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INTEGRATED ASSESSMENT OF THE MAGDALENA RIVER DELTA AND ESTUARY SOCIO-ECOLOGICAL SYSTEM

Thesis in: Environmental Assessment

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CONFIRM THAT:

This master's dissertation titled 'Integrated Assessment of the Magdalena River Delta and Estuary Socio-Ecological System' prepared by David Gallo Vélez summarizes her master thesis and considering that it meets all legal requirements, authorize its presentation and defence to qualify for the degree of MSc. in Water and Coastal Management.

Ravenna, (date of defence)

Prof. Alice Newton

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I dedicate this master thesis to my beloved family, my partner, and the sea.

"Knowing is the key to caring, and with caring there is hope that people will be motivated to take positive actions. They might not care even if they know, but they can't care if they are unaware." Sylvia A. Earle, The World Is Blue: How Our Fate and the Ocean's Are One

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ABSTRACT

River-mouth systems and deltas are hotspots where many of the coastal symptoms can be found, moreover, these systems provide essential ecosystem services (e.g., recreation, food provisioning, protection against natural hazards). The present study focuses on the socio-ecological system (SES) that is present in the estuary formed in the central Caribbean Region in Colombia at the main river-mouth of the Magdalena River. This research seeks to assess the multidimensional sustainability of the Magdalena river-mouth system in order to improve the knowledge basis for its integrated management. To do so, an assessment tool named 'Circles of Coastal Sustainability' was used to evaluate the system splitting it into four domains (environmental, social, economic and governance) that were divided into 5 categories each. These domains were evaluated through a total of 52 indicators distributed like this: 16 for the Environmental domain, 16 for the Economic domain, 12 for the Social domain and, 8 for the Governance domain. The results show that the overall sustainability of the Magdalena River-mouth SES is classified as 'Satisfactory'. None of the domains is in 'Excellent' or 'Bad' conditions. However, the evaluation of the categories shows that four (4) of them have 'Poor' conditions (i.e., Social Benefits, Demographics, Economic Security, and Resources Management). Hence, it is recommended to put those categories at the centre of the discussion to define management strategies (e.g., Preserving and restoring habitats; tackling sources of pollution and excessive sediment; local reduction of net GHG and adaptation to climate change; participation of local communities in the management design and implementation) without disregarding the interrelation with the other categories and dimensions. Finally, it is argued that despite all the improvement opportunities, the CCS is a valuable tool to evaluate the sustainability of coastal systems in Colombia and the world.

Key words:

Socio-ecological assessment; Magdalena River; Colombia; Caribbean; coasts; Sustainability; Integrated Coastal Zone Management

RESUMEN

Las desembocaduras y deltas de los ríos son zonas donde se encuentran muchos de los síntomas costeros, además, estos sistemas proporcionan servicios ecosistémicos esenciales (por ejemplo, recreación, provisión de alimentos, protección contra las amenazas naturales). El presente estudio se centra en el sistema socioecológico (SES) del estuario formado en la desembocadura principal del Río Magdalena que descarga sus aguas en el centro de la Región Caribe colombiana. Esta investigación tiene como proposito evaluar la sostenibilidad multidimensional del sistema socioecologico en la desembocadura del Magdalena con el fin de mejorar la base de conocimientos para su gestión integral. Para ello, se utilizó una herramienta de evaluación denominada "Círculos de Sostenibilidad Costera". Así, el sistema se dividió en cuatro dominios (ambiental, social, económico y de gobernanza) que se estan compuestos de 5 categorías cada uno. Estos dominios se evaluaron a través de un total de 52 indicadores distribuidos así 16 para el ámbito medioambiental, 16 para el económico, 12 para el social y 8 para el de gobernanza. Los resultados muestran que la sostenibilidad general del SES de la desembocadura del río Magdalena se clasifica como 'Satisfactoria'. Ninguno de los ámbitos está en condiciones "Excelentes" o "Malas". Sin embargo, la evaluación de las categorías muestra que algunas de ellas tienen condiciones 'Malas' (por ejemplo, Beneficios Sociales, Demografía, Seguridad Económica y Gestión de Recursos). Por lo tanto, se recomienda poner esas categorías en el centro de la discusión para definir las estrategias de gestión sin desconocer la interrelación que existe con las demás categorías y dimensiones. Algunas de las medidas discutidas son la preservación y restauración de los hábitats; el control de las fuentes de contaminación y el exceso de sedimentos; medidas locales de mitigación y adaptación al cambio climático; la participación de las comunidades locales en el diseño y la aplicación de la gestión, entre otros. Finalmente, se argumenta que a pesar de todas las oportunidades de mejora, el CCS es una herramienta valiosa para evaluar la sostenibilidad de los sistemas costeros en Colombia y en el mundo.

Palabras clave:

Evaluación socio-ecológica; Río Magdalena; Colombia; Caribe; Costas; Sostenibilidad; Gestión integrada de zonas costeras

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ACRONYMS AND ABBREVIATIONS

ACMP	Consensual Fisheries Management Agreements
AMSL	Above Mean Sea Level
BECO	Colombian Energy Balance
BMA	Barranquilla Metropolitan Area
CAR	Corporación Autónoma Regional
CARDIQUE	Corporación Autónoma Regional del Canal del Dique
CCS	Circles of Coastal Sustainability
CEDAW	Convention on the Elimination of All Forms of Discrimination against Women
CEPAL	Economic Commission for Latin America
CGSM	Ciénaga Grande de Santa Marta
CITUR	Colombia Tourism Information Centre
CLC	Corine Land Cover
CLME	Caribbean Large Marine Ecosystem
CLME+	CLME and Adjacent regions
CONPES	National Council for Economic and Social Policy
CRA	Corporación Autónoma Regional del Atlántico
DANE	Departamento Administrativo Nacional de Estadística
ECV	National Survey on Quality of Life
ENA	National Study of Water
EnMP	Endogenic Managed Pressures
ENSIN	Nutritional Status National Survey
ETIS	European Tourism Indicator System
EU	European Union
ExUP	Exogenic Unmanage Pressures
FNCE	Non-conventional renewable energy sources
GDP	Gross Domestic Product
GHG	Greenhouse gasses
GMSL	Global Mean Sea Level
GVA	Gross Value Added
ICZM	Integrated Coastal Zone Management
IDEAM	Instituto de Hidrología, Meteorología y Estudios Ambientales
IEA	International Energy Agency
IER	Relative Effort Indicator
INAC	National Anti-Corruption Index
INVEMAR	Instituto de Investigaciones Marinas y Costeras José Benito Vives de Andréis
INVIAS	National Roads Institute
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change

