Aquatic Renewable Energy Potential in Colombia: A Preliminary Study

Ramon Fernando Colmenares-Quintero[1*], Natalia Rojas[2], Marieth Baquero-Almazo[1], Salvador Villar-Villar[1], Luis Guarín-García[1], Kim E. Stansfield[3], and Juan Carlos Colmenares-Quintero[1,4]

1. Engineering Research Institute (In^3), Universidad Cooperativa de Colombia, Calle 50A N° 41-27, Medellín, Colombia.
2. Aquatera Ltd., Old Academy Business Centre, Stromness, Orkney, KW16 3AW, United Kingdom.
3. VoCATE Ltd., 2 Fountain Place, Worcester, Worcestershire, WR1 3HW, United Kingdom.
4. Institute of Physical Chemistry, Polish Academy of Sciences, Kasprzaka 44/52, 01-224 Warsaw, Poland.

*Corresponding author: ramon.colmenaresq@campusucc.edu.co

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I. INTRODUCTION

AQUATIC renewable energy is an emerging technology with great applicability in coastal areas and communities with high water resource potential. [1] explains that there are not yet mature standards and guidelines for the development and testing of these devices, however, marine energy is a complex sector that encompasses a wide landscape of energy solutions. In the same vein, [2] argues that the great potential of ocean energy is partly due to the huge range of possibilities: wave, tidal, ocean current, ocean thermal and osmotic (salinity gradient) energy. In addition to these, it is essential to consider the technologies developed primarily for onshore applications, and to see how these systems can be linked.

In a Latin American and Caribbean context, [3] explains that Colombia has a great extension and variety of renewable energies. Several studies and projects have been carried out at the prototype level related to marine energy for areas with high water resource potential in Colombia. The study carried out by [4] shows an estimated sea level rise of 1.04 m for the year 2100 that will impact 86 municipalities on the Colombian coast, which makes Colombia an optimal territory for the applicability of prototypes and support in increasing the level of technological maturity of marine energy.

On the other hand, considering the high-water potential of Colombia in marine renewable energies, [5] highlights numerous advantages of the applicability of one of these types of technologies, such as tidal energy, taking into account that tidal currents are predictable and very reliable, which places it ahead of other renewable energy sources. The power to be produced by tidal energy can be accurately calculated in advance, allowing it to be easily integrated into Colombia's existing electricity grids.

II. BACKGROUND

Baseline Colombia Characteristics

Colombia is a country located in the north-western corner of South America. It has 928,660 km2 of sea and 2,900 km of coastline, with a population of around 48 million. Its geographical position makes it the only South American country with coasts on both the Caribbean Sea and the Pacific Ocean and rivers.

The Colombian Caribbean coast is a very dry region, with a high average temperature, low rainfall, and high solar radiation values. There are several large rivers in this coast, as is the region where all the precipitation from the Colombian mountain ranges drains to.

The Colombian Pacific coast is one of the rainiest places in the world (Fig. 1), and due to its relative isolation from the rest of the country and its jungle vegetation, Pacific communities are generally small, not connected to the electricity grid and lacking transport infrastructure.

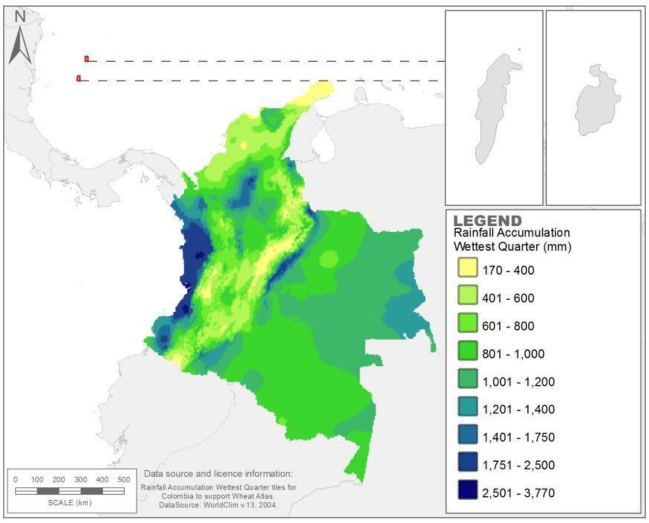

Fig. 1. Precipitation

Finance and policy

Financing is a very important element for marine and run of river (RH) industries. Most of these technologies are in an early development stage and the levelized cost of electricity is higher than other generation technologies.

