# C2 Wave Energy desalination and Tourism Strategic Plan

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## 1 Introduction

The MARIBE combination presented here is Wave Energy powered Desalination and Tourism in the Caribbean basin. This concept is based on the ability of a wave energy converter (WEC) to supply the power needs of desalination in combination with the added value of tourism located in the Caribbean basin. The basics of combining the blue growth sector, wave energy, with the blue economy sector, tourism, here are that the WEC will supply drinking water via desalination and this will be fed into a location to increase the tourist amenity. The desalination technology referred to in this plan is Reverse Osmosis (RO) which is an established technology. The desalination unit will be placed on a pier, marina or breakwater as discussed in the case studies. Further details of the desalination stages are presented in Appendix 1.

### Case Study 1:

The concept is based on Marina with a desalination unit placed on the platform of the marina. The power to the RO unit would be supplied by a wave energy converter technology of adequate power (note: multiple WEC units may be required). This concept can be broadened out to cover many areas of coastal communities where there is a need for sustainable water resources that maximise net revenue from tourism and enable growth by attracting increased tourist numbers. This concept combination would demonstrate multiple use of space (MUS) whilst providing services for the tourism and leisure industry such as water refilling station for leisure vehicles, supply of clean drinking water meeting the demand for increased berthing amenities in the Caribbean.

### Case Study 2:

Supplying entire desalination energy needs of a small island with larger WEC device. A small island in the Caribbean that is importing its water demand and its electricity generation is based on diesel generators. Solution to imported water is the introduction of a WEC to meet the requirements of the island. The example used is based on data taken an island study done on Ponza Island. The water demand per year is directly proportional to the increased tourist numbers during the year.

**Basin suitability:** The suitability of the Caribbean for wave energy is not widespread and its very location dependant. Certain areas have a low wave resource, kW/m of wave front. In the enclosed basin area of the Caribbean Sea an extractable wave energy resource is limited [1]. The islands in the Lesser Antilles of the Caribbean possibly have a wave climate that is more suitable for energy extraction on the eastern Atlantic Ocean exposed coasts. Yet the records and instrumentation is scarce in this area hence there is no wave information for very large extensions of the coastal areas of the Caribbean countries [2]. Wave energy would need to be sufficient for energy production and or desalination. Tourism is a very high priority for the Caribbean.

This concept is considered a multiple use of space (MUS) as both tourism and wave energy are collaborating to share the ocean space within close proximity to highly touristic coastal regions for benefit of both industries. There is no exact examples existing of this concept but there are examples of demonstration wave energy pilots powering desalination. An example of the current device developers in this regard is presented in section 2.3.

**Socio-Economics:** This multi-use of space will have a positive impact on new jobs, increased tourism net revenue from energy and water cost reduction and access to a sustainable source of drinking water. By reducing costs of water transport along with increasing tourism numbers the net benefits should be increased. This can be in addition to CO2 free production of clean water achieving security and sustainability of supply.

**Key threats:** There is a lack of data on the wave resource availability in the location in addition to a lack of renewable energy projects in general which is a big threat to investment in a new venture. For example the Caribbean Regional Electricity Generation, Interconnection, and Fuels Supply Strategy did not evaluate ocean energy resources [3]. The reason for this is they are not commercially demonstrated technology. This would indicate that Ocean Energy would not be eligible for support from the International Development Association (IDA) and/or the International Bank for Reconstruction and Development (IBRD). In addition to this the threat of tropical hurricanes will make insurance and survivability a key concern for investors. Currently Ocean energy has high CAPEX and OPEX costs in addition to an underdeveloped Caribbean supply chain.

Figure 1 shows the islands in the Caribbean region along with the non-sovereign territories of European countries. The islands form the base of the research and the market.

