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Marine Current Power Generation in Trinidad: A Case Study

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Abstract: *Development of alternative energy sources has attracted worldwide interest given the adverse effects of fossil fuels on the global climate as well as its unsustainability. It is in this context that this report examines the feasibility of marine power generation at the 14 km wide Serpent's Mouth in Trinidad. It is part of the narrow Columbus Channel which lies between Trinidad and Venezuela. At this location, depth varies between 30 - 48 m and a marine current of approximately 1.5 m/s suggests the possibility of generating power through submerged turbines.The conditions are similar to those at Strangford Lough in the Irish Sea, where the world's first marine current turbine was installed in 2008 for generating 2 MW of power. After taking into account the technical, environmental, and economic factors, this paper concludes it is feasible to use The Serpent's Mouth location for Power Generation.*

Keywords: *Columbus Channel, Marine Current Turbines (MCTs), Power Generation, Marine Renewable Energy (MRE)*

1. Introduction

A mere 14 km separates Trinidad (10.4606° N, 61.2486° W) and Venezuela (10.5000° N, 66.9667° W) at the Serpent's Mouth. Such a constriction, at the Columbus Channel, creates a Venturi effect as the Guiana Current flows into the Gulf of Paria. The resulting current velocities in the range 2 – 3 knots (1-1.5 ms^{-1}) provide an opportunity for renewable power generation, through the use of Marine Current Turbines (MCTs). Against this background, this paper investigates the feasibility of power generation from marine currents off the southern coast of Trinidad. It may be noted that the feasibility of power generation by MCTs has been considered in different parts of the world. Indeed, one MCT is currently producing 2 MW of power in the Irish Sea (Fraenkel 2007). Figure 1 depicts the location of Trinidad and its Serpent's Mouth.

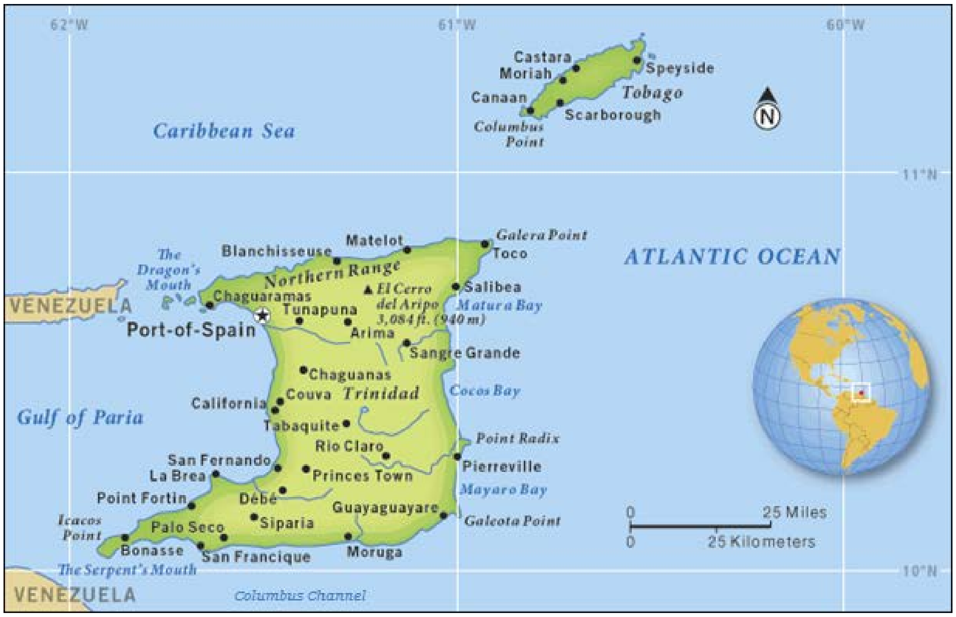


Figure 1. Location of Trinidad and its Serpent's Mouth

2. Location Selection

Within the island region of Trinidad exists two locations that can be considered for Marine Renewable Energy (MRE) generation. On the northwest of the island exists The Dragon's Mouth and to the southwest of the island, The Serpent's Mouth.

The Government of the Republic of Trinidad and Tobago and the Government of the Republic of Venezuela, hereinafter referred to as the Contracting Parties, resolving in a true spirit of cooperation and friendship to settle permanently as good neighbors the limits of the marine and submarine areas within which the respective Governments exercise sovereignty, sovereign rights and jurisdiction through the establishment of a precise and equitable maritime boundary between the two countries (United Nations 2002). All operations are to be kept within the delimitation line (see Figure 2).

