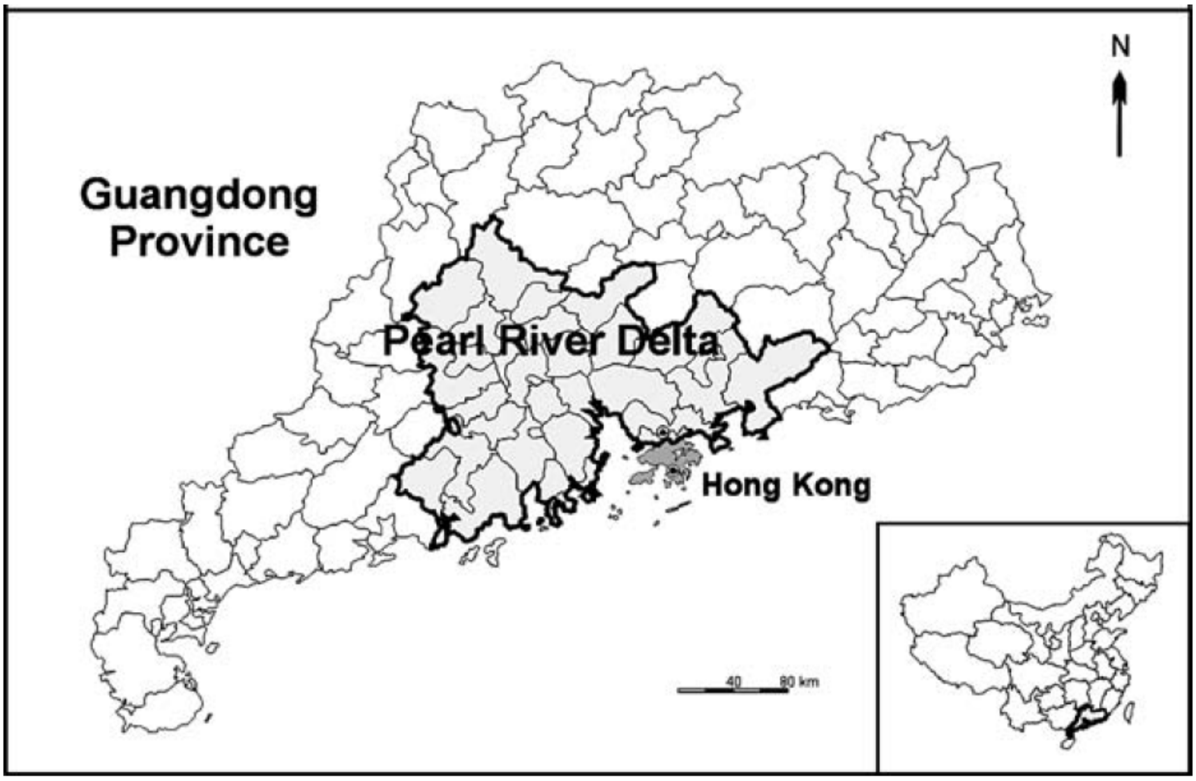


Figure A.2 Map of Guangdong province, Hong Kong.

1) Demographics: Hong Kong has an area of 1100km^2 seven million residents where 8% of the population are foreign nationals (non-Chinese)
2) Geographical aspects: Hong Kong is located in the south east coast of China. It is divided into 4 main areas, namely, New Territories, Kowloon, Hong Kong Island and Lantau Island. As one of the most densely populated cities in the world, developed land is less than 25% where 40% of the total land area is designated as country parks.
3) Economic activities: Hong Kong is a global hub of international business, commerce and trading with an estimated GDP of 351.1 US$ BN by 2012. It has the third busiest container port in the world which handled 24.4 million TEUs (Twenty-foot equivalent) by 2011.
4) Transportation network: Hong Kong has a very high usage of public transports (including railways, trams, buses, minibuses, taxis and ferries) with 12 million passenger journeys per day.

5) Energy sources: Hong Kong consumed 151,000 TJ of electricity by 2010 where the commercial and residential sectors consumed 91% of the total energy. The electricity consumption per capita in Hong Kong is 5,950 in 2009 comparing to 11,865 in the US, 2,287 in China and 553 in Philippines. In 2009, 77% of the electricity was generated by coal and natural gas where the rest of 23% is generated by a nuclear plant that is positioned outside Hong Kong's territories.
6) Current sustainable policies: The energy policies in Hong Kong is mainly to reduce the consumption side, including Energy Efficiency Registration Scheme for Buildings, Buildings Energy Efficiency Ordinance (Cap. 610), Mandatory Energy Efficiency Labelling Scheme, Scheme on Fresh Water Cooling Towers.

Table A.2 SWOT analysis for Hong Kong.