IRCA	Water Quality for Human Consumption Risk Index
IUCN	International Union for Conservation of Nature
MR or RM	Magdalena River
MRm-SES	Magdalena River-mouth Socio-ecological System
MRV	Measuring, reporting, and verifying system for climate finance
MWQI	Marine Water Quality Index
NARP	Black, Afro-Colombian, Raizal and Palenquero
NDC	Nationally Determined Contributions
NGO	Non-governmental organization
OECD	Organisation for Economic Co-operation and Development
OHI	Ocean Health Index
PCERM	Per Capita Expenditure on Risk Management
PNAOCI	National Environmental Policy towards Sustainable Development of Oceanic Spaces, Coastal and Island Regions of Colombia
PNOEC	National Ocean and Coastal Spaces Policy
PNUD	United Nations Development Programme
POMIUAC	Integrated Management Plan for the Coastal Environmental Unit
RCP	Representative Concentration Pathways
SDG	Sustainable Development Goals
SGSSS	General System of Social Security in Health
SIN	National Interconnected System
SISCLIMA	Sistema Nacional de Cambio Climático
sLMR	shared Living Marine Resources
SLR	Sea-level rise
SSL	Suspended Sediment Load
SST	Sea surface temperature
SZH	Hydrographic Subzone
TCNCC	Third National Communication on Climate Change
TDF	Tropical Dry Forest
UAC	Coastal Environmental Unit
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPME	Mining and Energy Planning Unit
WCR	Wide Caribbean Region
WEF	Wave Energy Flux
WEO	World Energy Outlook
WOA	World Ocean Assessment
WOR	World Ocean Review
WRI	Water Regulation Index

1 INTRODUCTION

This thesis dissertation is submitted to the Alma Mater Studiorum – Università di Bologna, Italy in partial fulfilment of the requirements for the Erasmus Mundus Joint Master's Degree in Water and Coastal Management (WACOMA), in conjunction with the Universidade do Algarve, Portugal and the Universidad de Cádiz, Spain. The hypothesis to be evaluated is that the Magdalena River-mouth Socio-ecological system does not exhibit a high level of sustainability due to multiple pressures and the lack of an integrative approach to management.

Setting the scene

The ocean and its related habitats, including the coastal areas, provide benefits to the global community (e.g., climate regulation, coastal protection, food, recreation, transport routes). However, those benefits rely on the maintenance of the natural processes, marine species and ecosystem functioning which can be affected by human activities. (United Nations, 2021, p. 5)

Coasts are special habitats in the transitional zone between land and sea forming part of a land-ocean continuum system (Crossland, 2005). Due to its variety of landscapes and matching services, coasts have always been places of particular interest for human settlers. According to the United Nations, 2.8 million people live within 100 Km of the coast. (Future Ocean et al., 2017, p. 183)

Coastal systems are subject to multiple syndromes including sediment unbalance, variation in water flows, eutrophication and contamination due to inputs from inland activities (e.g. industry, agriculture), changes in land-use and destruction of natural cover, urban sprawling, loss of biodiversity, exploitation of non-renewable resources and global change (e.g. climate change and sea-level rise). (Newton et al., 2012, p. 40). All these syndromes can be connected to 5 main drivers of change that affect the ocean's status, for better or for worse, and they are: population growth and demographics, economic activities, technological advances, changing governance structures and geopolitical instability and climate change (United Nations, 2021, p. 7)

Which system is in the centre of the present analysis?

Now along the coast it is possible to find river-mouth systems and deltas which are hotspots where many of the coastal symptoms can be found (Newton et al., 2012, pp. 42–43), moreover, these systems provide essential ecosystem services (e.g. recreation, food provisioning, protection against natural hazards) (United Nations, 2021, p. 343).

River deltas are formed by the accumulation of the sediments at the mouth of a river, its presence along any coast indicates that the sediment input from the river is higher than the sediment that can be removed or redistributed by coastal processes. This condition highlights that one critical characteristic of deltas is their dependence on sediment supply from rivers. Historically, these systems have been profoundly influenced by human, for example, agriculture and forestry influence the delta growth due to the negative effects in the basin that increase erosion and sediment transport by the rivers. Another example of human driven changes in deltas is their subsidence due to the extraction of fluids (e.g. water or oil) that leads to the compaction of the sediment layers reducing its volume and contributing to higher relative sea-level rise rates (Davis & FitzGerald, 2020). Increased urbanization and industrialization, changing hydrogeomorphology, large-scale engineering projects and climate change, among others, are also pressures and hazards for these systems (Michael Elliott et al., 2019).

Estuaries and deltas share multiple characteristics, namely, both typically have tidal flats and wetlands, mangrove swamps, they are influenced by rivers, waves and tides and they are places of sediment accumulation. However, the main difference between the two of them is that an estuary is merely a coastal embayment whereas deltas, which can be formed by multiple estuaries, necessarily have the characteristic that they protrude into the ocean. Estuaries are commonly classified based on the interaction between fresh and saltwater as stratified, partially mixed, and mixed estuaries (Davis & FitzGerald, 2020). Now, in terms of impacts, these systems have been affected by population growth, constructions of commercial harbours, dredging activities and increased inputs from pollutants, that have led to habitat and biodiversity loss (Michael Elliott et al., 2019).

The Magdalena River delta - What are the problems of the system?

The present study focuses on the socio-ecological system that is present in the estuary formed at the main river-mouth (i.e., Bocas de Ceniza) of the Magdalena River (henceforth MRm-SES) which, at the same time, is a component of the deltaic system from the same river.

The Magdalena River basin is the largest in the northern Andes of South America. Along its axis live approximately 80% of the population in Colombia and 80% of the GDP of the country is generated. The sediment yield for this basin is the highest among the rivers draining in the Caribbean coast and the sediment discharges have the same magnitude of rivers with bigger basins (e.g., Amazonas, Paraná, and Orinoco) (Restrepo López et al., 2017). Moreover, the Magdalena contributes to 89% of the sediment discharged by the Colombian rivers along the Caribbean coast (J. D. Restrepo et al., 2021, p. 55).

The delta of the Magdalena River is formed in Colombia's central Caribbean region, and it is an area of upmost importance for the environmental and socio-economic dynamics of the Caribbean region in Colombia. The two main cities of the Caribbean region (i.e., Cartagena and Barranquilla Metropolitan Area – BMA) are located within its boundaries. Considering only the population of those two cities (i.e. 3 million people), the MRm-SES was home to nearly a quarter of the population in the Caribbean region of Colombia in 2018 (excluding Antioquia) (DANE, 2018). In economic terms, the Atlántico and Bolívar produce more than half and nearly 8% of the Caribbean region and Colombia's GDP during 2018, respectively. (DANE, 2021b).