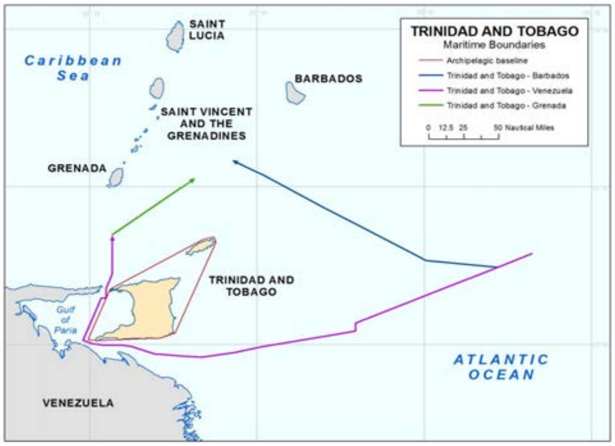


Figure 2. Delimitation Line of Trinidad and Tobago

2.1 The Serpent's Mouth

Flow Rate:

As aforementioned, current velocities range from 2-3 knots (1-1.5 ms^{-1}) from the Guiana Current and the Orinoco River Discharge.

Obstructions and landmasses:

Soldado Rock is a small land mass located in the Gulf of Paria east of Icacos Point in Trinidad and north of the Venezuelan mainland (see Figure 3). It is under the ownership of the Republic of Trinidad and Tobago.

Bathymetry:

As stated before, the depths of Serpent's mouth ranges 30-48 meters. All depths above thirty (30) meters will not be considered for power generation (see Figure 4).

2.2 The Dragon's Mouth

Current velocities within The Dragon's Mouth range from 2-2.5 knots (1-1.3 ms-1) from the Gulf of Paria outflow (NGIA, 2014).

Figure 3. Soldado Rock

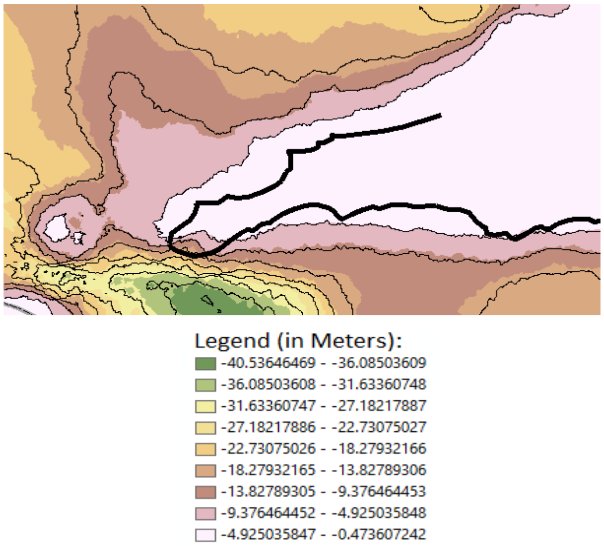


Figure 4. Bathymetric Chart - The Serpent's Mouth

Obstructions and landmasses:

The Bocas Islands lie between Trinidad and Venezuela, in The Dragons' Mouth. The islet masses are Chacachacare, Monos, Huevos and Gaspar Grande and Little Gasparee, all under the ownership of the Republic of Trinidad and Tobago (see Figure 5).

Bathymetry:

The depths of The Dragon's mouth range from 30-50 meters. Between the islands, the seafloor depths plunge from 50m to around 400m, as a result of the mountain building processes of the Northern Range, which caused downward buckling in the Bocas area. The area also suffers continued scouring from the outflow of the Gulf of Paria (Kenny, 2000). Figure 6 shows a Bathymetric Chart of The Dragon's Mouth.

Figure 5. Bocas Del Dragon Islands

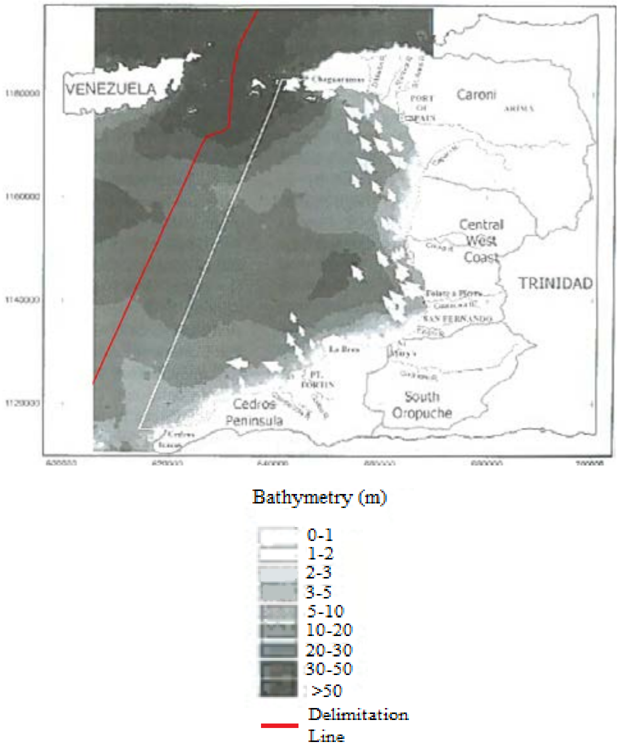


Figure 6. Bathymetric Chart - The Dragon’s Mouth

2.3 Site Selection

Considering the characteristics of both The Dragon’s Mouth and The Serpent’s Mouth locations as described above, The Serpent’s Mouth location was chosen for MRE generation. The Serpent’s Mouth location possess more desirable conditions, having a greater average flow velocity and less obstructions within the location, giving more operating area for the MCTs. Also, the Dragon’s Mouth area contains deeper scour holes within its vicinity, which challenge the construction of convention pile foundations.