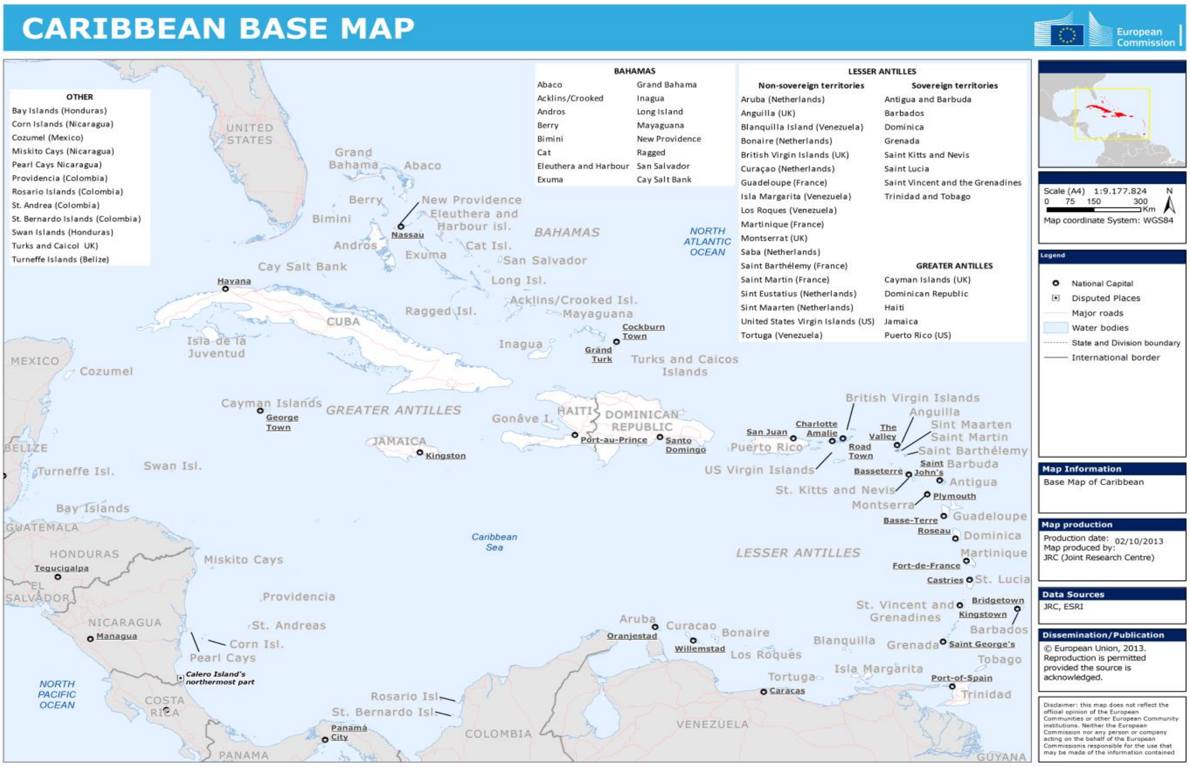


Figure 1 European Commission Map of Caribbean (http://ec.europa.eu/echo/where/latin-america-carribean/caribbean_en)

## 2 Products

The products offered are

- Wave powered desalination system.
- Drinking Water via Reverse Osmosis (RO)

Example product offerings are detailed in the case studies that follow in sections 2.1 & 2.2.

## 2.1 Product offering 1

- **15kW WEC with RO unit mounted on breakwater of a Tourist Marina**

Small Scale initial market offering initially based on Marina with desalination unit, power supplied by small autonomous wave energy converter. This concept can be broadened out to cover many areas of coastal communities where there is a need for water resources that add to the tourism amenity and ability to attract increased tourist numbers. This concept combination would provide services for the tourism and leisure industry such as water refilling station for leisure vehicles, supply of clean drinking water meeting the demand for increased berthing amenities in the Caribbean.

As presented in Table 1 a 15kW WEC is more than capable of meeting the annual water requirements of a Marina by providing the electric energy that will power the RO. In this case the 15kW WEC would supply almost 3 times the specific energy consumption needed to desalinate enough water for 100 boats. The excess energy can be used to either supply and store more water or used to meet electrical demands on site at the marina. Exporting to the grid is not considered as an option for small scale kW devices.

**Table 1 Case Study 1 Summary Data**

| | | |
|---|---|---|
| A | Average Electrical Energy Demand for RO [1] | $4kWh/m^3$ |
| B | Annual Water Demand for Marina [2] | 1825m3 |
| C (A X B) | Annual Electrical Energy Requirement of RO | 7300kWh |
| D | Annual Energy of 15kW Bref-HB WEC[3] | 20, 919 kWh |
| | Capacity factor[4] | 15.92% |
| E (D/C) | Demand Met by WEC | 287 % (almost 3 times required energy requirement) |

## 2.2 Product offering 2

- **1MW WEC supplying entire drinking water needs of small Tourist island location via RO**

Larger scale market offering powering the desalination needs of an entire tourist island. Supplying entire energy needs of a small island with larger WEC device. This product would suit the islands in the Caribbean that import its water or is currently desalinating sea water in addition to its electricity generation being based on diesel generators. The solution to imported water and or diesel desalinated water is the introduction of a WEC to meet the requirements of the island. The example used is based on data taken an island study done on Ponza Island, Italy [4]. The water demand per year was found to be directly proportional to the increased tourist numbers during the summer.

