PREFEASIBILITY DESIGN OF A TIDAL BARRAGE POWER PLANT IN TUMACO, COLOMBIA

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I. Introduction

THE growing global concern for non-conventional and renewable energy sources is based on several factors that justify their multiple benefits and advantages over conventional energy sources. One of the main factors is its important contribution to the reduction of greenhouse gases, helping to counteract climate change and its negative impacts on the environment. (Cerdá et al., 2012). The motivation towards renewables is also driven by the need to eliminate energy dependence on conventional sources and thus promote energy security in the future. Countries dependent on fossil fuel imports are linked to steadily rising international prices and supply disruptions. In this sense, renewable sources are an option for these importing countries to diversify their energy matrix and reduce their vulnerability to changes in the global energy market. (Fraga-López & Martínez, 2007)

Colombia's maritime areas represent 45% of the territory and its coasts have an approximate length of 3,100 km (1,300 km in the Pacific Ocean). Avella Andrés Osorio Elizabeth Parra et al., n.d.), where there are potentials to exploit marine energies such as tidal energy. This energy can be generated using sea level height differences, implementing gates and turbines in a reservoir (see Fig. 1), or by installing a series of horizontal axis reversible microturbines to take advantage of tidal currents. The city of Tumaco located in the Colombian Pacific, has the possibility of developing this type of technology (reservoir type), even with local tidal heights with a range of less than 4 m, as companies such as EMEC Marine Energy have in recent years developed turbines that allow operating under these conditions with current speeds of less than 2 m/s. To this end, this research implemented a hydrodynamic model to estimate the tidal energy potential that could be produced through a reservoir-type plant.

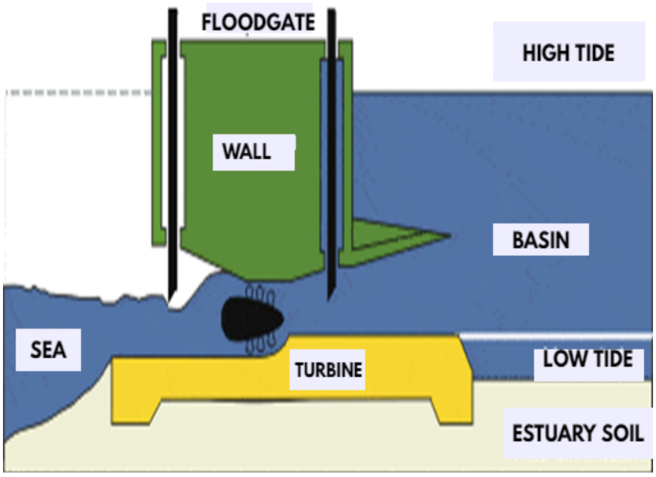

Fig. 1. Reservoir type system. Source: AREATECNOLOGIA.COM

As for the information required to create the hydrodynamic model, a sweep of information was conducted in local and international databases, among them Dimar, NOOA, which are characterized by being open source. Also, through the Unified Information System (SUI), administered by the Superintendence of Domestic Public Services of Colombia, it was possible to estimate the demand for electricity in the urban area of the Municipality of Tumaco-Colombia. To develop a technical-economic model that allows us to know what the value of the levelized cost of energy (LCOE) is and thus decide the viability of the project.(DIMAR, 2022)(NOOA, 2022)

II. Methods

The methodology implemented in this work is organized as follows: 1- estimation of local electricity demand, 2- technical-economic evaluation (CAPEX, OPEX, LCOE, internal rate of return), 3- characterization of the resource through hydrodynamic modeling (Delft3D model), 4- environmental assessment, social and economic recommendations. (See Fig.2.)

Estimation of local electricity demand, this stage consists of estimating the electricity demand at the residential level of the area in which the tidal plant will be located. To this end, a sweep of historical data was conducted on the web portal of the Unified Information System (SUI), administered by the Superintendence of Domestic Public Services of Colombia, considering parameters such as service provider company and consumption value, among others (see table I).