3. Physical Setting

3.1 Prevailing currents

The location of Trinidad and Tobago on the continental shelf of South America and immediately adjacent to the outflow of the Orinoco River determines the nature and form of its coastal and marine environment (EMA 1996)., the outflow from the Orinoco River is a key determining factor in the proposed location, as it adds to current flows into the Gulf of Paria.

Adding to the current flow velocities passing through the Serpent’s Mouth is the, the South Equatorial Current, the main current around and into the region. The South Equatorial Current flows toward the west where it divides into two branches, but one continues to the Northern Hemisphere with the Guiana (Guyana) Current into the Caribbean. This northwest flowing branch flows into Columbus Channel, passing the Serpent’s Mouth into the Gulf of Paria (see Figure 1).

The multiple rivers are identified as the major contributors to current velocities pass the Serpent’s Mouth. They outflow along the northern continent of South America from the Orinoco River and the Guiana Current coming from the Atlantic through the Columbus Channel.

3.2 Tides

The tides around Trinidad and Tobago are semi-diurnal. High and low tides alternate every 12 hours varying around the coasts, with high tides peaking at 1.2 meters. The predominant wave direction along the shores of both Trinidad and Tobago is from the east, although seasonal variations occur under the effects of trade winds. The west coast of Trinidad facing into the Gulf of Paria is largely sheltered from swell-waves; however it can be exposed to significant swell during the wet season, when waves generated in the Atlantic pass through the Dragon’s Mouth (James, 1996).

3.3 Waves

Trinidad and Tobago is subject to wind driven waves, generally from the east, only changing with seasonal variations associated with changes in the trade winds.This wave regime is typical for this latitude. On the east coasts of both Trinidad and Tobago, sea conditions are turbulent at all times, and from January to May conditions become difficult along the north coast of Trinidad. The Gulf of Paria is sheltered with generally very low wave energy levels, which only experiences high swells during the winter storm activity in the Atlantic when some northerly swells make their way through the Dragon's Mouth. Also large swells are reported in the Gulf (EMA 1996).

3.4 Soil type

Within the Columbus channel and surrounding areas exists varied bottom types ranging from mud to mudstone (EMA 1996). The depth to bedrock or soil layer thickness is unknown as there is no data for this area.

3.5 Seasonality of Flow Velocities

The climate of the Orinoco basin is tropical, with the wet and dry seasons marked by differences in rainfall rather than in temperature,. This seasonality is determined by the annual north to south migrations of the inter-tropical convergence zone (ITCZ). This seasonality of rainfall determines the flow velocities coming from the Orinoco basin through the Columbus Channel (EMA, 1996).

4. Technical Feasibility

4.1 Assumptions and Approximations

Several assumptions and approximations were made. These include:

1) The useable area was idealised as a large rectangular open channel,
2) An average depth of 37 meters within the useable area was used for MCT rotor sizing,
3) The width of the rectangular channel is approximately 5.6 kilometers,
4) The length of the channel is approximately 20 kilometers, and
5) The flow velocity used was 1.25 m/s.

4.2 Turbine Array Placement

In order to assure maximum yield from the project, multiple MCTs were placed in an array to generate as much energy as space permits. The feasibility of ten (10) MCTs was tested and placed at 200 meters center to center spanwise over 2 kilometers within the designated area. The total turbine spacing makes provision for boat passing and fishing within approximately 3 kilometers of the channel. Figure 7 shows the turbine array within The Serpent's Mouth.

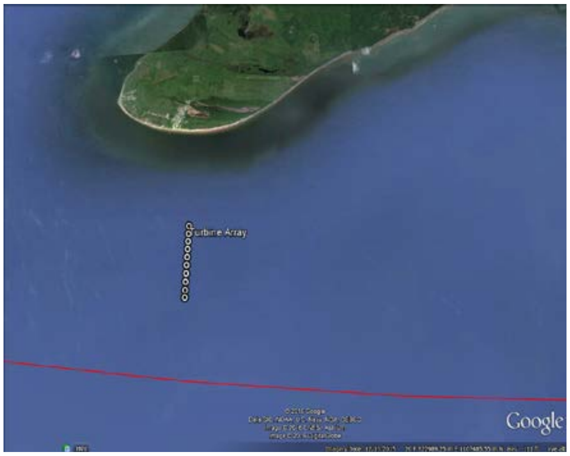


Figure 7. Turbine Array within The Serpent's Mouth

4.3 Rotor Sizing

Lower Boundary

Depth to the seabed is a direct factor to potential energy generation; therefore, the channel was idealised as an open channel to find the Critical Depth of the channel. To do so the Specific Energy versus Depth graph was plotted for the location. The Specific Energy of water is the total depth, or head, of the channel in relation to a specific location. The Critical Depth is the depth within the channel at which the Specific Energy is lowest. Figure 8 shows the allowable depth region