As shown in Table 2, a 1MW Wavestar device WEC will not meet the annual water requirements of an island. Yet it is able to deliver 74%. In this case the 1MW WEC would supply almost the specific energy

[1] Average specific energy consumption (SEC) http://www.ijesd.org/papers/243-B20001.pdf
[2] This is based on 100 boats at 50 litres a day see Appendix for calculations
[3] This is based on modelling simulation ran in Exceedence Finance
[4] Use of Exceedence finance http://www.makingrenewablescommercial.com/

consumption needed to desalinate enough water for a population of 3000 and the increased demand of tourists. In order to be completely self-sufficient in desal water, 2 WEC devices would be required. There would be an excess of energy then to address. The excess energy could be used to either supply and store more water or for export to the local grid. Further calculations, assumptions and modelling data for Table 2.

**Table 2 Case Study 2 Summary Data**

| | | |
|---|---|---|
| A | Average Electrical Energy Demand for RO [5] | 4kWh/$m^3$ |
| B | Annual Water Demand for Island[6] | 400,000 m3 |
| C (A x B) | Annual Electrical Energy Requirement of RO | 1,600,000 kWh |
| D | Annual Energy of 1MW Wavestar WEC[7] | 1,188,000 kWh |
| | Capacity factor[8] | 13.56 % |
| E ( D/C) | Demand Met by WEC | 74 % (26% short of energy required to supply total water demand) |

## 2.3 Current Products Sources (Competition).

Currently there are some products that could perform the functions discussed in the case studies. These are all still at a pre commercial stage of development. Examples of such are provided in Table 3.

**Table 3 Product Offering on the Market**

| Company | Technology Type | Progress/Prospects | TRL | Link |
|---|---|---|---|---|
| Carnegie Wave Energy | WEC that is fully submerged, pumping technology that drives the hydraulic fluid onshore | Progressing very well | TRL 7 | http://carnegiewave.com/current-projects/ |
| Resolute Marine Energy | Wave Energy Converter that can power both desalination and provide energy, hybrid | Progressive in the Testing and development phase. Integrated Testing due in 2016 | TRL 6 | http://www.resolutemarine.com/ |
| SAROS Desalination | Wave Energy directly driving desalination no electricity | Early Stage development | TRL 4 | http://sarosdesalination.com/ |
| Albatern Wave Energy | Wave Energy Converter that has stated it can power RO | Tested at Pilot and developing next phase | TRL 6 | http://albatern.co.uk/markets/island-remote-communities/ |

5 Average specific energy consumption (SEC) http://www.ijesd.org/papers/243-B20001.pdf
6 Preliminary Assessment of Wave Energy Use in an Off-grid Minor Island Desalination Plant
7 This is based on modelling simulation ran in Exceedence Finance
8 Use of Exceedence finance http://www.makingrenewablescommercial.com/

## 3 Market Analysis

The first focus of the market entry strategy is to access the countries with most connections to the European Union due to access of funding and investors. The 18 non sovereign territories in the Lesser Antilles are an ideal entry point. These include the European Union the 'outermost regions Martinique, Guadeloupe, French Guiana, Saint-Martin that are a priority area for EU support. Following this market entry an approach would be made to enter all markets in the Caribbean followed by a global approach. For the case studies all the countries in location that are suitable are evaluated. Fig 1 lists these islands.

### 3.1 Sizing

#### Case Study 1:

By taking the outputs derived in 2.1 Product Offering 1 a market size for the WECs based on a list of Caribbean islands can be chosen. The Market size is estimated to be 42 WECs (see Table 3)