Overall, the estuaries and deltas around the world show a general decline in the flow of water and sediments due to changes in land management and the constructions of dams. This reduced sediment input exacerbates coastal erosion processes and, thus, the loss of coastal wetlands (United Nations, 2021, p. 342). Contrary to that general trend, the situation in the Magdalena River delta exhibits and increase of sediment inputs mainly due to detrimental land management practices (J. D. Restrepo et al., 2015; Juan Camilo Restrepo et al., 2016; J. D. Restrepo et al., 2018).

The Magdalena River delta is affected from both Exogenic Unmanaged Pressures (ExUP) and Endogenic Managed Pressures (EnMP) (M. Elliott et al., 2017). The former, are those outside the study (or managed) area and their causes cannot be directly tackle within that particular system, however, the system still needs to deal with their consequences or state changes, such as sedimentary unbalance, climate change, eustatic sea-level change, soil denudation/erosion in the basin, sea surface temperature change, plastic litter influxes (transported by marine currents and fluvial fluxes), increased flux of contaminants (e.g. litter and toxic substances) and nutrient inputs from the Magdalena river, among others (Acosta-Coley et al., 2019; Bustos Usta & Torres Parra, 2021; J. D. Restrepo, 2008; J. D. Restrepo et al., 2015; Juan Camilo Restrepo et al., 2016; Tejeda-Benítez et al., 2018).

On the other hand, the Endogenic Managed Pressures (EnMP) are those that occur within the study area and can be directly managed. Some examples in the Magdalena delta and estuaries are litter and waste generation, nutrients and other contaminants inputs, untreated or inadequately treated wastewater disposal to soil and water bodies, deforestation, infrastructure construction, irruption of sediment inputs and the littoral drift, introduction of alien species, among others (Ávila & Gallo, 2021; Chacon et al., 2020; Portz et al., 2020; N. Rangel-Buitrago et al., 2019; N. Rangel-Buitrago et al., 2021; Torres-Bejarano et al., 2020; Tosic et al., 2018; Villate et al., 2020).

The ideal scenario – Defining Sustainability.

Considering the multiple problems that exist in such an important and complex system as the Magdalena River delta, how can the sustainability of this system be evaluated in order to obtain a comprehensive understanding of its state and based on those findings, design and/or prioritise effective management strategies that help improving the different domains that comprise the system? To answer this question, this study uses an adaptation of the Circles of Coastal Sustainability (CCS) framework developed by Natalia Alencar et. al. 2020 which, in addition to involving the economic, socio-cultural and environmental spheres (i.e. the widely disseminated concept of the three pillars of sustainability) (Future Ocean et al., 2017, p. 17), recognises the importance of a fourth domain related to the policy and governance of the other three. And this is because governance is a fundamental aspect to determine whether humankind can develop and thrive in a world of limited resources (P. de Alencar et al., 2020). After all, the sustainability concept necessarily incorporates a normative domain in order to derive clear directions for action and the implementation of appropriate measures (Future Ocean et al., 2015, p. 16).

Now, in order to select a set of indicators to assess the sustainability of the system, it is necessary, as a first step, to understand the concept of sustainability, which can often have different interpretations (Future Ocean et al., 2017).

For this assessment, the sustainability was defined by establishing a general set of conditions or characteristics which reflect the best status that a system could reach. These characteristics are based on the concepts from the SDGs, the OECD, and other secondary sources. They constitute by no means a set of final conditions that define ‘sustainability’ for every system, but they were regarded as a good starting point to conduct this assessment. Table 1.1 summarizes the sustainability descriptors for the four domains that comprise the CCS framework.

Table 1.1. Multidimensional sustainability goals for a system.

Environmental	**Social and cultural**
A small share of the energy comes from fossil fuels and, overall, GHG capture in natural areas is higher than the emissions. Not only the natural cover represents an important share of the system's area but there is a gaining trend of natural and seminatural landcover. Marine and/or terrestrial planning and/or protection mechanisms are significant at a regional level assuring prevention of pollution, equitable access to resources and without overexploitation. Conditions to keep biodiversity are present and they are reflected by a non-existent risk of extinction for any species (OECD, 2020, pp. 205–216; Pintér et al., 2014).	People's life expectancy approximates life span (the age a species can reach under optimal circumstances) suggesting no contribution of external conditioning factors such as income or gender-related inequalities, food scarcity, health problems resulting from poor environmental quality and/or lack of social interaction and support (e.g., suicides, substances abuse). People present a high degree or total satisfaction with their living conditions and, overall, experience more positive than negative feelings. There is a balance between work time, family commitments and leisure time. People have access to quality education. Literacy rates are high. Most of the people have access to recreational spaces (e.g. beach or parks) which are easily accessible in terms of time, distance and/or transport mode(OECD, 2020). "Demographic changes do not pose a risk to the integrity of natural ecosystems and societies", everyone has access to integral and high-quality health services as well as basic sanitation and hygiene services (Pintér et al., 2014). There is respect for and conditions promote the existence of different ideas, cultures, religions and traditions(Future Ocean et al., 2015).
Economic	**Governance**
Households have financial security (microeconomic). Investment in economic capital and infrastructure stock are done in a way that do not increase the pressures over the environmental domain or, in other words, deplete the natural capital (e.g. more GHG emissions or material footprint) (OECD, 2020) "Economic growth ensures an acceptable employment rate and decent jobs" (Pintér et al., 2014, p. 9) Horizontal (i.e., between socio-demographic groups such as by gender, age or education) and vertical (between those at the top and those at the bottom of the achievement scale in each dimension) inequalities are low. People can afford living in houses that provide sufficient space and good sanitary conditions without limiting their spending on other essentials (OECD, 2020). A small share of the population lives in multidimensional poverty. There are appropriate economic policies to support macroeconomic stability and resilience. R&D has significant increase in the green, blue and circular economy (Pintér et al., 2014).	All the citizens (regardless age, gender, ethnicity) actively participate in communitarian activities that shape the society they live in (e.g., elections, volunteering through formal organizations, among others). Corruption is inexistent. There is a very high degree of trust and representativeness (e.g. socio-demographic groups, ethnicities, gender) in the public institutions (OECD, 2020). A long-term but adaptative vision of sustainability is incorporated in all the plans and management strategies. Decentralized decisions and institutions at the local level are integrated with subsidiary bodies and strategies at the regional and international level. Progress in all domains is appropriately monitored and information is available for all the stakeholders (Pintér et al., 2014). Finally, it is expected that management includes instruments regulating the rights of use of common-pool resources, participatory decision making structures, conflict resolution mechanisms, a fair distribution of benefits and responsibilities and, when necessary, mechanisms to enforce compliance with regulations (Future Ocean et al., 2021, p. 276; Gari et al., 2017)

Source: the author.