STRENGHTS: • High percentage of public transport • High energy stability (city blackout rarely happens)	**WEAKNESSES:** • High population density • Urban heat due to high density of buildings
OPPORTUNITIES: • Use of electrical vehicles for public transport • Regulation of building energy efficient policies	**THREATS:** • Flooding risk due to more frequent hurricane • Regional severe air pollution contributed by the nearby city.

A.3 Lagos, Nigeria

Figure A.3 Map of Nigeria showing Lagos.

1) Demographics: Lagos State is physically the smallest state in Nigeria with an area of 3,577 sq. km. which is about 0.4 per cent of the total land area in Nigeria. The city has the highest population which makes up approximately 10% of the national population. After the state census conducted in 2006, the population of Lagos State was put to be 17.5 million with a growth rate of 3.2 per cent. This rate will statistically put its current population to be over 21 million. Lagos is further divided into two major regions: Lagos-Mainland and Lagos- Island and the latter is inhabited by approximately 85 % of the state population.
2) Geographical aspects: Lagos state is located in the rain forest region of Africa and covers approximately 187 km of Nigeria's coastline which is 20 % of the total coastline. The city lies at an average elevation of 3 meters above sea level and has two very different seasons: the dry season between October and March and the rainy season from April to October that reaches an average rainfall of 1532 mm and the rainy season.
3) Economic activities: Nigeria currently accounts for 50 per cent of West Africa's gross domestic product (GDP) and this can be attributed to the economic growth of Lagos Metropolis. Lagos State is the second largest contributor to the national economic growth after the oil-rich Rivers State. Lagos is home to about 2,000 industrial concerns, 10,000

commercial ventures and 22 industrial estates. 60 per cent of Nigerian's industrial and commercial activities take place in Lagos State. The human activities associated with the coastal area of Lagos State are fishing, recreational facilities, aquaculture and sand mining.

4) Transportation network: The major mode of transportation in Lagos is the use of private vehicles and public bus transportation. Lagos has an average of 224 vehicles per kilometre compared to the world average of 11 vehicles per kilometre. These characteristics make Lagos one of the cities with the highest vehicular density in the world. Public road transportation mode in Lagos can be divided into two categories: bus transportation and motorcycle transportation and due to the poor state of the first and the reckless nature of the motorcycle riders, many car owners find it more convenient to travel across the city by car. The rail system in Lagos Metropolis is a 25 km railway line. There is a presence of water transportation in Lagos for the purpose of transporting people and goods. This is achieved by the use of locally made canoes which are sometimes motor-propelled but in most cases, paddled.
5) Energy sources: Lagos rely on fossil fuel and combustible biomass as the main source of energy. Combustible biomass is mostly utilized in suburban areas in Lagos due to serious shortage of access to commercial alternatives. The two major sources of electricity in Nigeria are hydroelectric and gas turbines.
6) Emissions in the city: Every year waste from the Sahara desert reaches Lagos increasing the emission levels. Studies identified the sources of emissions in the city as follows: the evaporative sources from gasoline and solvent use; major vehicle combustion emission within the city and fugitive natural gas leakage which is likely from the city electricity production.

Table A.3 SWOT analysis for the city of Lagos.

STRENGHTS	WEAKNESSES
• High literacy rate (87%) • 187 km of coastal line • Financial hub for all of West Africa • Cultural diversity	• Imbalanced modal split with high use of private vehicles • Insufficient public transport • Heavy congestion and pollution • Rapid population growth
OPPORTUNITIES	**THREATS**
• Potential solar energy development due to tropical weather • Potential development of maritime traffic that would reduce road congestion	• Highly prone to flooding due to its flat topography • Annual rise of CO due to waste arriving from the Sahara desert