**Table 3 Market Size for 15kW WEC at Marina**

| Country | Population | Number of Marinas Based on Island and population [9] | Water Demand of 100 boat Marina using 5000L/day | Annual water demand (m3) | Desalination electricity demand (Average Energy Demand for RO 4kWh/$m^3$) | Number of 15kW WECs, based on 20, 919 kWh AEP[10] |
|---|---|---|---|---|---|---|
| Calculations | | A | A*5000L=B | B*0.365=C | C*4kWh=D | D/20,919 =E Rounded to 1 |
| **British Virgin Islands** | 28,054 | 1 | 5000 | 1,825 | 7,300 | 1.0 |
| **Montserrat (UK)** | 4,299 | 1 | 5000 | 1,825 | 7,300 | 1.0 |
| **Antigua and Barbuda** | 85,567 | 2 | 10000 | 7,300 | 29,200 | 1.0 |
| **Barbados** | 277,821 | 4 | 20000 | 29,200 | 116,800 | 6.0 |
| **Dominica** | 71,293 | 2 | 10000 | 7,300 | 29,200 | 1.0 |
| **Grenada** | 103,328 | 2 | 10000 | 7,300 | 29,200 | 1.0 |
| **Saint Kitts and Nevis** | 46,204 | 1 | 5000 | 1,825 | 7,300 | 1.0 |
| **Saint Lucia** | 166,526 | 3 | 15000 | 16,425 | 65,700 | 3.0 |
| **Trinidad and Tobago** | 1,349,667 | 4 | 20000 | 29,200 | 116,800 | 5.0 |
| **Cayman Islands (UK)** | 58,238 | 2 | 10000 | 7,300 | 29,200 | 1.0 |
| **Jamaica** | 2,723,246 | 5 | 25000 | 45,625 | 182,500 | 9.0 |
| Puerto Rico | 3,548,397 | 6 | 30000 | 65,700 | 262,800 | 12.0 |
| | | | | | **Total sum E** | **42** |

[9] There are some assumptions made to approximate a number of Marinas that could be required based on the island and the population. 1 marina per 50,000 population, up to a maximum of 4 marinas per island.

[10] AEP=Annual Energy Output

*Case Study 2:*

Market size analysis returns 2600 1MW WECs see Table 4. The initial market appraisal would be considered to be to get minimum of one 1MW WEC per island to meet power desalination.

**Table 4 Market Size for 1MW WEC supplying Population with drinking water via RO**

| Country | Population | Water Demand (L/capita/day)[11] | Annual water demand (m3) | Desalination electricity demand (kWh) | Number devices based on 1MW machine producing 1,188,000 kWh AEP[12] |
|---|---|---|---|---|---|
| | A | B | A*B*0.365=C | C*4kWh=D | D/1,188,00=E |
| **British Virgin Islands** | 28,054 | 250 | 2,559,928 | 10,239,710 | 9 |
| **Montserrat (UK)** | 4,299 | 250 | 392,284 | 1,569,135 | 1 |
| **Antigua and Barbuda** | 85,567 | 250 | 7,807,989 | 31,231,955 | 26 |
| **Barbados** | 277,821 | 250 | 25,351,166 | 101,404,665 | 85 |
| **Dominica** | 71,293 | 250 | 6,505,486 | 26,021,945 | 22 |
| **Grenada** | 103,328 | 250 | 9,428,680 | 37,714,720 | 32 |
| **Saint Kitts and Nevis** | 46,204 | 250 | 4,216,115 | 16,864,460 | 14 |
| **Saint Lucia** | 166,526 | 250 | 15,195,498 | 60,781,990 | 51 |
| **Trinidad and Tobago** | 1,349,667 | 250 | 123,157,114 | 492,628,455 | 415 |
| **Cayman Islands (UK)** | 58,238 | 250 | 5,314,218 | 21,256,870 | 18 |
| **Jamaica** | 2,723,246 | 250 | 248,496,198 | 993,984,790 | 837 |
| **Puerto Rico** | 3,548,397 | 250 | 323,791,226 | 1,295,164,905 | 1090 |
| | | | | **Total devices (Sum E)** | **2600** |

## 3.2 Development drivers

### *3.2.1 Policy*

EU policy therefore focuses on improving accessibility, increasing competitiveness and strengthening regional integration (SEC(2007).

The policy for the Outermost Regions (OR) is to increase the use of renewable energy sources one of which is wave energy. Overall the policy is to improve the energy balance of the ORs so as to lessen their dependence on outside sources.

[11] Assumed standard water cons
[12] Modeled by exceedance finance.

### *3.2.2 Population current and growth*

The population of the region is considered to be in growth as MARIBE research on the basin indicated [5]. It is considered to have a huge growth potential for Tourism numbers & revenue also.