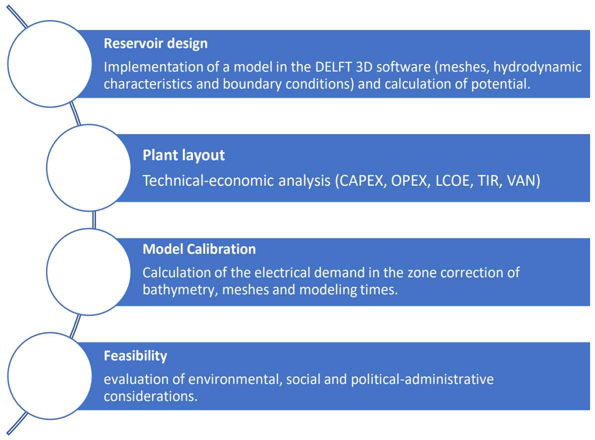

Fig. 2. Proposed methodology. Own source.

By analyzing historical data on energy consumption, it will be possible to identify patterns or particularities in the energy consumption of the region and thus be able to determine the nominal power of the plant.

Technical-economic evaluation, the feasibility of a power plant project encompasses a thorough analysis of the costs associated with the construction, operation, and maintenance of such a plant. A key parameter used in this assessment is the levelized cost of energy (LCOE), which provides an average measure of the cost of generating electricity over the life of the plant.

To calculate the LCOE for a specific tidal power plant, several factors must be considered. First, the cost of construction (CAPEX) is an important aspect since it includes the expenses associated with the installation of the structures necessary to capture the energy of the tides as well as the infrastructure required for their operation.

In addition, the cost of maintenance and operation (OPEX) is critical in determining the LCOE. This involves the expenses needed to keep the plant running optimally over time, including monitoring equipment, performing repairs, and staffing needed to perform these tasks.

The service life of the plant is another essential factor in the calculation of the LCOE. It refers to the estimated period during which the tidal power plant is expected to operate efficiently and profitably. Lifetime has a direct impact on the distribution of total project costs over time.

TABLE I
CHARACTERIZATION OF ENERGY CONSUMPTION IN TUMACO. SOURCE: SUI

Department:	NARIÑO-COLOMBIA
Municipality:	SAN ANDRÉS DE TUMACO
Year:	2022
Zone:	Urban
Provider company:	CEDENAR S.A.
User type:	Residential
Stratum:	(1-2-3-4-5-6)
Year-end subscribers:	Annual subscribers
Consumption year:	KW-h consumed per year
Consummation value:	Total invoiced value (Pesos)
Average bill:	Average bill per subscriber (Pesos)
Average consumption:	(kW-h/User)
Average rate:	($/kW-h)

The generating capacity of the plant is also considered in the economic evaluation. Generating capacity refers to the amount of electricity the plant can produce in each period.

The higher the generation capacity, the higher the electricity production, which is therefore a crucial factor in determining the average cost of generation.

Here is a basic formula for calculating the LCOE of a tidal plant (Lillo et al., 2019).

$$LCOE = \frac{Cf}{MWh * (1+r)^{T}} \tag{1}$$

Where:
Cf: Total tidal plant cost, including initial investment (IC) and operation and maintenance (O&M) costs.
Ic: Initial investment, which includes the cost of building the plant.
O&M: Operation and maintenance costs during the life of the plant.
MWh: Annual electricity generation in gigawatt-hours.
r: Discount rate, which reflects the opportunity cost of invested capital.
T: Plant shelf life in years.
As for the efficiency coefficient of tidal turbines, it shows that only a maximum of 59.3% of the total kinetic energy available in the flow can be extracted. In addition, hydrodynamic, mechanical, and electrical processes further reduce total energy production. Therefore, in practice, most real turbines exhibit efficiencies below the Betz limit, with values ranging from 0.4 to 0.5 for modern axial flow turbines. (Khare et al., 2019)

On the other hand, in Colombia, it is possible to implement a tidal plant type reservoir since there are laws such as "1715 of 2014" that encourage the implementation of electricity generation through unconventional sources, because they promote incentives to income, accounting, rates, and VAT, generating that effect the value of the LCOE decreases and can compete with the values of the levelized cost of energy of conventional sources of electricity generation (hydroelectric, solar, wind, among others).