Generalizing the idea that Gari et al. (2017, p. 9) suggested for the sustainable governance of the common-pool resources (i.e., setting a minimum temporal boundary) and extending it to the all the domains of coastal sustainability, it is important to highlight that the concept of sustainability in this study is based on criteria from sources whose timespan do not overpasses 2030-2050. In other words, what is sustainable now and in the following 2 or 3 decades, could change eventually. Therefore, the necessity of and adaptative vision for the system.

Purpose of this study

The SDG 14 aims to *“Conserve and sustainably use the oceans, seas and marine resources for sustainable development”.* But a sustainable use of the ocean and related ecosystems cannot be achieved without understanding its processes and functioning as well as without having coherent knowledge of the impacts of human activities (United Nations, 2021, p. 13) at different scales (local, national, regional and global). Hence, this study is important because it seeks to improve the knowledge basis for the integrated management of the Magdalena river-mouth socio-ecological system (MRm-SES).

As accurately described in the World Ocean Review - WOR 7: “*The term ‘Integrated Coastal Zone Management’ denotes a regulatory and governance approach in which coastal areas are recognized as a complex, dynamic system involving multiple interactions between human communities and marine and coastal ecosystems across zonal and sectoral boundaries. This means (...) that coastal issues can no longer be addressed solely within the parameters of the traditional [economic] sectors” (Future Ocean et al., 2021, p. 266)*

Therefore, the present study is an attempt to understand the main issues hindering the sustainability of the MRm-SES, leaving behind a sectorial view and moving towards a holistic approach that recognizes not only the multiple interactions that occur within the system but also the connections that exist with other compartments that have been commonly managed as separate components (e.g. the river basin and the sea) but, in reality, they work as whole interchanging matter and energy.

N**otes about this document and its structure**

This document is divided in five chapters besides the introduction. The second chapter ‘Scope of the research’ defines the ‘boundaries’ of the present study describing the hypothesis, objectives and research questions formulated for the present investigation. The methodology is presented in Chapter 3 which describes with more details the study area and the Circles of Coastal Sustainability (CCS) framework and how it was adapted to the MRm-SES context. The most significant changes compared to the original version of the CCS (i.e., applied as study case for the coast of Spain) correspond to the use of quantitative variables and the attempt to establish quantitative criteria to evaluate the system rather than using a qualitative approach. Additionally, the original graphical representation proposed by P. de Alencar et al. (2020) was redesigned.

The chapter four (4) contains the results, namely, the sustainability levels of each of the indicators, subcategories, categories, and domains from the MRm-SES which are summarized in the new graphical representation selected for communication purposes. The chapter 5 covers the management implications of the results presented in the previous chapter as well as the discussion on possible improvements for this assessment. Finally, the conclusions contain a summary of the key findings in the present study and the answers to the research questions proposed in chapter 2.

It is important to note that, in this document, every time that the term 'Study Area' is used, it corresponds to the area that was specifically defined in the methodology, unless otherwise stated.

Also, important to mention that according to the administrative division in Colombia, the study area contains municipalities from two departments: 19 from the Atlántico and 1 from Bolívar (i.e., <20% of the territory). However, the portion of Bolívar that is included is significantly smaller than the rest of the area, therefore, some of the information, specially the one concerning the Environmental domain, might be assumed as equivalent to the one from the department of the Atlántico. And the rationale behind this is because this information was only available at a departmental level, in other words, there is no information at municipal level and, assuming that the information generated for the department of Bolívar, which is extensive and spatially diverse, does not reflect appropriately the conditions in the stretch of territory of Santa Catalina. In any case, when the information was available specifically for Santa Catalina, it was used for the assessment of the corresponding indicators.

2 SCOPE OF THE RESEARCH

The present research corresponds to an integrated assessment of a socio-ecological system in the coastal area of Colombia, specifically, the Magdalena River delta and estuary at 'Bocas de Ceniza' in the central Caribbean region.

The Magdalena river-mouth is a major estuary on the Caribbean coast of Colombia. Identifying and understanding the key issues in the different domains of an estuarine system and how they interact with each other, is the first step to inform decision-makers and/or to define strategies for tackling the main problems and move towards a sustainable system.

2.1 HYPOTHESIS

The Magdalena River-mouth does not exhibit a high level of sustainability due to the incidence of multiple pressures and the lack of an integrative approach to tackle them. Because of this, it is expected that a holistic socio-ecological framework such as the CCS can be adapted for the Colombian context to evaluate the sustainability of a coastal system. Moreover, it can be used to identify priority issues and to define effective management strategies to improve the sustainability of the system under study.

2.2 OBJECTIVE

2.2.1 General objective

- To assess the multidimensional sustainability of the Magdalena river-mouth system in order to improve the knowledge basis for its integrated management.

2.2.2 Specific objectives

- To define the system boundaries for the Magdalena river-mouth system considering the different domains of the socio-ecological system.
- To define locally relevant indicators for the assessment of the distinct categories that comprise the multiple domains of the socio-ecological system (i.e., environmental, social, economy/governance).
- To assess the overall sustainability of the Magdalena river-mouth system

- To identify the categories and domains with poor and bad sustainability and the possible reasons behind that situation
- To discuss strategies to improve the management of the system regarding the categories with poor and bad sustainability
- To evaluate the advantages, challenges, and opportunities of implementing a holistic socio-ecological framework, more specifically, the CCS in the local context.

2.3 RESEARCH QUESTIONS

The present research started with the following question: Understanding sustainability in its broadest definition, that is involving the three classic pillars (e.g., environment, economy, and society) with an added domain related to governance, **Is the Magdalena River-mouth socio-ecological system sustainable?**

From this main interrogative other complementary questions emerged:

- How to define the boundaries of my system when its sustainability is closely intertwined with adjacent systems?

- What indicators can be used/developed to assess the sustainability of the system using the circles of coastal sustainability methodology?

- What are the categories/domains that require most attention/action based on the sustainability scores obtained in the assessment?

- Can a socio-ecological assessment of the Magdalena river-mouth system help to improve the management of the study area?