The existence of renewable energy laws, as shown in Table 1 [6]–[12], provides a legal framework for the promotion of renewable energy and offers an indication of the country's support.

TABLE I
POLICIES AND INCENTIVES OVERVIEW IN COLOMBIA

Policy	Declare	Year
Law 697	Promotes the use of non-conventional energies within the Rational and Efficient Energy Use program.	2001
Law 1715	New additions of non-hydro renewable capacity by using tax breaks.	2014
The Generation Expansion Plan 2031	Areas with high river potential and accessibility to water resources.	2018
Resolution 045	Value added tax (VAT) exemptions for machinery, equipment, and labour in renewable energy projects.	2016
The National Development Plan 2022	Expansion of missing technical and environmental regulations for the development of non-conventional energy sources, creating a one-stop shop to streamline the process.	2018
UPME's National Energy Plan 2050	Aims to install other sources of energy to achieve a diversification of the basket and ensure a reliable energy supply.	2020
Law 2099	Whereby provisions are issued for the energy transition, the dynamisation of the energy market.	2021

Colombia applies laws and programs for the promotion of non-conventional energies. The Generation Expansion Plan mentions possible projects to be implemented in areas with high river potential and accessibility to water resources. Laws 1715/2014 and Law 2099/2021, establishes provisions for the energy transition and a strongly promotes access to an energy market.

Aquatic resources

From marine resources, energy can be extracted from the mechanical motion of fluctuations of different frequencies of large masses of moving water, such as surface waves and tides, as well as from other physical and thermal processes. The marine energy resources studied in this document are:

Wave Energy: The winds interacting with the sea surface transfer energy, and this results in the generation of waves. Moreover, the winds are caused by pressure differences in the atmosphere created by solar heating [13].

Tidal Energy: Tidal stream technologies rely on the tides created by the gravitational pull of the moon and sun on the seas [14].

Run of river: this resource has an important application with hydrokinetic turbines, which capture and harness the energy of a moving fluid and convert it into electricity [15].

III. METHODS

Research and review of scientific literature

To carry out this study, research was conducted on the potential of aquatic renewable energies in Colombia, based on an exhaustive search in academic databases. Studies published in the last 10 years were selected for obtaining updated information on the subject, the most important areas with energy potential and the needs of the territory in areas such as resilience to rising fuel costs, employment and territorial development for the industry, the community, and the region.

Characterisation of aquatic renewable energy potential in Colombia

The analysis and synthesis of the results obtained from the selected studies was carried out, focusing on the geographical, political, environmental, financial, social and legal aspects in the national context, following the national guidelines present in Law 697, Law 1715 and Law 2099, as these have facilitated the investment and development of marine renewable energy projects, promoting the transition towards a sustainable energy matrix and generating economic, social and environmental benefits.

Presentation of results and challenges identified

In this stage, several projects with aquatic renewable energy sources were identified, where relevant data was collected on the efficiency of the energy production capacity, the technologies used and the associated technical challenges, in addition to analysing the possible opportunities for the development of technologies of this type, as well as the factors that influence their performance in the market. Emerging trends, areas of active research and key technical challenges requiring attention were identified, mainly in power generation, but also in commercial sector development, etc.

IV. RESULTS

Wave and tidal power technologies are developing rapidly but particularly wave's technology remains at a pre-commercial stage of development. These technologies are expected to become cost and functionally competitive with other forms of renewables in the coming years [16].

There are secondary benefits associated with the incorporation of wave and tidal power in the energy mix related to energy diversity, energy security and resilience to increasing fuel costs. Indirect benefits in terms of employment and wealth creation opportunities also were identified. Along with these benefits there are the possible impacts shared with traditional energy systems, as well as new impacts for example on sea and coastal users and on customers who are served by currently cheaper, but less sustainable, forms of energy.

Wave Energy

Wave energy devices can be located on the shoreline, nearshore or offshore. The wave power resource in Colombia is relatively small when compared with other places of the world, where 40 kW/m and above is considered an attractive level of wave power. However, significant power may be generated with schemes such as the one proposed in other sheltered seas such as the Baltic [17], where the technology has been developed to be optimal in seas with significant wave heights less than 2 m and peak periods around seven seconds. In Table 2 are summarised the main potential points for wave energy projects.