Resource characterization through hydrodynamic modelling, at this stage, it is important to characterize the tidal resources at the site. For this, a hydrodynamic model was used in the DELFT 3D software, which is composed of a hydrodynamic module (Flow) and a wave module (Wave). The "Flow" module solves the Navier-Stokes equations and using a flexible mesh, uses a finite difference scheme using the RANS (Reynolds Averaged Navier Stokes) method. (Home - Delft3D - Os. Deltares.Nl, n.d.)

This model seeks to respond to the level of technical prefeasibility of implementing a tidal plant, analyzing.

Physical processes such as water flow, sediment transport, water quality, and coastal morphology. Thanks to the fact that it discretizes the system in a mesh of cells, in this study it was every 20 meters horizontally and vertically, and then used mathematical equations to calculate the flow of water, speeds, depths, and salinity levels in the waters near Tumaco Bay. (See Fig. 3)

On the other hand, studies on tidal energy in Colombia present the energy potential of the country's Pacific coast. The study indicates that the Buenaventura Bay Area has a high potential for tidal power generation with the implementation of a model to simulate hydrodynamics and analyze the response of currents during high and low tide events. (Rueda-Bayona et al., 2023)

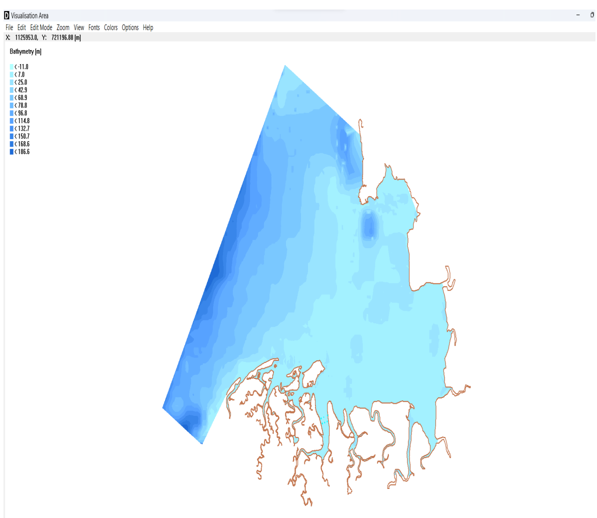

Fig.1. Study area. Source: Own

III. Results

The results of this study demonstrate that the similarity in terms of tidal regime at the Lake Sihwa power plant in South Korea is similar (semi-diurnal, mesotidal) to the tidal regime at Tumaco, increasing the level of prefeasibility of implementing this type of tidal dam plant in Colombia. (South Korea's largest tidal power plant - Morís Arroes, n.d.)

The projection of the total accumulated electricity demand until 2070 is 63,070,265 kilowatt-hours (kWh), distributed in four socioeconomic strata.