- What are the difficulties, advantages, and opportunities of using a socio-ecological framework, such as the CCS, to assess Colombia’s coastal systems?

3 METHODOLOGY

3.1 STUDY AREA

The present assessment is focused on the socio-ecological system of Magdalena River delta and estuary at ‘Bocas de Ceniza’. It covers a stretch of coast which encompasses 90-km-lenght coastline with NE-SW primary orientation and some sectors E-W-oriented (See Figure 3.2). The study area has an extension of 390,000 ha, 60% corresponds to land and the remaining 40% corresponds to the marine area. From the total area, a small portion (i.e., 11%) is within the authority of the Santa Catalina municipality (Bolívar department) whereas most of the study area is located within the administrative boundaries of the Atlántico department. It is important to note that every time a reference to ‘Study Area’ is made in this document, it corresponds to the red polygon in Figure 3.2, unless otherwise stated.

The Magdalena River delta is arcuate and has an estimated area of 1,690 km^2 formed by the river of the same name. After passing through Calamar, the Magdalena River splits and most of the flow (i.e., > 90%) continues its course to the main mouth at ‘Bocas de Ceniza’, near the city of Barranquilla. Additionally, the river has a secondary mouth at Cartagena's and Barbacoas' bay where a tenth of the streamflow is discharged through an artificial structure called ‘Canal del Dique’. Finally, the waters from this river represent an important influx of fresh water for the largest and most complex of Colombia's swamp marshes the 'Cienaga Grande de Santa Marta - CGSM’ (Ávila & Gallo, 2021; Juan Camilo Restrepo et al., 2016). Precisely, Figure 3.1 provides a simplified graphical representation of the Magdalena River basin and how it is connected to the Caribbean Sea.

Delimitation of the study area was, first and foremost, based on environmental aspects, namely, drainage basins discharging its waters to the left margin of the lower Magdalena River (between Calamar and Bocas de Ceniza) and directly to the Caribbean Sea; the continental shelf (i.e., isobath -200m or 12 nautical miles from the low water line in areas where the continental shelf was very narrow such as in front of 'Bocas de Ceniza'). Further adjustment was done based on administrative aspects (e.g., urban settlements, municipal and departmental boundaries). In cases where the administrative criteria led to an obvious disruption of a continuous habitat (e.g., ‘Ciénaga del Totumo’ that is shared between the Atlántico and Bolívar departments), preference was given to the environmental criterium.

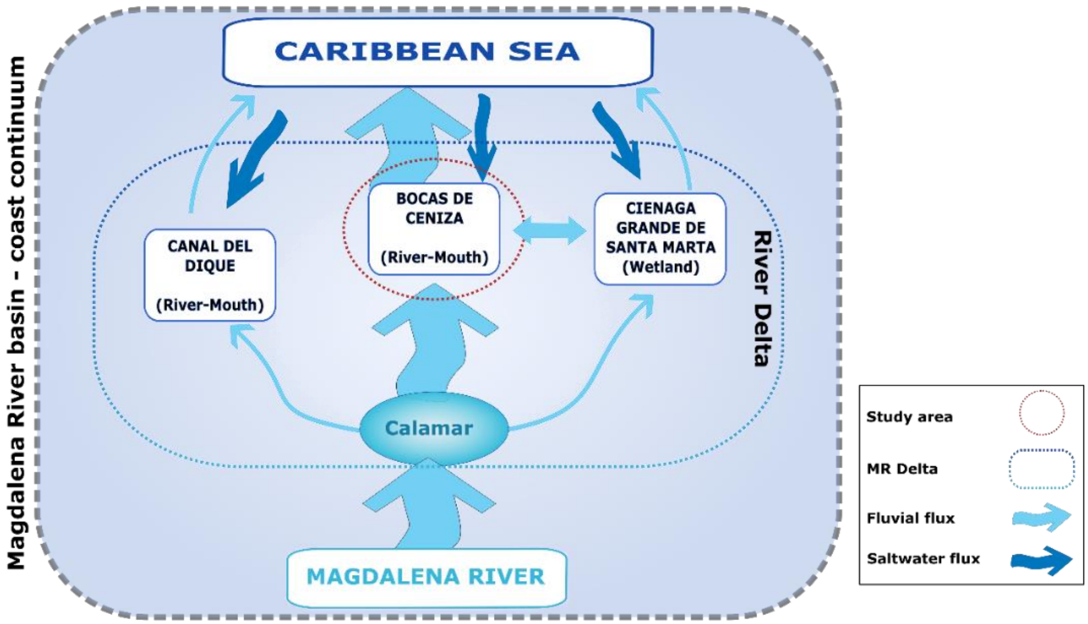


Figure 3.1. The Magdalena River basin – coast continuum. Conceptual diagram.

Source: the author.