A.4 New York, United States

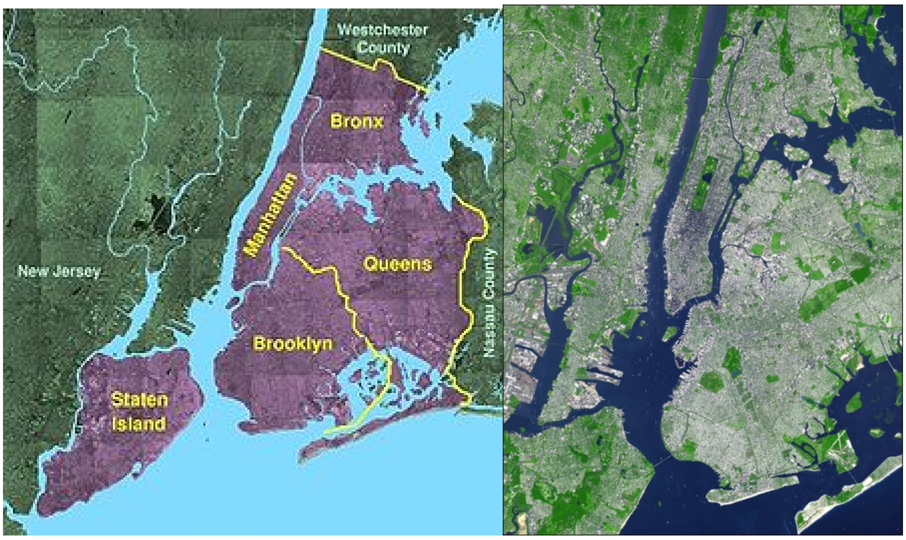
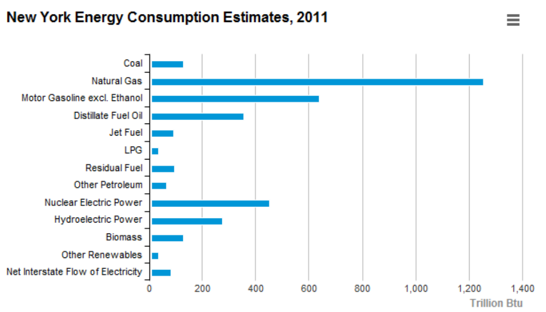
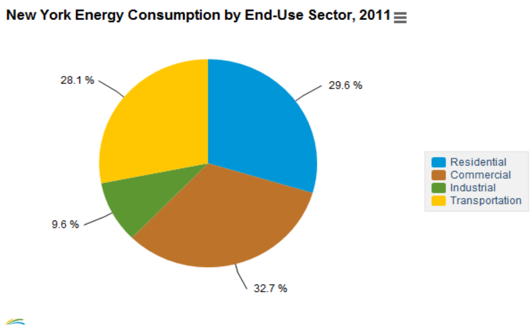


Figure A.4 Map of New York City.

1) Demographics: The city includes five boroughs: Manhattan; Brooklyn; Bronx; Queens and Staten Island with an estimated record high of 8,336,697 residents as of 2012. NYC is the most populous city in the United States.
2) Geographical aspects: New York City is located in the north eastern United States, in southern part of New York State, at the mouth of the Hudson River, which feeds into a naturally sheltered harbour and then into the Atlantic Ocean. Its geographic features have helped the city grow in significance as a major trading port (Port of New York &New Jersey) in the United States
3) Economic activities: New York is a global hub of international business and commerce with an estimated GDP of 1,180.3 $BN by 2010. The port of New York/New Jersey is the 3rd largest trading port in the country.
4) Transportation network: New York is especially at risk if the sea level rises, due to many of the bridges connecting to boroughs, and entrances to roads and rail tunnels. High-traffic locations such as the airports, the Holland Tunnel, the Lincoln Tunnel, and the Passenger Ship Terminal are located in areas vulnerable to flooding. Flooding would be expensive to reverse.

5) Energy sources:





6) Current sustainable policies: Green Building Initiative, Property Tax Incentive for Green buildings, solar, wind and Biomass energy systems exemption.

Table A.4 SWOT analysis for New York City.

STRENGHTS:	**WEAKNESSES:**
• 3rd largest trading port in U.S. • International financial hub • Cultural diversity	• Large size of transportation volume with vulnerable infrastructures • Top three energy sources(natural gas, motor gasoline ethanol, nuclear electricity power) are non-renewable • Dependent on external energy sources.
OPPORTUNITIES:	**THREATS:**
• Political planning in renewable energy • Innovative technology and financial benefit by implementing renewable energy	• Hurricane and flooding are risky for city's infrastructure • Shortage of electricity caused by heat waves from rising temperature

A.5 SWOT analysis for San Andres

A complete description of the city features is present in chapter 4 as the focus of this research has been San Andres.

The table below summarises the in depth SWOT analysis that has been carried out.

Table A.5 SWOT analysis for San Andres.

STRENGHTS:	WEAKNESSES:
• Landscape. • Marine protected area. • Cultural heritage. • Sustainable fishing policies. • Immigration policy. • Best preserved marine ecosystems in the Caribbean.	• Island environment and therefore remote location. • Decision making is slow and difficult because of centralized government. • Dependent on external energy sources. • Relies entirely on fossil fuel energy sources. • Lack of energy policy. • Fragile ecosystems. • Lack of political will to implement policies, mainly at the national level. • Relatively small economy. • Very high density population. • High emissions of CO_2 per capita. • Dependent on external food supply • Overexploitation of aquifers. • Dependent on external supply of construction materials.

SWOT analysis for San Andres. (contd.).

OPPORTUNITIES:	**THREATS:**
• Exploitation of renewable energies: Eolic, solar, thermal energy from the ocean. • Sustainable fishing. • Offshore availability of natural gas. • Tourism and eco-tourism. • Aquaculture	• Overpopulation • Climate change including strength and frequency of hurricanes and coral bleaching. • Offshore oil and gas exploration. • Oil spills. • Reducing fish stocks. • Invasive species. • Salinization and depletion of aquifers. • Deforestation and erosion.