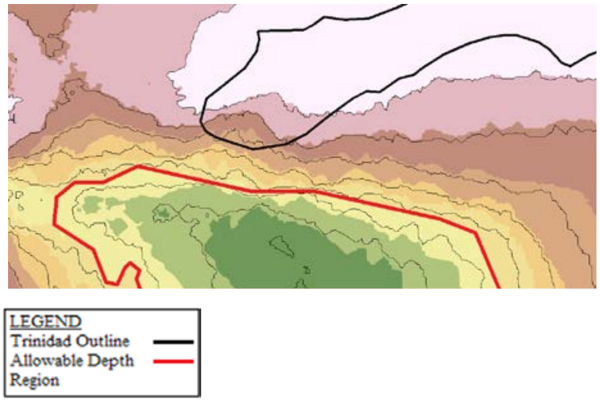


Figure 8. Allowable Depth Region

Under this depth lies the supercritical flow of the channel where the specific energy increases exponentially as it tends to the seafloor. Although supercritical flow increases exponentially when approaching zero (0) depth, the presence of sedimentation and scour, along with the boundary layers experienced on the ocean floor, cause uncertainty in yield and potential risk of the turbine. Therefore, the critical depth was found to use the subcritical flow for energy generation over that point. Figure 9 is a graph showing specific energy versus depth.

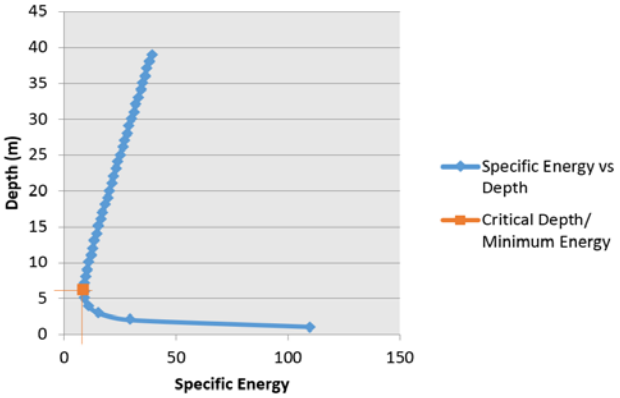


Figure 9. Specific energy versus depth

Upper Boundary

Also considered was the possibility of damage due to wave forces. As a preventative measure, the wave base where wind wave energy will dissipate at was calculated as clearance.

Having these two limiting factors along with optimum power generation, depths of at least thirty (30) meters must be used to have an adequate rotor diameter.

Critical Depth

$$h_c = ({q^2}/{g})^{1/3}$$
$$h_c = ({46.25^2}/{9.81})^{1/3}$$
$$h_c = 6.02 \text{ meters}$$

where,
q = Flow Rate
g = Acceleration due to Gravity

4.4 Wave Clearance

Deep Water Approximation:

$$d = {gT^2}/{2\pi}$$

Wave number: $k_o = {2\pi}/{d}$
Celerity: $\sqrt{y\ x\ (gxh)}$ = 2.62
Wavelength: $\lambda = C_oT$ = 9.64 m
Wave base = $\lambda/2$ = 4.82 m
Therefore, the Rotor Blade will be 25 m.

4.5 Turbine Power Output

The hydrokinetic turbine is like taking a wind turbine, turning it upside down and sticking it into the water. (Fraenkel, 2013). The design of the turbine is a double rotor horizontal axis hydrokinetic marine current turbine. Horizontal axis hydrokinetic turbines are one amongst the various machines which can be used to extract the kinetic energy of water streams. They are meant to be placed in water streams of rivers or oceans and generate electricity in the order of 15 to 1,000 kW without making significant changes to the environment. The key factor in the design of the turbine is the density of the water. This would potentially cause the marine current turbine to provide a greater power output than that of its renewable counterpart. Figure 6 shows a Marine Current Turbine.

