Construction of a feasibility index for Salinity Gradient Energy (SGE) projects in the Colombian Caribbean region.

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I. Introduction

CLIMATE change is one of the greatest challenges humanity faces in the 21st century, with potentially catastrophic consequences for the planet and life on it. Scientific evidence shows that human activity, particularly the burning of fossil fuels, is the primary cause of climate change [1] [2]. According to the Intergovernmental Panel on Climate Change (IPCC) report from 2014 [3], greenhouse gas emissions are the main driver of global warming and climate change. Greenhouse gas emissions have increased by 70% between 1970 and 2004 [2], and they are expected to continue rising in the coming decades [4].

The need to reduce greenhouse gas emissions has led to an increase in research and development of clean and renewable energy technologies [5]. However, the viability of renewable energies depends largely on their economic and technical feasibility [6]. It is crucial to consider that energy conversion from conventional to alternative sources must be economically competitive to enable true sustainable growth [7].

The term "Sustainable Development" was coined in 1987 in the Brundtland Report and was defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The ambiguity of this definition sometimes hinders the proper application of the concept of sustainable development in decision-making regarding development policies [8]. Since then, the concept of sustainable development has evolved [9] and has adapted to the needs of a growing population and increasingly demanding economic sectors.

In line with the definition of sustainable development, agreements have been made between nations to address global issues, with climate change being a key focus. The Paris Agreement and the United Nations' Sustainable Development Goals (SDGs) for 2030 represent part of the global efforts to address the issue of global warming [10]. In this context, renewable energies emerge as a solution to reduce greenhouse gas emissions in the energy and transportation sectors [11].

Marine renewable energies have gained attention from the scientific community in recent decades due to their practically unlimited potential and their lack of greenhouse gas emissions during production. The ocean contains primarily five forms of energy that can be harnessed: temperature differences between vertical layers, potential and kinetic energy in waves, kinetic energy of ocean currents, tidal kinetic and potential energy, and energy released during the mixing of water masses with different salinity levels [12].

Marine renewable energies have been identified as a promising source for electricity generation [13]. Salinity Gradient Energy (SGE), wave energy, tidal and ocean current energy, ocean thermal energy (OTEC), and marine photovoltaic and wind energy are alternatives that have the potential to significantly contribute to clean energy generation in the future due to their high global potential. Despite their high generation potential, the implementation of these marine renewable energies in the energy market still faces technical and economic challenges. Therefore, it is crucial to assess the feasibility of these technologies in different regions and climatic conditions [14]. The construction of a feasibility index can be a valuable tool to evaluate the viability of implementing and sustaining marine renewable energy projects in different coastal regions [15].

Multiple Criteria Decision Making (MCDM) tools are extensively used in different fields, such as social and environmental studies, industry and at government level; one of these tools is the Analytic Hierarchy Process (AHP), which provides a methodology to evaluate and numerically calibrate multiple quantitative as well as qualitative variables, separating them in multiple levels of criteria and subcriteria, also referred in this paper as dimensions and factors.

The objective of this investigation is to construct a feasibility index applied to the generation of SGE in the Colombian Caribbean region (Fig. 1), considering technical, environmental, governmental, economic, and

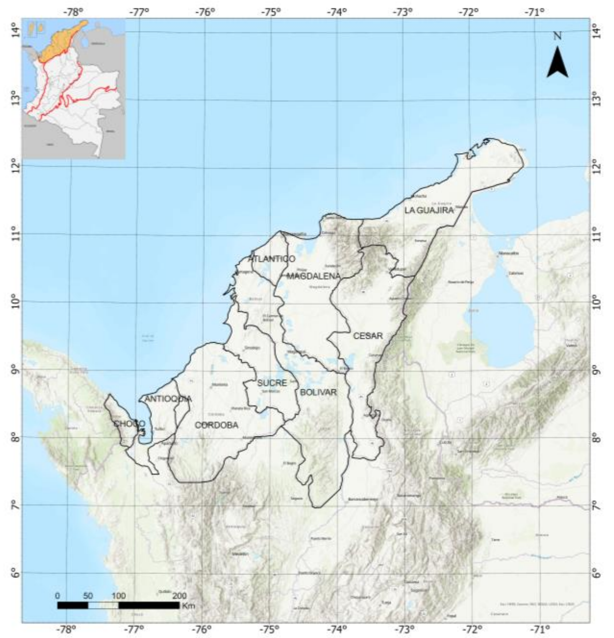

Fig. 1. Colombian departments that belong to the Caribbean region.

social factors. The multidimensional assessment of the feasibility of these energies in Colombia can be a valuable tool for planning and decision-making in the energy sector, as well as for identifying opportunities for the development of marine renewable energies in the country.