TABLE II
SUMMARY OF MAIN SITES FOR WAVE ENERGY DEVELOPMENT

No.	Region	Seasonal mean power - DJF
1	Santa Marta	4.5 kW/m
2	Barranquilla	5 kW/m
3	Isla Providencia	< 1 kW/m
4	Isla San Andres	< 1 kW/m
5	Isla Fuerte	1.4 kW/m

Adapted from [18].

Tidal Energy

The tides in Colombia offer a resource mainly on the Pacific side, ranging from 3-4 metres [18]. The Colombian Pacific region has a low-density population and scarce infrastructure, and thus, human intervention in the area has been minimal.

The highest power could yield a maximum power supply close to 8.1 MW for Buenaventura Bay, nevertheless, the simulated speed is very low compared with places where there might be future commercial developments that have current speeds around 2 m/s, which would be equivalent to about 960 W/m2.

Marine energy as a resource idea for generating electricity for Colombia, is still in an initial stage, focused on research and prospection of the resource, through modelling and data analysis for specific places along the Colombian costs. In table 3 are summarised the main potential points for tidal energy projects.

TABLE III
SUMMARY OF MAIN SITES FOR TIDAL ENERGY DEVELOPMENT

No.	Region	Mean current speed	Power in Flood tide
1	Buenaventura, Malaga Bay	0.8 m/s	250 W/m2
2	Buenaventura Chanel	1.5 m/s	330 W/m2
3	Off Buenaventura Port	3 m/s	450 W/m2
4	Delta San Juan	-	750 W/m2

Adapted from [18] and Aquatera's Tidal Database.

Run of river energy

Colombia has a favourable overview for hydroelectric energy generation, Fig. 2 shows the main river of Colombia; the local mean water speed needed for RH would be between 1.5 and 2 m/s as a limit for commercial viability.

In Colombia the Small Hydro Power (SHP) is an important energy source for rural electrification and distributed generation and is promoted more in The Non-Interconnected Zones (NIZ) than inside The National Interconnected System (NIS).

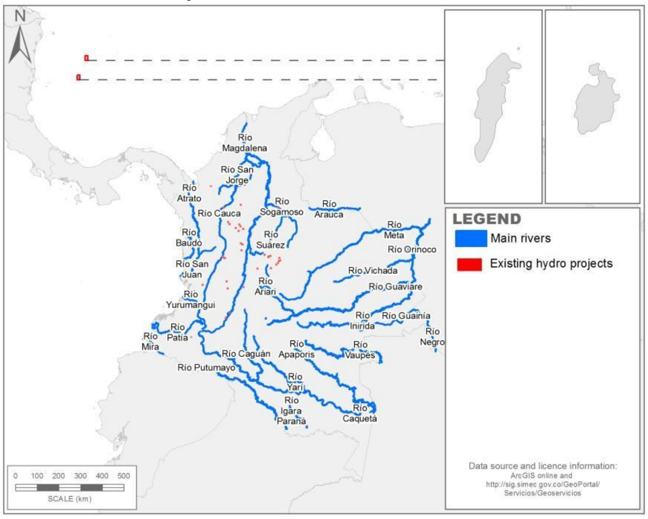

Fig. 2. Main rivers in Colombia

Barriers and Limitations

The barriers that are directly associated with the marine energy sector need to be refined at the initial stage of any project and together with the general barriers that affect renewable energy in Colombia, considering economic, regulatory, infrastructure and technological aspects.

An example of this is that due to the lack of financially non-viable projects of this type of technology, there is no clearly defined licensing and concession process that considers the stages and investment risk associated with this type of marine energy development.

For the selection of potential zones for the development of both marine and run-of-river energy projects, certain immediate barriers can be identified, related to spatial areas to be avoided. These barriers are mainly related to social, environmental, climatological, and geographical factors, which are useful to apply as a first approximation for the selection of potential zones.