Power Output

The power relations for tidal current resources are similar to those used in wind applications. The power, P, available in a tidal current, is given by:

$$P = \frac{1}{2}\sigma A V^3$$

where, P = power output
σ = density of seawater
A = Rotor swept area
V = current velocity

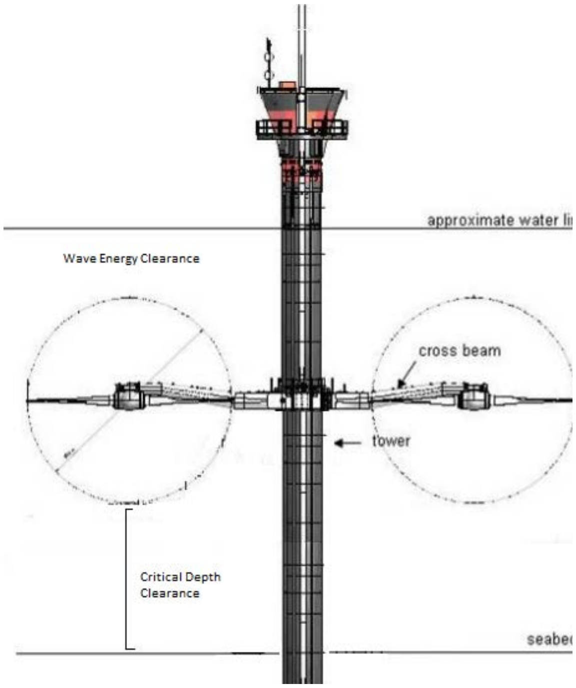


Figure 6. Marine Current Turbine

However, the actual power that an MCT can capture is:

$$P = \frac{1}{2}\sigma A V^3 \vartheta$$

Where, ϑ = Betz's Limit

Therefore, using a rotor diameter of 25 meters

$$P = \frac{1}{2}(1029)(1.25^3)(\frac{\pi 25^2}{4})\ (0.6)$$
P = 295.96 Kilowatts per Rotor

Since the design is a double rotor turbine, the total power output of the turbine is:
Total power = 295.96 kilowatts x 2 rotors
Total power = 591.92 kilowatts per MCT

Turbine Array Power Output

Total Power Output = 10 turbines x 591.92 kilowatts
Total Power Output = 5.919 Megawatts ~ 6 Megawatts

Scour

The passing of the Guiana Current/Orinoco River discharge through the Columbus Channel has a powerful erosional effect. Therefore, a scour depth analysis is required to ensure the design of the MCT structure (Julien, 2002). This is determined by:

$$\frac{\Delta z}{h} = 2.0\,\mathrm{K1K2}\left(\frac{a}{h}\right)^{0.65} Fr^{0.43}$$

Where,
Δz = Scour depth
a = Monopile Diameter
h = Upstream Water Depth
K1 = Correction for Shape (see Table 1)
K2 = Correction for Flow Angle (see Table 2)
Fr = Upstream Froude Number

$$\therefore \frac{\Delta z}{37} = 2.0\,(1)(1)\left(\frac{3.5}{37}\right)^{0.65}\left(\frac{1.25}{\sqrt{(9.81 \times 37)}}\right)^{0.43}$$

$$\therefore \textbf{Scour Depth}\,, \boldsymbol{\Delta z = 4.92 \sim 5\ meters}$$

Table 1. Correction for Shape

Pier Type	K1
Square nose	1.1
Round Nose	1
Circular cylinder	1
Sharp nose	0.9
Groups of Cylinders	1

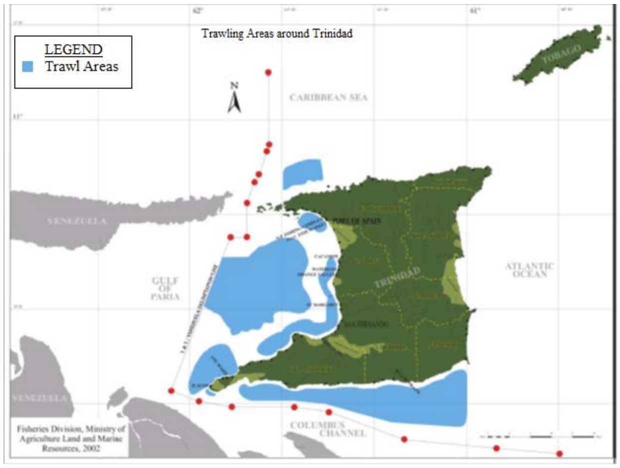
Table 2. Correction for Flow Angle

Attack	Correction Factor, K2		
Angle θp	Lp/a=4	Lp/a=8	Lp/a=12
0	1	1	1
15	1.5	2	2.5
30	2	2.5	3.5
45	2.3	3.3	4.3
90	2.5	3.9	5