### *3.2.3 Water resources*

Figure 2 demonstrates the demand for water in the Caribbean basin but also from a global perspective the demand. The red colouring in the Caribbean islands indicates that the water supply is under high stress hence the huge market potential. Current usage of desalination is at 1% of world population, based on 2014 figures from Global Water Intelligence but the estimated demand dependence on desalination by 2025 is an increase to 14% of world population.

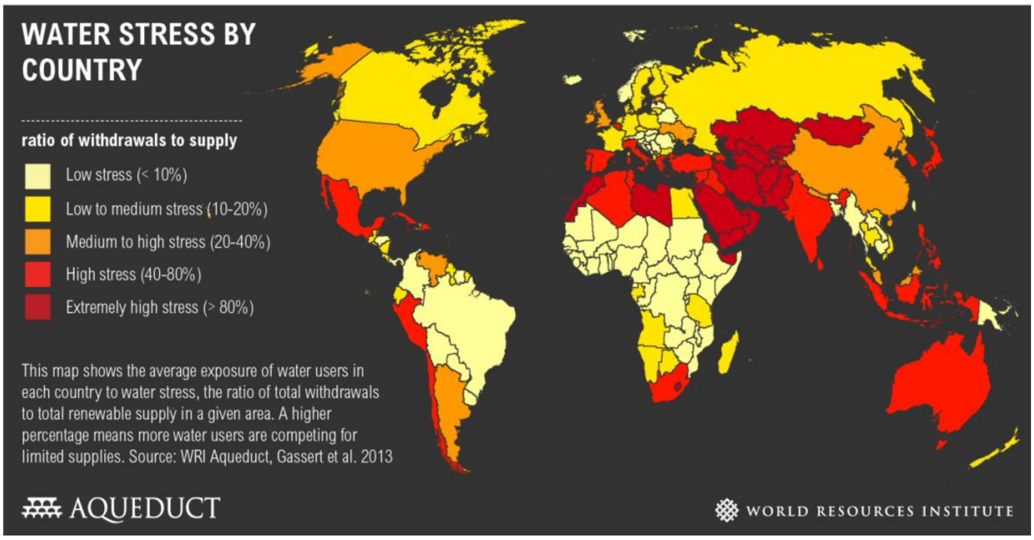


**Figure 2 Water Scarcity Issues (Global Water Intel)**

### *3.2.3 Cost of water and cost of electricity and or diesel*

Table 2 presents the cost of drinking water per island. The variation in water costs is significant with Anguilla paying 16 times more per litre than Barbados.

| Country | Drinking Water Costs €/m3 |
|---|---|
| Barbados | 1.949 |
| St Martin (Dutch jurisdiction) | 2.813 |
| British Virgin Islands/ Tortola | 4.044 |
| Nevis | 4.044 |
| Santa Lucia | 4.044 |
| St Vincent | 4.044 |
| Montserrat | 5.258 |
| Dominica | 6.431 |
| Antigua | 10.111 |
| St Martin (French Jurisdiction) | 15.628 |
| Anguilla | 16.178 |

**Table 3 Water Cost for Caribbean Islands (data sourced from web searches)**

Table 3 displays the costs of electricity. The variation is also significant , although not varying to the same degree as water charges, with up to 50% variation between Barbados and US Virgin Islands. The costs of electricity is almost double or triple that paid in Ireland, depending on the Ireland (Ireland pays €0.17/kWH).

The high cost of water drives cheaper and more local water alternative sources, and high electricity costs drives local renewable sources, such as wave energy.

| Country | Electricity Costs €/kWh |
|---|---|
| Barbados | 0.31 |
| Jamaica | 0.33 |
| St. Lucia | 0.34 |
| Grenada | 0.37 |
| Dominica | 0.38 |
| Grand Cayman | 0.38 |
| Bermuda | 0.39 |
| U.S. Virgin Islands | 0.48 |

**Table 4 Electricity Costs for Caribbean Islands (data sourced from web searches)**

## 4 Customers

- Marinas new and existing
- Island Nations governments and utilities
- Eco Hotels (not considered in this report but they are high potential)

For the marina customers it being identified by MARIBE that breakwaters would be essential to deploy both wave energy and tourism. A breakwater is a critical structure as it is required to protect the marina from adverse conditions. The layout of the breakwater would be such that it reduces incident waves to levels that will allow normal operations to continue at all times. An area that needs a breakwater will have a wave resource that may be exploitable close to the breakwater and this is the proposed deployment location. An example is Puerto del Rey Marina. This is a marina located in Fajardo, Puerto Rico. With a capacity of 1,100 boats, it is one of the largest marinas in the Caribbean. It is relatively exposed to a significant wave height beyond the safety of its breakwaters. Existing and new marinas would be the targeted customers. In the market analysis MARIBE identified based on population a need for 42 new marinas.