On the other hand, a significant number of SHP plants with small capacities, such as mini and micro hydropower plants have been built across the country in NIZ as a practical solution for meeting the communities' energy needs. However, energy production of a SHP station during the year is not constant due to substantial weather variations. In some cases, especially during periods of drought, they must be combined with backup fossil fuel-based generators that can ensure energy supply to the community.

In terms of social factors, Colombia has some sensibilities with the indigenous communities, which under certain areas they are protected as can be appreciated in Fig. 3. For these areas there may be some special treatment and regulatory conditions for a potential energy project to be developed.

In line with protected areas, Colombia has an open data platform for National Natural Parks (PNN) which, by the end of 2022, has registered 62 natural protected areas typologies including natural parks, natural reserves, natural sanctuaries, natural areas, natural districts, and an island. All these direct barriers will be considered for the preliminary selection of potential sites.

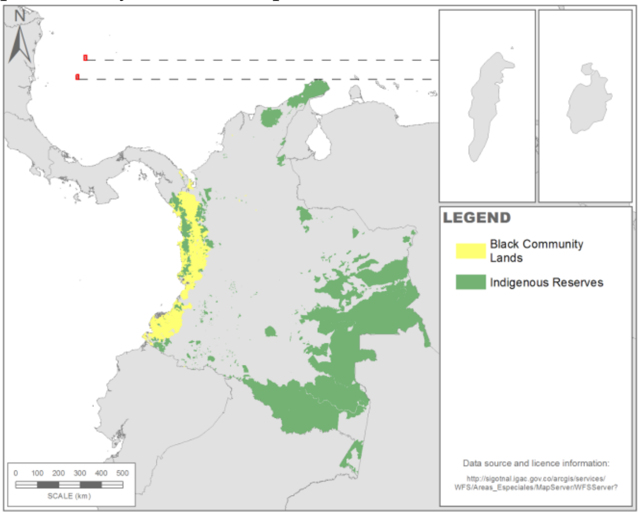

Fig. 3. Indigenous and black communities

Potential areas in Colombia

Tidal energy has very few locations for energy extraction that need to be assessed locally to understand the suitability of the sites for future projects. These locations are in NIZ.

Fig. 4 shows the main tidal and waves locations and their distances to the main ports. Infrastructure and supply chain and important factors on future projects developments in the country.

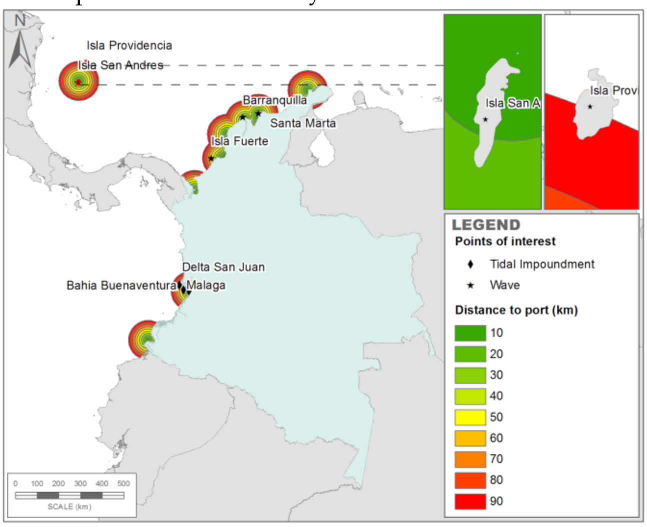

Fig. 4. Distance from ports to tidal and waves sites

In the case of isolated areas, where conventional solutions for electricity supply are mainly based on the use of diesel generator sets, there are populated areas inside NIZ areas with rivers hydro that should be evaluated in more detail with the aim that marine and hydrokinetic technologies could represent cost-effective and competitive solutions given the high costs associated mainly with the transport and consumption of diesel (Fig. 5 and Fig. 6).