5. Environmental Feasibility

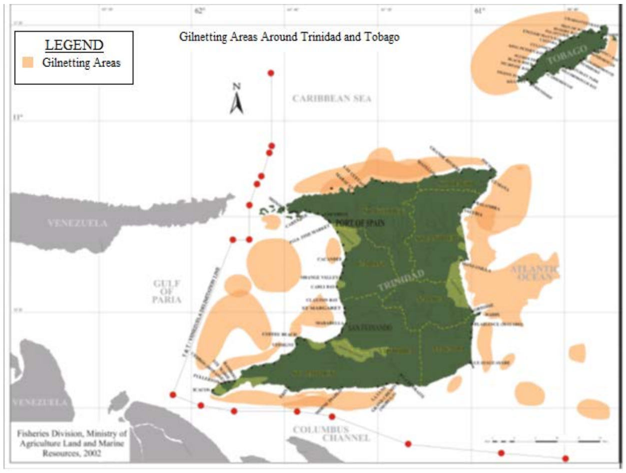
5.1 Environmental Impact Assessment

Marine life is expected to be impacted, as foreign objects were placed within their ecosystem. The more prominent activities, being fishing and shipping, are also expected to be adversely impacted. Within the Serpent's Mouth area, Gillnetting and Trawling are most common (see Figures 7 and 8) (Mangal, 2008). As such, fishing and boating operations will need to be restricted to a 3 kilometer area within the Serpent's Mouth to make provisions for the active MCTs.



Fisheries Division, Ministry of Agriculture Land and Marine Resources, 2002

Figure 7. Trawling areas around Trinidad



Fisheries Division, Ministry of Agriculture Land and Marine Resources, 2002

Figure 8. Gillnetting areas around Trinidad and Tobago

Fishing depends on marine life. As the marine life thrives, fishing will thrive. The two options for marine life protection are Fish Caging (Aquaculture) and Turbine Screening. Table 3 shows a summary of the Environmental Impact Analysis, whereas Table 4 shows a selection criteria matrix

The limited available information about the effects of acoustics on marine animals from marine energy devices suggests that animals are unlikely to be killed or seriously injured by the operational or pin-piled installations sounds generated by the turbines (PNNL, 2013).

5.2 Turbine Screen Considerations

The boundary layers around the netting material will minutely reduce flow velocities because of space sizing requirements, ensuring that the smallest of commercial fish cannot pass through the screen. Furthermore, it must protect both the front and back of the turbine because of current direction changes. The reduced flow velocity from the netting along with the wake velocities can further reduce the flow rate experienced by the turbine, ultimately reducing power generation by the array. The screen must not be flat, as ocean currents can pin fish unto the screen, and there is the likelihood of marine animals being trapped within the netting material.

5.3 Aquaculture Considerations

Fish farms using cages, in which the fish live and breed, ensure that the population of the fish is maintained because they are in no harm of turbine passage. Breeding standards can be imposed to increase the quality of fish for trading. It also increases the probability of the catch to 100%. Farms can be set up inland or offshore, or both to supply a higher demand. This is a control measure to help maintain the

Table 3. Environmental Impact Analysis

Hazard	**Impact**	**Mitigation**
Greenhouse Gas Emissions	Without the emission of pollutants and greenhouse gases into the atmosphere, MRE does not contribute to climate change or acid rain. Thus, it is considered environmentally sustainable.	None Needed.
Death/Injury by MCT interaction	Marine mammals and fish can suffer from mechanical strike when passing the turbine. Smaller fish can suffer from shear and pressure cavitation severely injuring or killing them.	Adoption of Aquaculture or turbine screens.
Marine Pollution	Some lubricants, paints and coating applied to the MCTs can be extremely toxic to the surrounding ecosystem.	Lubricants and Paints would need to be carefully selected with the implications of their use fully considered.
Disruption of Fishing and Shipping activities	The presence of operating MCTs will interrupt fishing activities and shipping activities if there is not sufficient clearance between the MCT rotor tip and the water surface.	Restricted fishing and shipping area within Marked turbine operation area.
Seabed Deformation	The flow around the base of the MCT will cause scour, changing the seabed surface.	Riprap will be place around the monopile base.
Change in Flow patterns	The presence of obstructions within flow path will cause a change in flow patterns and flow rates throughout the channel.	-
Operation Acoustics	The sound from the operating MCTs may mask marine animals' hearing and thus their ability to engage in social interaction, locate prey, avoid predators, and navigate hazards.	-

Table 4. Selection Criteria Matrix

Aquaclture Measure							**Turbine Screen Measure**						
Fatal Risks													
		Rating			Residual Rating				Rating			Residual Rating	
Hazard	Population at Risk	Typical Impact	Probability	Control Measures	Typical Impact	Probability	Hazard	Population at Risk	Typical Impact	Probability	Control Measures	Typical Impact	Probability
Mechanical Strike	All Marine Life	5	3	Fish Caging	5	3	Mechanical Strike	All Marine Life	5	3	Turbine Screens	5	1
Shear	Smaller Marine Life	5	3	Fish Caging	5	3	Shear	Smaller Marine Life	5	3	Turbine Screens	5	1
Cavitation/ Pressure	Smaller Marine Life	5	3	Fish Caging	5	3	Cavitation/ Pressure	Smaller Marine Life	5	3	Turbine Screens	5	1
Fisheries Industry													
Catch	Fisheries	5	3	Fish Caging	5	5	Catch	Fisheries	5	3	Turbine Screens	5	3
Turbine Interaction													
Turbine Efficiency	Power Generation	5	5	Fish Caging	5	5	Turbine Efficiency	Power Generation	5	5	Turbine Screens	5	3

fisheries industry, but outside of the cage, where the wildlife still exists around the MCTs, there is no protection. Thus, aquaculture is fit for economic sustainability, not the protection of the marine wildlife.

