Technical-economic assessment for the construction of tidal stream turbines in Valle del Cauca, Colombia

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I. Introduction

MITIGATE the production of CO2 is one of the worldwide goals, because these greenhouse gas emissions (GHG) contribute to the climate change. To reduce the environmental impacts of GHG, several projects of technological development of the Renewables have been performed. Colombia is a country committed with the energy transition, and thanks to its geography has the chance for accessing to different renewable energy sources [1]. According to Quintero and Rueda-Bayona [2] Colombia has tidal energy in the central Pacific. They calculated the energy potentials of tidal currents in the central zone of the Colombian Pacific coast through hydrodynamic modeling (Delft3D), validated with in situ data, and found that in Bahía Málaga and Buenaventura exist potential for implementing tidal turbines.

To harness marine energy there are different devices, which have been designed to generate electricity for commercial use, therefore, the cost of energy is an important criterion [3]. Magagna et al. [4] conducted a critical review of ocean energy development in Europe, and described the political context of the European Union (EU) and pointed several challenges to overcome for implementing ocean energy technologies. The study concluded that marine energy development is hampered by technological development, finance and markets, environmental and administrative issues, and grid availability. Therefore, in order to carry out a project to implement technology that allows the use of tidal energy, it is necessary to make a technical and economic evaluation.

The development of tidal technologies has progressed significantly in recent years, where different companies are testing prototypes and monitoring demonstration arrays [5]. The planning of new investments for new energy projects, the LCOE (Levelized Cost of Electricity) is a useful parameter, which provides an estimate of the cost of electricity over a period of time and reflects the capital cost, operating cost, dismantling cost and expected annual energy production (AEP) [5].

To achieve a technical-economic evaluation it is necessary to take into account many aspects, e.g., Santolin et al. [6] presented a method to size the capacity of a small hydroelectric power plant based on technical-economic analysis, considering the type of turbine, machine dimensions, annual energy production, maximum installation height to avoid the onset of cavitation, machine cost, net present value (NPV) and internal rate of return (IRR), allowing to choose the appropriate design of operational conditions, what enhance the profitability and viability of the plant. Jeroen et al [7] showed a techno-economic optimization method for small wind turbines, and developed a turbine cost model by collecting price data from wind turbine manufacturers. The results of the optimization process confirm that the economic performance increases considerably by significantly increasing the ratio between the rotor size and the power of the powertrain. Giacomo et al. [8] performed an evaluation of the LCOE for a self-balancing tidal kinetic turbine (SintEnergy), which showed a low CAPEX (Capital Expenditure) and high LCOE because it is in the development stage. Barbarelli et al [9] carried out the techno-economic evaluation of a self-balancing tidal kinetic turbine array configuration. First, he defined technical and performance evaluation of the array, constituted by several connected turbines, then, by means of an economic model he detected the optimal number and diameter of the turbines, finally he applied the methodology in Messina Strait - Italy, where he evaluated the annual energy yield and the levelized cost of energy, showing that an array of 5 turbines of 5 m diameter can ensure the lowest LCOE among the evaluated configurations. Rodrigues et al [10] performed a cost-benefit analysis based on a hydromorphodynamic model applied to a tidal energy project using an Evopod prototype in the Ria Formosa, Algarve (Portugal). The results showed that with the current costs and benefits, the project is not economically viable. However, there are ranges of admissible parameters that make the project viable, such as a significant reduction in investment costs, the increment of the capacity factors and favourable energy prices.

Considering the literature review, two types of turbines were identified with technical characteristics to operate properly in marine waters of the Colombian Pacific, with technical-economic information which is uncommon to find in the open literature. To this end, this paper evaluated the two current turbines mentioned above to identify potentialities for their implementation in Colombia. The evaluation used technical-economic parameters such as LCOE for the two turbine models, also including factors such as site-depth, flow velocity and water properties.

II. Methods

The evaluation was carried out in the Aguadulce creek located in Buenaventura, the velocities were taken from a point evaluated by Rueda-Bayona et al. [12], and are presented in Figure 1.

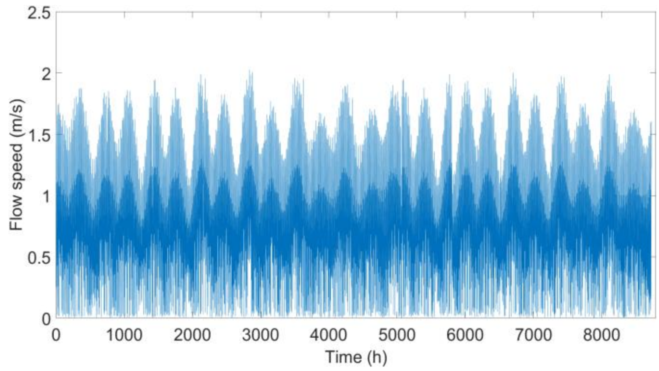

Fig. 1. Depth modeled average annual current velocity during 2021 in Buenaventura Bay.

These velocities were used to calculate the available turbine power (P), as follows:

$$P = \frac{1}{2}\rho U^3 ACp \tag{1}$$

Where, ρ is the density (1003.8 Kg/m^3), A is the swept area of the turbine, U is the flow velocity and Cp is the power coefficient.