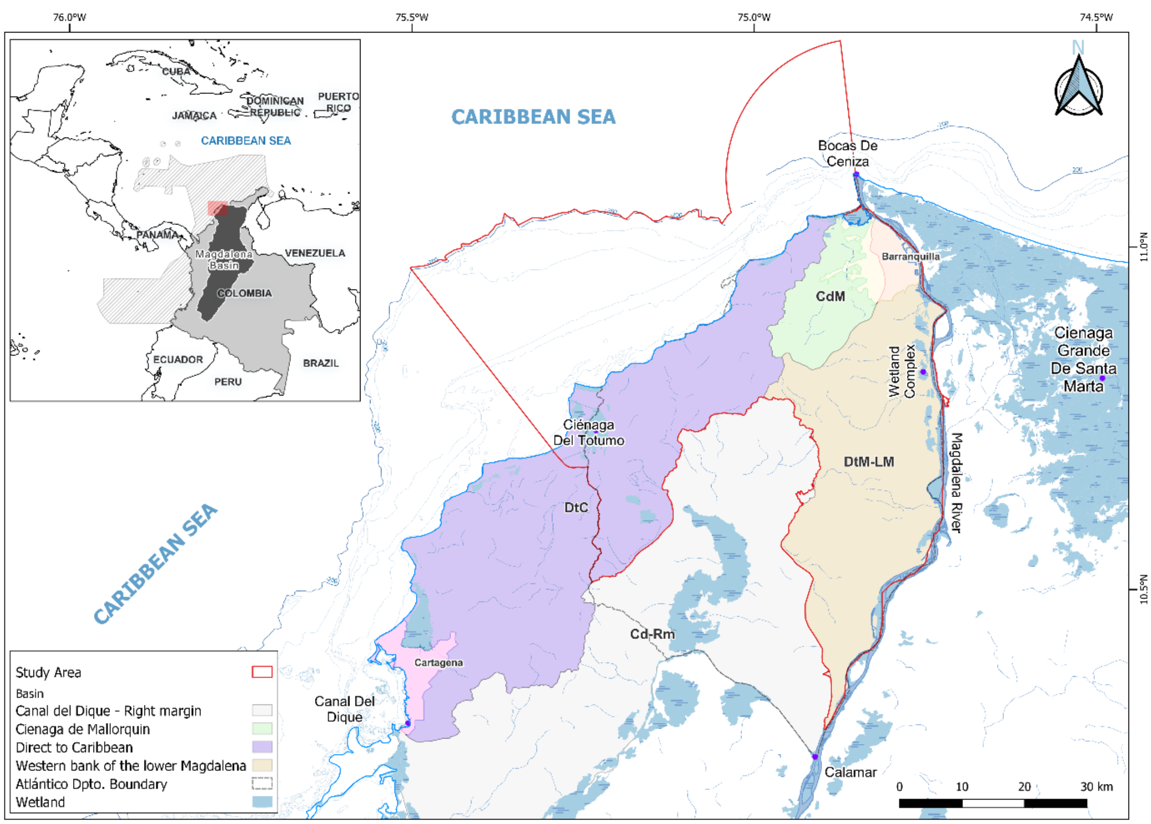


Figure 3.2. Location of the study area (Coordinate Reference System EPSG 4326 – WGS 84)

Source: the author.

3.1.1 Climate

The Atlántico presents seasonal variations controlled by the shifts in the Intertropical Convergence Zone (ITCZ). Hence, there are two wet periods (i.e., the main one goes from Sep-Nov and another one between Apr-May) and two dry periods (i.e., the main one goes from Dec-Mar and the second one, locally referred as 'Veranillo de San Juan', between Jun-Aug). The average number of days with precipitation in the Atlántico ranges between 50 - 100 days a year, and the mean temperature is 26-28 °C. (IDEAM, 2015) Winds have mean velocity values lower than 12 m/s. The highest mean values are associated with winds blowing from the NE during the dry period (Jan-Mar). Lower mean values are registered during the wet season (Sep - Nov) when the winds blow from the east. (N. Rangel-Buitrago et al., 2017, p. 144)

3.1.2 Geomorphology

Before all the engineering structures built after 1936 to prevent siltation, facilitate commercial navigation and to increase and concentrate the flow along the main channel, the Magdalena river delta could be classified as wave-dominated, with *"presence of extensive beach ridges, several river-mouths and barrier islands, swamps, and an extensive network of interconnected coastal lagoons and frontal bars in the distributaries"* (Juan C. Restrepo et al., 2020, p. 3). However, the main discharge channel has been heavily modified since, producing impacts on the surrounding coastal geomorphology. Up to today, the Magdalena river-mouth is set to have a width of 430 m, a minimum depth of 9.15 m and the western and eastern jetties has lengths of 7.4 and 1.4 km, respectively. (Juan Camilo Restrepo et al., 2016, p. 4)

In this region, the tectonic processes have shaped the current topography and the geomorphological units vary from low-medium mountain areas to coastal plains. (N. Rangel-Buitrago et al., 2017, p. 143).

The geomorphology in the coastal zone of the Department of Atlántico can be grouped in two: 1. Geomorphological units associated to high coasts; and 2. Geomorphological units associated to low-lying areas. The first group is widely distributed along the study area. It is dominated by hills and cliffs with altitudes lower than 125m Above Mean Sea Level (AMSL). This geomorphological unit has been shaped and eroded by the sea and is characterized by wide inlets and rocky promontories, resulting in an irregular coastline. Additionally, some sites present wave-cut platforms (abrasion platforms). Another characteristic unit within this group are the salt flats and flood plains, which are prone to tidal flooding. The second group is formed by 9 different geomorphological units including: spits, coastal bars, beaches, mangrove areas, coastal lagoons, swamps, alluvial plains, coastal plains and water bodies. (DIMAR & CIOH, 2013, pp. 97–106)

3.1.3 Hydrology

The Atlántico department is divided into four (4) drainage basin (see Figure 3.2). The four (4) drainage basins (or hydrographic sub-zones as called by the IDEAM in Colombia) are ‘Canal del Dique – Right Margin’ (Cd-Rm), ‘Ciénaga de Mallorquin’ (CdM), ‘Direct to Caribbean’ (DtC) and ‘Western bank of the lower Magdalena’ (DtM-LM). A brief description of each of these basins is presented in Table 3.1.

Table 3.1. Drainage basins in the Atlántico department.

Name	Brief description	IDEAM Code	Abbreviation in this study
Ciénaga de Mallorquín	The area is 26,000 ha approx. The main watercourse is 'Arroyo Grande' whose main tributaries are 'Arroyo Granada' and 'Arroyo Hondo'. The municipalities of Puerto Colombia, Barranquilla, Galapa, Baranoa, Soledad and Tubará are part of this basin. 'Arroyo Hondo' and 'Arroyo Santo Domingo' watercourses receive the stormwater and treated wastewater from Barranquilla. Three swamps are in this basin: 'Ciénaga de Mallorquín', 'Lago del Cisne' and 'Ciénaga de Manatíes'.	SZH: 2909	CdM
Direct to Caribbean	Located in the north-western part of the study area it covers eight municipalities of the Atlántico and other municipalities of Bolívar department among which there is Santa Catalina (included in this study). Its total extension is 187,000 ha approx., however, only 82,000 ha (i.e., 44%) are within the study area. This basin contains more than fifteen creeks, and the main swamps are: 'Ciénaga del Totumo', 'Ciénaga de Balboa', 'Ciénaga La Redonda', 'Ciénaga El Rodeo', 'Ciénaga Uvero', 'Cienaga de Luruaco', 'Laguna de Puerto Colombia', among others.	SZH: 1206	DtC
Western bank of the lower Magdalena	With an area of 115,000 ha approx. in this basin there are more than eleven swamps and twelve creeks. The main creek in this basin is the 'Arroyo Grande'. Most of the creeks in this area drain its waters to any of the swamps that form a wetland complex which is composed for the following water bodies: 'Complejo Lagunar de Malambo', 'La Bahía' swamp, 'Ciénaga Grande de Malambo', 'Ciénaga El Convento', 'Ciénaga de Santo Tomás', 'Ciénaga de Sabanagrande', among others.	SZH: 2904	DtM-LM
Canal del Dique	It has an area of 404,000 ha approx. and covers three departments and twenty-five municipalities. Its water drains to Cartagena Bay through an artificial channel named 'Canal del Dique'. **Important: This basin is out of the scope of the present study.**	SZH: 2903	CD-RM

Source: Gallo Vélez et al. (2022)

The present study focuses the CdM, DtC and DtM-LM drainage basins, considering that the pressures and impacts that are manifested in them can have direct or indirect repercussions on the coastal zone and marine waters. The first basin (i.e., Cd-Rm), in the south of the Atlántico, was excluded since it is part of the 'Canal del Dique' subsystem, which is out of the scope for the present assessment.