Marine life activity in the presence of MCTs

From the SeaGen project at Strandford Lough, they have reported that no major impacts were encountered with marine life. The resident seal and porpoises swim freely in and out of the Lough while the turbine was operating. Also, post mortem evaluation of marine mammals did not reveal any evidence of fatal strike by the SeaGen device. From observations at the Europeans Marine Energy Center, no marine mammals have been observed interacting with the turbines, but seals and porpoises were observed transiting through the region around the turbine. No fish have been observed swimming through the turbine while the turbine is rotating.

Verdant Power in New York also produced results showing resident and migratory fish avoided their turbines, preferring the stay closer inshore in slower waters (PNNL, 2013). Other than the SeaGen turbine, which has a manually operated shutdown function when marine mammals enter 30 m of the turbine. No others have any protective measure to accommodate the marine life, but have all reported little to no marine life interaction with the MCTs.

In light of this, the Aquaculture measure was chosen as the control measure to maintain maximum turbine efficiency and safeguard to the fisheries industry.

Bio-fouling

Most of the tidal energy structures to be submerged in saltwater are expected to experience bio-fouling. The main problem as it relates to MCTs is the drag forces induced upon the rotor blades as a result of the increased weight. The blades rotate slower, reducing power generation, because of its increased weight. To protect the MCT against fouling, antifouling coatings are used. The turbines need regular maintenance is needed (Delauney, 2010).

As expected, any coating will have an impact on the surrounding environs. Since this a problem with antifouling technologies, some contain copper or tributyltin (TBT) which have undesired effects on marine organisms. More environmentally friendly antifouling paints are to be explored to reduce environmental impacts.

6. Economic Feasibility

6.1 Considerations and Assumptions

Several considerations and assumptions were made. These include:

1) All power generated was sold to the Electrical power grid.
2) Annual energy consumption was estimated at 7.59 billion kWh (2014) (IndexMundi 2015).
3) Residential power usage is 27% of total energy consumption (Newsday 2007).
4) The residential population was used as 342200 homes (Newsday 2007).
5) MCT capital cost increases linearly with increase rotor diameter.
6) The exchange rate between TTD and the USD is used as $1.00 to $6.49.
7) The service life of MCT was taken as 20 years.

Array Viability

Producing an average 6MWh, the array generates 4261858.82 kWh monthly. Per month, the average residence consumes 500 kWh; this allows the MCT array to generate power for 8523 residential homes monthly. Table 5 shows the MCT viability.

Table 5. Turbine Viability

Energy Supply	kWh	Turbine Supply	kWh
Annual Consumption	7590000000	Array power output (kW)	5919.25
Residential Consumption	2049300000	Array Energy production	5919.25
Residential (1 hr)	0.68	Monthly Production	4261858.82
Monthly Consumption	492.213958	Average Residential Consumption	500
Number of homes supplied by MCT Array			8523.717646

MCT Costing

The capital costing for the MCTs were estimated as a linear increase from the capital costs of the 16m rotor SeaGen turbine and the 18m Pilot turbine located within the Bay of Fundy. With the capital cost for the 16m turbine being $5.15 million USD and the 18m turbine being $5.81 million USD gives the difference of $662720 USD. Linearly, this would give $331360 per 1m rotor diameter, giving our 25m MCT a capital cost of $ 8.1 million USD.

Array Costing

Mass production and installation have reduced the capital costs for arrays per kWh. Using $4598/kWh USD, the capital cost for the 10 MCT array is estimated $47 million USD.

Annual Life Cycle Unit Cost

At a rate of $0.19 USD/kWh, the life cycle cost of the array approximates to $10 million USD.

6.2 Economic Feasibility and Considerations

For viability to be achieved, power generated would have to be sold at a rate of $0.30 USD/kWh. Table 6 shows a summary of benefits (revenue) and costs (expenditures), and Table 7.shows the computation of Net Present Value, of the project.

Table 6. Benefits (Revenue) and Costs (Expenditures)

Benefit	
Rate ($)	$ 0.30
Array kWh	5919.25
Annual kWh	51852615.68
Annual Revenue (USD)	$ 15,555,784.70
Cost	
Capital	$ 47,032,095.63
Annual Life Cycle Unit Cost	$ 9,989,510.65
Service Life (yrs)	20
Total Expenditure	$ 246,822,308.72

With the project becoming feasible at the rate of $0.30 USD/kWh, this is quite costly. However, increased awareness about climate change may prove a fillip to investment in renewable energy. Small Island Developing States are particularly vulnerable to sea level rise and ecological changes. Therefore, exploitation of our renewable energy potential is critical for the preservation of our fragile ecosystems.