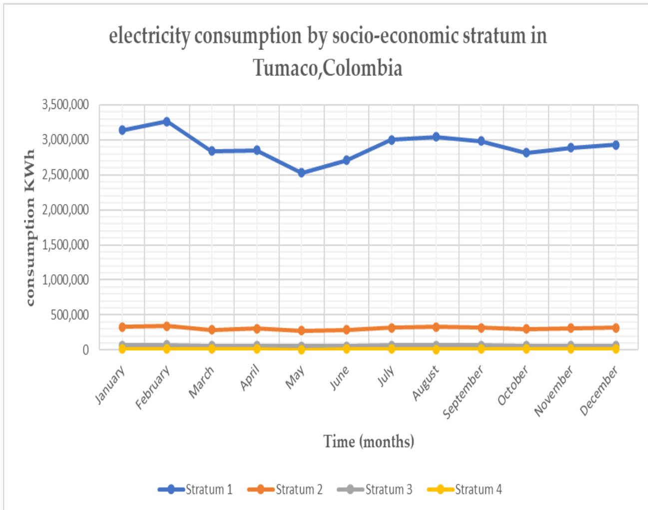

Fig. 2. Electricity consumption in Tumaco, Colombia. Source: Own

The results obtained in terms of demand projection are striking, since they show that the lowest socioeconomic stratum (level 1) is usually the one with the least resources to access electricity service. However, this study found that this stratum is the one that most demands electricity to meet its basic needs, such as lighting, the operation of appliances and the use of electronic devices (see figure 4). Consequently, the findings of this study have important implications for electricity supply planning in Tumaco, as it is necessary to take measures to ensure that the low-income population has access to a more economical and reliable energy service.

According to the results obtained in table 2, the LCOE value is 75.71 $/MWh (1), taking as a reference the speeds in the months of December and April in the coastal area of Buenaventura, Colombia; However, this result is variable compared to certain parameters such as: Discount rate, because it can change significantly in the face of changes in the economy of a country; the location of the project, as renewable energies that use elements found in nature (tides) as a primary source tend to be vulnerable to climate changes that may occur; technology used because year after year private equity companies such as EMEC MARINE ENERGY are dedicated to developing turbines to implement them in electric power generating plants. (EMEC: European Marine Energy Centre, n.d.)

TABLE II MODEL LEVELIZED COST OF TIDAL PLANT ENERGY. OWN SOURCE

LCOE MODEL OF PLANT -TIDAL TYPE RESERVOIR OF TUMACO, COLOMBIA	
Nominal power of the plant (MW)	100
Initial Investment ($)	$100,000,000
Operation and maintenance cost*	$5,000,000
Plant life (years)	25
Hours of the year worked	4000
Plant factor (%)	40%
Energy required for Aux services (%)	10%
Network interconnection loss (%)	10%
Fixed unit cost in $/MW*	4000
Variable unit cost $/MW*	0.04
Depreciation rate	10%
Tax rate	19%
expected power generation in the year (MW)	128000
Plant efficiency (%)	70%
Plant availability (%)	50%
Plant degradation (%)	5%
LCOE ($/MWh)	75.71

*Note: The value of the currency is in US dollars

As for the environmental aspects, the possible impact on marine fauna and flora, the decrease in water quality, must be considered. For this reason, a literature review was carried out to find a solution or to reduce the effects of the construction of this type of project. This was achieved thanks to the fact that national legislation obliges developers to obtain the respective environmental license for the development of this type of projects, which implies the realization of the respective Environmental Impact Studies that include, among other aspects, information on the biotic, abiotic, and socioeconomic components of the area of influence. However, to date, the Environmental Agency (ANLA) has not formulated generic Terms of Reference for offshore wind projects regarding the environmental licensing process, so to date ANLA only issues specific Terms of Reference for each offshore wind project that officially requests them. (ANLA, 2022; WORLD BANK GROUP, 2022)

IV. DISCUSSION AND CONCLUSION

Tidal energy has great potential in Colombia. However, its large-scale viability is still uncertain due to the complexity and cost of the technology, which is still in the development stages. In addition, it is important to consider potential environmental, social, and cultural impacts before undertaking tidal energy projects in the country. A comprehensive approach and detailed analysis are required to assess its feasibility and determine the best way to harness this renewable energy source in Colombia.

The results of this study show that the LCOE of offshore wind and tidal energy are in the same range. In 2021, the LCOE of China's offshore wind was $91/MWh, while the LCOE of tidal energy was $75.71/MWh. This suggests that both energy sources are economically viable. However, it is important to note that the LCOE can vary depending on factors such as plant location, plant design, and construction costs. Therefore, more detailed studies in different regions are needed to assess the LCOE of offshore wind and tidal energy.

In conclusion, evaluating the prefeasibility of designing a reservoir-type tidal power plant in Tumaco, Colombia, is an important step in evaluating the feasibility of this type of project. Tidal energy is a form of renewable energy that can be an interesting option for countries looking to reduce their dependence on fossil fuels, reduce greenhouse gas emissions, or satisfy a part of their country's energy matrix.

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