Since ocean energy technologies are still in relatively early stages of the life cycle, their LCOEs are uncertain and difficult to estimate accurately. Currently, the LCOE for tidal energy is estimated from 0.20 USD/kWh to 0.45 USD/kWh, and is expected to reach 0.11 USD/kWh by 2030 [11].

LCOE is estimated as follows:

$$LCOE = \frac{TIC \times FCR + OPEX}{AEP} \tag{2}$$

Where, TIC is the total installed cost, FCR is the fixed charge rate and OPEX is the operating expenditures.

Due to the site conditions, the turbines must have a maximum diameter of 5 m. Then, two types of technologies were analysed: Evopod with a diameter of 4.5 m and Cp of 0.4 [13], and SintEnergy with Cp of 0.4 and diameters of 3 m, 4 m and 5 m [8, 9].

The investment costs (IC) for the Evopod turbine are seen in table I and were taken from [13]. The SintEnergy results are in table II, taken from [9].

TABLE I
INVESTMENT COSTS FOR THE EVOPOD TURBINE. TAKEN FROM [13]

IC Description	USD/Turbine
Turbine (floating structure)	65570.04
Moorings	34285.95
Controls/instrumentation	2223.60
Power take-off	56217.84
Power connection	54838.99
Structure installation	39567.00
Mooring installation	18393.75
Grid connection installation	25931.10
Commissioning	5663.64
Project, planning, legal and financial management	17395.31
Contingency	16004.47
Construction insurance	8001.69
Total (USD/Turbine)	**344093.38**

TABLE II
INVESTMENT COSTS FOR THE SINTENERGY TURBINE. TAKEN FROM [9]

	Diameter (m)		
IC Description	3	4	5
Generator and converter, cable	91974.20	114962.30	143705.60
Blades, body, rotor	79286.60	91178.50	104858.00
Mooring	39240.00	62784.00	100454.40
Installation	16840.50	21516.60	27925.80
Design and project management	11172.50	13450.60	15706.90
Site improvement and other issues (network, etc.)	21047.90	26890.30	34901.80
Total (USD/Turbine)	**259561.70**	**330782.30**	**427552.50**

The operating expenses, planned maintenance expenses and mechanical component insurance were taken into account. Operating expenses were estimated as 2.5% of the control and instrumentation related expenses, and component insurance was estimated as 2% of the component expenses [13].

III. RESULTS

The annual energy generated is shown in Figure 2.

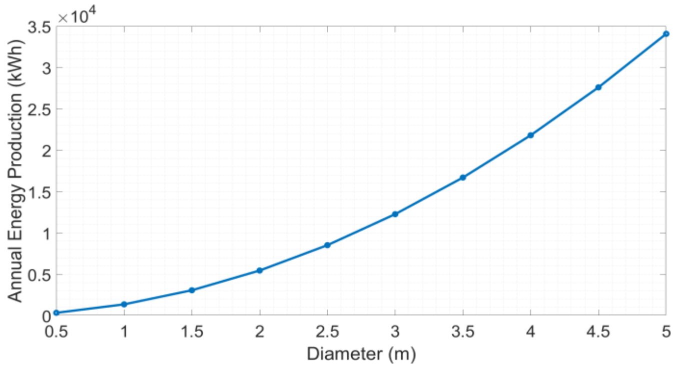

Fig. 2. Annual power generated as a function of turbine diameter.

Operating costs (OC) were estimated for the evaluated turbines and are presented in table III for Evopod and table IV for SintEnergy.

TABLE III

ESTIMATED OPERATING COSTS EVOPOD TURBINE.

CO Description	USD/Turbine
Planned maintenance	1461.04
Mechanical components insurance	4262.73
Total (USD/Turbine)	**5723.77**

TABLE IV

ESTIMATED OPERATING COSTS SINTENERGY TURBINE.

	Diameter (m)		
CO Description	3	4	5
Planned maintenance	3280.40	4443.70	6104.00
Mechanical components insurance	4631.00	5916.30	7678.40
Total (USD/Turbine)	**7911.40**	**10359.90**	**13782.40**

Assuming FCR of 9.5% [14], the LCOE values shown in table V are obtained.

TABLE V

ESTIMATED LCOE FOR THE EVALUATED TURBINES.

Turbine	Evopod	SintEnergy		
Diameter	4.5 m	3 m	4 m	5 m
LCOE (USD/KWh)	**1.39**	**2.65**	**1.92**	**1.60**

IV. DISCUSSION & CONCLUSION

The increase in turbine diameter leads to higher costs and also increases the annual energy production, but although there is an increase in costs, when evaluating the LCOE, we observe that this value decreases.

The Evopod turbine has the lowest LCOE (1.39 USD/KWh), this is because this technology is more mature, since it is in the pre-commercial stage, while the SintEnergy is still in the development stage.

The LCOE is high compared to the commercial range currently in the market (0.20 USD/kWh - 0.45 USD/kWh), so it is necessary to reduce these costs through more research and new public policies that encourage technological development and reduce investment risks.

The aspects to be improved in the technological development of turbines are the reduction of manufacturing costs, which are high due to the low availability of construction materials such as glass and carbon fibers. In addition, these two materials generate significant environmental impacts, which limits the development of these technologies. Thus, an alternative to reduce the mentioned costs is through the use of more environmentally friendly materials of natural origin, i.e., polymers reinforced with natural fibers [15]. For the above, it is necessary that local industry of Buenaventura, Valle del Cauca department and academia work together to reduce the technological limitations and achieve a reduction in the production costs of the technology.

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