For the island nations, it has been identified by MARIBE research that 2600 devices would serve the entire water needs of the islands. Having access to drinking water and renewable energy will add to tourism in addition to being able to provide the needs of new or existing eco hotels.

## 5 Competition

An analysis was undertaken of what products and technology would be competition or an alternative to the WEC desalination and tourism concept. These are presented in the Table 5 below.

| **Technology Type** | **Company** | **Comments** | **TRL Level** | **Link** |
|---|---|---|---|---|
| Solar PV and/or Wind | Element Water Makers | Wave could be the renewable component in this concept | TRL 9 | http://www.elementalwatermakers.com/products |
| Wind And PV to power desalination | Project (WREN) Australia | Operational demonstration. Wave could be the renewable component in this concept | TRL 9 | http://www.eco-business.com/press-releases/creating-power-and-drinking-water-with-lower-costs-and-emissions/ |
| Diesel Power | Siemens | Off the shelf but not environmentally or sustainably based | Technology is Ready | |
| Grid Connection | Caribbean TSOs | If close to grid connection very attractive | Technology is Ready | |

Table 5 Summary of Current/Possible Competition to Desalination Concept

## 6 Revenue

As some of the islands are domicile of EU countries these would be most suitable for development within MARIBE, due to eligibility for grants and tariff support schemes.

- **Economic Partnership Agreement** (EPA) between the EU and the countries of CARIFORUM, financed by the **European Development Fund (EFD)** which aims to fund projects for the economic, social and human development of the region.
- **Caribbean Investment Facility**: based on the objectives of the EU-CARIFORUM agreement the facility mobilises resources for strategic economic projects and the support of the private sector. The support is provided in the form of investment grants, technical assistance, risk capitals and other risk sharing instruments.
- **International Development Association** (IDA) and/or the International Bank for Reconstruction and Development (IBRD). Yet as noted in the introduction Ocean is not considered a commercial technology so would be currently ineligible for support through this mechanism. In the future this could be availed of. (NEXANT, 2010)

The French island of Martinique is developing a WEC converter through EU funding, NERO.

## 7 Strategic Roadmap

The Strategic Roadmap plan is to demonstrate how the combination could progress through the Technology Readiness Levels (TRL) based on its current status.

- Desalination is proven its technology ready.
- Breakwaters with increased Tourism are proven, technology ready
- The combination of wave, desalination and tourism is still very much a concept, TRL 3-4
- Standalone WECs as presented in products vary from TRL 3-8

- H2Ocean-Concept-TRL 3
- The wave energy concept, Carnegie, is at TRL 7 or TRL 8

An example is presented for progress through the various stages of development of the concept in Table 6. Each stage relies on a successful completion of the current level in order to progress and would follow a protocol such as the HMRC Development & Evaluation Protocol [6].

| 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|
| **TRL 4** | **TRL 4** | **TRL 5** | **TRL 5** | **TRL 6** |
| Test a 1:20 scale prototype WEC in lab to Validate Technology and ascertain RO ability in Lab | Continious testing and simulation of the concept, working on validation and refinement | 1:4 sacle Validate Technology in non exposed wave climate/test site in Caribbean | Retrieve 1:4 test device and test and validate all results | Progress Plans to Full scale prototype deployment off Martinique |
| Obtain H2020 funding | | European Investment Bank Fuding | | Angel Investors |
| **IRL 4** | | **IRL 5** | | **IRL 6** |

Table 6 **Proposed 5 year Strategic Roadmap**

## 8 Conclusion

Desalination driven by renewable energy makes great market sense in the Caribbean islands due to:

- high electricity prices,
- poor grid access with some islands requiring use of diesel generators.
- high water scarcity, due to low rain fall, high population and high tourism water consumption, leading to high water costs

Research in this paper has identified Dominica as an ideal first island for pilot, due to high costs of both water and electricity. Antigua, St Martin and Anguilla, would follow with extremely high prices paid for water.

When inspecting the market via marinas, tourism has been demonstrated to provide sufficient market for small scale wave/desalination product.

In Conclusion, Wave energy powered desalination has high prospects, but will need to demonstrate in operation precommercially before it's likely to see large developments or investments from the private sector in this area.

# 8 References


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