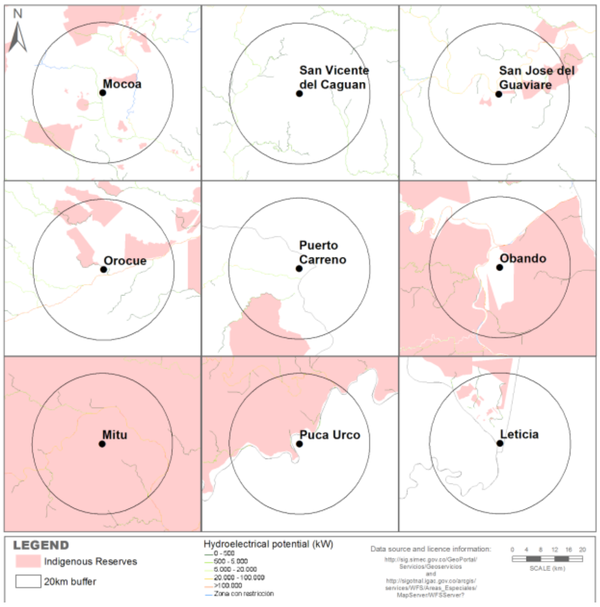

Fig. 5. East populated areas with RHK potential.

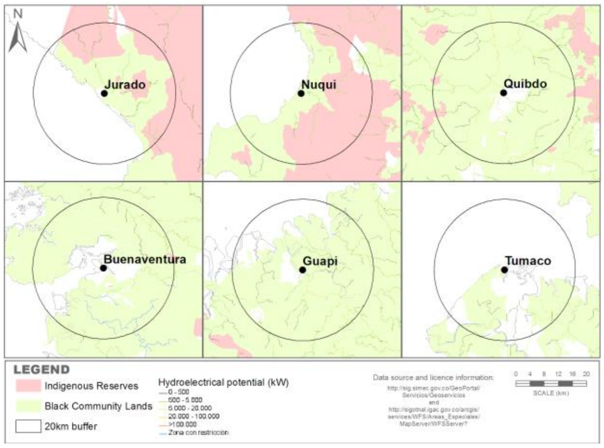

Fig. 6. West populated areas with RHK potential.

The number of isolated systems needing power in Colombia is large and the government strongly supports NCRE initiatives for these areas. Marine energy and HR applications where existing costs are higher (such as replacing diesel generation) are likely to become viable sooner, although this will be balanced by the ability to achieve economies of scale through larger projects. Aquatera Ltd. and the Engineering Research Institute (*In*[3]) of the Universidad Cooperativa de Colombia (UCC) believe that tidal and river power can already be competitive with diesel generation in some cases, particularly in remote areas.

V. DISCUSSION

Until marine and RH energy could compete directly with other sources of generation in the country, projects would need support to develop the first projects until the technology cost could compete with other sources. The balance between costs, revenue, business conditions and competitive alternatives determines the commercial viability of a technology in a particular location and there are conditions in Colombia that are worthy of note:

- Labour costs in Colombia are lower and devices may be manufactured cheaper than in many US/European countries.
- General vessel, crew and diver rates are also lower in Colombia than in many other areas.
- There are many areas with a significant power demand isolated from transmission and distribution systems, and therefore rely on fossil fuels with high cost of power generation and low liability.
- Niche markets are a viable approach for pilot projects in the country.

It is estimated that it may be possible to reduce levelized energy costs for tidal and RH energy by as much as 20% in Colombia compared to the UK. This is due mainly to reduced labour and standard vessel costs.

It should be noted that based on this study, the collection of energy data would be recommended for the allocation of potential sites for future projects. The first pilot projects in the country would provide confidence in these industries and an understanding of how marine and RH projects could be developed, applying the concept of "learning by doing", but without leaving aside the understanding of the current regulatory framework for the development of these projects.

VI. Conclusion

The marine energy industry and its associated research and development activities face many challenges. These mainly stem from lack of large-scale operational experience in the sea and funding for both projects and coherent research and development programmes. The status of wave and marine current energy conversion technologies addressing issues related to their early stage as compared to others such as offshore wind is still challenging.

From the information available for this preliminary study marine energy resources potential in Colombia are not as high as other countries but enough for small or medium scale projects. On the other hand, RH is an emerging technology sector in which electricity-generating technologies are placed directly in the river flow without creating any artificial head or water or piping being a potential low-impact alternative. The sector has an undoubled potential in Colombia.

The region of the central, oriental, and occidental mountain ranges of Colombia are the areas with the highest hydrokinetic potential but local data needs to be gathered.

As future work, the possibility of assessing offshore wind energy is raised as it has not been considered in this preliminary study, it is advisable to collect information and data for future opportunities.

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