6.3 Economic and data Shortcomings

It should be stressed that the soil layer depths and the depth of bedrock are unknown. This information is needed to determine construction methods and actual construction costs. Depth to bedrock and seafloor characteristics can influence the type of foundation —

Table 7. Calculations of Net Present Value

Year	Cash flow	Present value	Payback	Discount Rate
0	$ -47,032,095.63	$ -47,032,095.63	$ -47,032,095.63	8%
1	$ 5,566,274.05	$ 5,153,957.45	$ -41,878,138.18	
2	$ 5,566,274.05	$ 4,772,182.83	$ -37,105,955.35	
3	$ 5,566,274.05	$ 4,418,687.80	$ -32,687,267.55	
4	$ 5,566,274.05	$ 4,091,377.60	$ -28,595,889.95	
5	$ 5,566,274.05	$ 3,788,312.59	$ -24,807,577.37	
6	$ 5,566,274.05	$ 3,507,696.84	$ -21,299,880.53	
7	$ 5,566,274.05	$ 3,247,867.45	$ -18,052,013.08	
8	$ 5,566,274.05	$ 3,007,284.67	$ -15,044,728.41	
9	$ 5,566,274.05	$ 2,784,522.84	$ -12,260,205.56	
10	$ 5,566,274.05	$ 2,578,261.89	$ -9,681,943.67	
11	$ 5,566,274.05	$ 2,387,279.53	$ -7,294,664.14	
12	$ 5,566,274.05	$ 2,210,444.01	$ -5,084,220.13	
13	$ 5,566,274.05	$ 2,046,707.42	$ -3,037,512.72	
14	$ 5,566,274.05	$ 1,895,099.46	$ -1,142,413.26	
15	$ 5,566,274.05	$ 1,754,721.72	$ 612,308.47	
16	$ 5,566,274.05	$ 1,624,742.33		
17	$ 5,566,274.05	$ 1,504,391.05		
18	$ 5,566,274.05	$ 1,392,954.68		
19	$ 5,566,274.05	$ 1,289,772.85		
20	$ 5,566,274.05	$ 1,194,234.12		
Net Present Value				$ 7,618,403.50
Internal Rate of Return				10%
Benefit/Cost Ratio				1.161983075
Payback Period				15 years

whether skin friction piles or end-bearing piles can be used. These varying types of foundation can have different costs, with friction piles being controlled by the length of pile, and end-bearing; depending on the type of foundation, whether tripod, gravity or monopole with guy wires.

The monetary funding would go toward foundation and stability operations of the MCTs. In this instance, judicial scaling was deployed by using the Unit Life Cycle cost for the pre-existing SeaGen MCT and linearly scaling it up to our MCT rotor diameter as a means of conpensation. As foundation costs are expected to be included within the Unit Life Cycle cost, this was used as the approximate cost of our MCT. With the nature of this pricing, it is understood that the varying seafloor characteristics between The Serpent's Mouth and Strangford Lough can serve to decrease the creditability of the approximated figure. This raises an unknown factor, which can substantiall impact costing. With the Cost-Benefit Ratio being 1.16; with the project only becoming acceptable at a Cost-Benefit ratio of 1, this would be too low to be considered a cushion range for the unknown cost associated with the foundation and stability issues.

Therefore, with the lack of data aforementioned, the economic path for MRE generation within The Serpent's Mouth is still unclear.

7. Conclusions

Regarding technical feasibility, MCTs can be sized up to 25 meters in rotor diameter. As the physical characteristics of the site location permits, it is possible to generate on average, 6 MW of power, peaking at 10 MW (Flow velocity of 1.5 m/s) of power from the MCT array. Each MCT will experience a scour depth of approximately 5 meters around their monopoles. Given the physical limitations of the site, it is technically feasible to place MCTs within the Serpent's Mouth.

Regarding environmental feasibility, the installation of the MCT array would have minimal environmental impacts, with compensative measures being deployed for the most common impacts of the MCTs. Therefore, the MCT array is deemed environmentally feasible.

For economic feasibility, considering the capital cost for the MCT array, the operations and maintenance costs and revenue generated at $0.30 USD/kWh, the project produces a Net Present Value of $7,618,403.50 and a Benefit-Cost ratio of 1.16, deeming this project, economically acceptable, but not feasible. With the limitations of site specific knowledge, unknown costing factors will be too large for a Cost-Benefit Ratio of 1.16 to be able to provide adequate room for uncertainty because of the unknown quantity of money.

Overall, the Marine Current Power Generation project within Trinidad can be seen as feasible, but only over time, where technological advancements are made within the field to increase the efficiency of MCTs, causes a higher optimum power generation to yield the maximum benefits of the Marine Renewable energy technology.

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