3.1.4 Oceanography

The Magdalena River-mouth at 'Bocas de Ceniza' consist of a *"stratified, turbid estuary, with a microtidal regime"* (Ana Carolina Torregroza-Espinosa, Restrepo, Escobar, et al., 2020, p. 2). According to the concentration of suspended solids (TSS), the Magdalena estuary can be classified as 'turbid' during the high-flow period and 'extremely turbid' during the low-flow period, which is the same order of magnitude of the Yangtze, Huang He and Amazon rivers. (Ana Carolina Torregroza-Espinosa, Restrepo, Escobar, et al., 2020, p. 2)

The area presents a mixed diurnal tidal regime with amplitudes between 0.2 and 0.6 m. Wave height can reach 5 m under the influence of cold fronts and the pass of Trade winds between January and March. (Ávila & Gallo, 2021, p. 2)

Surface water temperature in the estuary varies between 26 - 31 °C. The salinity values can be 0 PSU within the river mainstream and 33 PSU in the adjacent coastal zone, creating density gradients that define a buoyant plume. The Magdalena River influx to the Caribbean Sea leads to the formation of 3 differentiated surface water areas which are seawater (outside of the diffuse plume), river plume (solid plume) and a mixing area or plume front. (Ana Carolina Torregroza-Espinosa, Restrepo, Correa-Metrio, et al., 2020, p. 13)

The average significant wave height (Hs) is 1.6 m with an average peak period (T) of 7 s. From November to July, the waves are dominated by NE swells; for the remaining time waves from NW, WSW, and even SW occur. The lowest Hs occurs between August and October (1.5 m) while the highest Hs are present from November to July with magnitudes exceeding 2m. (N. Rangel-Buitrago et al., 2017, p. 144)

The northern trade winds are the main forcing mechanisms of the currents in the Caribbean. *"Close to the Magdalena River mouth, ocean currents have an average velocity of 0.3 m s^{-1} during the dry season, and 0.1 m s^{-1} during the wet season with a southward direction in both seasons"*

(Ana Carolina Torregroza-Espinosa, Restrepo, Correa-Metrio, et al., 2020, p. 2) Low-pressure systems are common in the Caribbean basin between June and November, generating strong winds, heavy rain and extreme waves that affect the study area. Additionally, cold fronts occurring between Feb-Mar can cause extreme wave events whose Hs can be increased by the combined effects with the Trade Winds blowing from ENE. (N. Rangel-Buitrago et al., 2017, p. 144)

3.1.5 Land used and ecosystems

The terrestrial portion of the study area is dominated by agricultural lands (e.g. pastures, heterogeneous agricultural areas, permanent and transitory crops, among others); followed by forests and seminatural areas (e.g. forests, scrub and/or herbaceous associations and open spaces with little or no vegetation); the artificial surfaces are the third largest group (e.g. urban fabric, industrial and commercial areas, infrastructure areas and mine extraction sites among others); finally, the wetlands and water bodies account for less than 10% of the total cover (e.g. water bodies and courses, inland swamps, coastal lagoons, among others).

Related with the land cover and climate are the ecosystems. In the study area, it is possible to find marine, aquatic, terrestrial and coastal ecosystems that are natural or transformed. According to the Map of Continental, Coastal and Marine Ecosystems from Colombia (2017), two biomes are present in the terrestrial portion of the study area: the Tropical Alternohygrometric Zonobioma and the Pedobiome of the Tropical Humid Zonobioma. These biomes encompass a diverse group of general ecosystems. Cattle agroecosystems and mosaics of crops and pastures are the largest ecosystems (together correspond to 50% of the area), followed by artificialized land, agro-ecosystems of crops, pastures and natural spaces, rivers and dry basal forest that represent almost a third of the land surface of the study area. Additionally, there are other ecosystems and habitats that are of great importance in the study area such as coastal lagoons, mangroves, tidal flats, soft bottoms of the continental shelf and rocky coastline and cliffs (IDEAM, IAvH, et al., 2017; López Rodríguez et al., 2012).

3.1.6 Demographics

All the municipalities within the department of the Atlántico plus the municipality of Santa Catalina (Bolívar department) were included in the socioeconomic characterization of the study area. According to the DANE census from 2018, the population in the whole department of the Atlántico grew over 15% since 2005 reaching more than 2.5 million inhabitants by 2018. From the total, 95% lives in urban areas and the other 5% lives in small, populated centres or dispersed along the rural area. The projections from DANE also show that the population is expected to increase by 24% in the following 15 years, surpassing 3 million inhabitants by 2035. (DANE, 2018). In terms of geographic distribution, more than 80% of the population is in the municipalities that form the Barranquilla Metropolitan Area - BMA (i.e., Barranquilla, Galapa, Malambo, Puerto Colombia and Soledad) which is the closest to the mouth of the Magdalena River in 'Bocas de Ceniza'.

3.2 SOCIO-ECOLOGICAL ASSESSMENT FRAMEWORK

Currently, there are different frameworks for the assessment of socio-ecological system, however, they are usually focused in either the social domain (e.g., How's Life?, The safe and just space for humanity) (OECD, 2020); the environmental domain (e.g., Planetary Boundaries, Ocean Health Index) (Halpern, 2020; Steffen et al., 2015); or in evaluating the causes and responses to particular problems or ecosystem services (e.g., DPSIR, DAPSIWRM and Ecosystem Services Approach) (M. Elliott et al., 2017; Patrício et al., 2016). In other cases, a more holistic approach has been considered (e.g., Circles of Sustainability) (James, 2015), however, that framework was not developed taken into consideration the particularities of the coastal areas. Hence, this study uses, as a main tool for the socio-ecological assessment, the Circles of Coastal Sustainability (CCS) which was developed with the idea of having a multidimensional approach to evaluate coastal systems (P. de Alencar et al., 2020).