II. Methods

A. *Selection of factors*

In this section, the aim is to establish a conceptual framework and make a pre-selection of factors and dimensions to be evaluated in the index based on a literature review. The goal is to extract key factors affecting the feasibility of marine renewable energy generation and assign them a relative weight to initiate the selection of factors that will be used in the final index. The information corresponding to these factors was collected from official and open databases. Additionally, existing challenges with the implementation of projects of this nature will be identified. This will be achieved through a review of existing research, books, and thesis works focused on renewable energies and index construction applied to renewable energy and sustainability.

For the selection of factors, the following criteria suggested by the OECD in 2003 [16] will be followed:

Policy relevance and user usefulness:

-Simplicity: should be easy to interpret.

-Pertinence: should be related to the stated objectives and contextual conditions.

-Relevance: should effectively support decision-making.

-Effectiveness: should be accurate.

Measurability:

-Sensitivity: reflects temporal changes in the variable.

-Data availability: data should be publicly available to promote result transparency.

Analytical soundness:

-Validity: should measure the effects and outcomes of the study variable.

-Reproducibility: measurements made by different individuals should yield the same results.

Additionally, for a factor to be selected, spatial data must exist and be available to the public. In this section, the Delphi method of consulting experts will be used to complement the information collected in the literature review. A list of decision-making agents and policy makers are going to be sent a questionnaire where they will be asked to organize and weight different variables related to renewable energy production; If possible, the results of this survey will be shared with the participants and, if necessary, a next round of questionnaires will be carried out to have a clear consensus. The resultant data is then to be organized and illustrated for a clear visualization and evaluation of the results.

B. *Spatial data processing*

In this stage, the aim is to gather available geographic information from official and freely accessible databases (governmental, NGOs, etc.) corresponding to the selected factors, this information will be used to generate suitability maps for each of the variables using geospatial tools, particularly the ArcGIS Pro software by Esri.

Subsequently, these maps will be overlayed with their respective weights to obtain a general figure of the study area. This process allows for the combination of multiple factors and their relative importance to create a comprehensive assessment of the area. Later, the resultant figures and spatial data is to be uploaded to Google Earth Engine for a more detailed visualization.

C. *Construction of a feasibility index*

Based on the weighting assigned to each dimension and factor, derived from the literature review and information collected from expert questionnaire, all supported by the Analytic Hierarchy Process (AHP), which offers advantages including, but not limited to, providing a mathematical foundation and the ability to verify the consistency of judgments, the next step is to normalize the numerical variables, which are measured on different scales, and justify the qualitative information in order to make them comparable. Subsequently, the indicators are weighted and aggregated to form sub-indices, which are ultimately integrated and weighted in the feasibility index. Lastly, sensitivity tests and pilot tests of the index are planned to be conducted at various points in the Colombian Caribbean to verify its correct formulation.

III. Expected results

Throughout this section it is to be remembered that the selection and subsequent weighting of the factors is to be confirmed once the results of the questionnaire are processed and analysed.

Following the proposed methodology, the following factors were selected (Fig. 2):

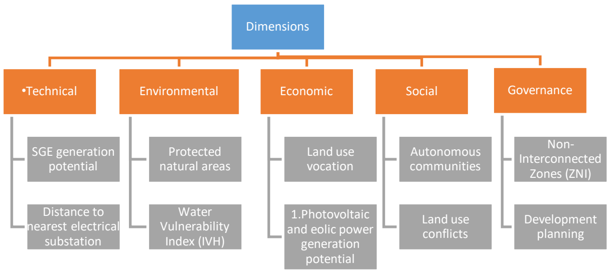

Fig. 2. Dimensions and factors selected for the Feasibility Index.

Following the selection of the factors, spatial data is searched and requested directly from different governmental entities such as Unidad de Planeación Minero Energética (UPME) or Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM) and processed to generate suitability maps (Fig. 3).

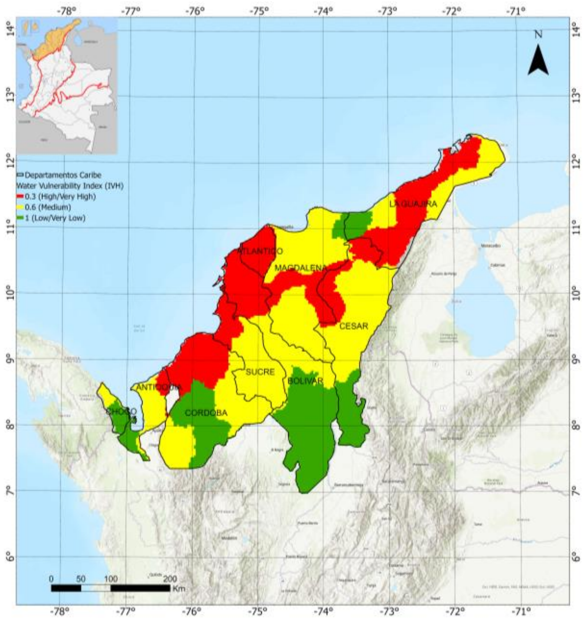

Fig. 3. Suitability map for the water vulnerability factor of the environmental dimension.

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