3.2.1 Overview

The Circles of Coastal Sustainability (CCS) is a framework developed to assess the *"critical processes that facilitate/constrain sustainability of the world's coastal zones. The (…) framework can support management by identifying key features that influence environmental sustainability and human well-being"* (P. de Alencar et al., 2020, p. 1)

To achieve this, the CCS framework uses a transdisciplinary approach that focuses on four (4) domains: Environment, Society and culture, Economy, and Governance. Those domains are divided in five (5) categories and, each category, can be sub-divided into different sub-categories allowing the assessment to account for the distinct levels of resilience, resistance, and hysteresis of local conditions. Also, assessing the different categories that belong to the different domains, provides a holistic approach to problem-solving based on the a systemic view of economic and social aspects coupled with environment, ecology and policy (P. de Alencar et al., 2020, p. 6).

Despite being developed and implemented for the first time in the European Union context (i.e., Spain), The CCS framework was constructed in a way where domains and categories (see Figure 3.3) should remain invariable to avoid *“reductionist efforts focused on individual components that can overlook critical interactions"*. However, subcategories and their indicators are intended to be selected upon local specificity and data availability which allows its adaptation to other coastal areas of the world. (P. de Alencar et al., 2020, p. 6). All the details about the rationale behind the creation of the framework and its methodology can be consulted in P. de Alencar et al. (2020).

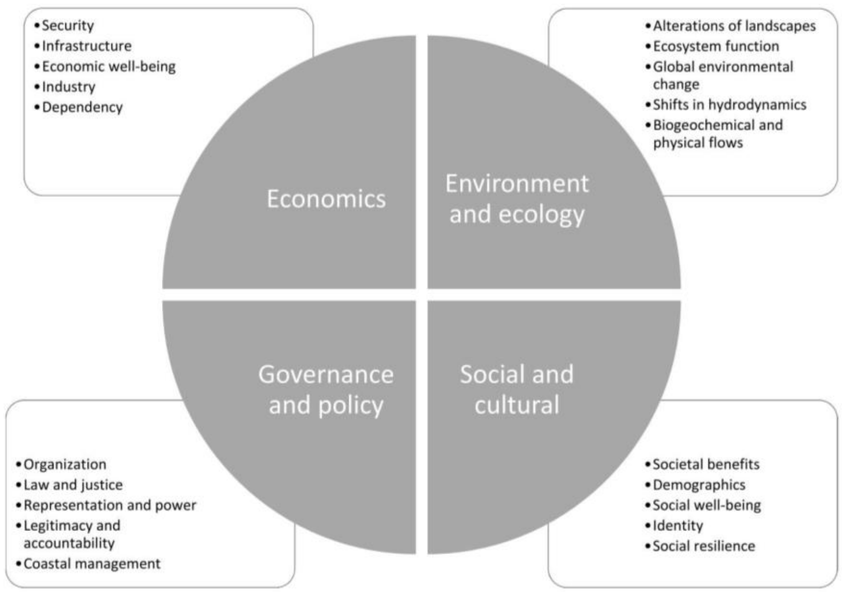


Figure 3.3. Graphical representation of the CCS framework showing the four domains with their respective categories.

Source: P. de Alencar et al. (2020, p. 6)

3.2.2 Subcategories and Indicators

As mentioned above, the CCS framework allows for the selection of sub-categories and indicators that are adapted to the local context. A summary explanation of the indicators chosen for the Magdalena River-mouth system is presented below.

Where possible, the chosen indicators correspond to those officially used at the national or international level (e.g., OECD or SDG indicators). Where insufficient data was available for an official indicator, or to close data gaps, other metrics from secondary and unofficial providers were selected. *“The selection criteria included the practicability of each indicator, the availability of data to support them, and the communicability of the information conveyed by them to managers and other stakeholders”* (P. de Alencar et al., 2020, p. 10).

3.2.2.1 Environmental domain

The environmental domain is assessed through the five indicators that are explained below:

3.2.2.1.1 Alteration of landscapes

This category was assessed through two subcategories: 'Land' and 'Shoreline'. The chosen indicators were 'Land-cover change' with a particular focus in the Tropical Dry Forest (TDF) change; and 'Shoreline armouring' (also known as hardening), respectively.

Land cover maps from 2002 and 2018, elaborated by the IDEAM according to an adapted version of Corine Land Cover (CLC) methodology, were used to calculate land cover change by major group (i.e., Artificial surfaces; Agricultural areas; Forests and semi-natural areas; wetlands; and water bodies) and their corresponding proportion within the study area. Additionally, secondary sources provided information on TDF loss (Juanita et al., 2019; Schubert et al., 2018). The shoreline armouring indicator took the information provided by N. Rangel-Buitrago et al. (2018) to estimate the percentage of the coast where hard protection structures have been built based on the total length of the protection structures (regardless their position to the coast – parallel or perpendicular) and the total length of the shoreline in the study area.

3.2.2.1.2 Ecosystem function

This category was assessed by using three subcategories, namely, Biodiversity Loss, Ecosystem services, and Biodiversity protection. The first subcategory uses the proportion of species which belong to any of the categories of the IUCN Red List of Threatened species as an indicator. The second subcategory was assessed with a 'Natural hazard Regulation' indicator, using the same approach from the Ocean Health Index (OHI) (Halpern et al., 2012; Samhouri et al., 2012). And finally, the biodiversity protection was measured using as a proxy the share of protected areas (in any category of protection - e.g., national/regional/local natural park, special management district, Civil Society Nature Reserve, among others) within the study area.

3.2.2.1.3 Global environmental change

This category was divided in two different subcategories, namely, 'Climate Change' and 'Natural Change'. A total of five (5) indicators were selected for the climate change subcategory: Sea-level change rate compared to global average; Sea surface temperature change; Atmospheric temperature change; Rainfall change; and Net Greenhouse Gasses (GHG) emissions. The 'Natural Change was assessed through the frequency of extreme events (i.e., River Flooding, Windstorms, Landslides, Rain, Wildfires, Storms, Swell, Drought, Torrential flood, and Others) reported for the Atlántico since 1980.

3.2.2.1.4 Shifts in hydrodynamics

For the purpose of assessing the sustainability of the study area, waves were chosen considering that they are one of the main factors involved in coastal development (i.e. movement of sediments directly or through wave-induced currents, causing longshore drift of sediments and, therefore, influencing the morphological processes along the coast). (Davis & FitzGerald, 2020). In this case, rather than selecting multiple parameters but trying to avoid the omission of important information, it was decided to use the Wave Energy Flux (WEF) to assess the hydrodynamic conditions of the study area, considering that this variable integrates the most important parameters when it comes to waves description: significant wave height (Hs) and periods (Tp) (Orejarena-Rondón et al., 2022).

3.2.2.1.5 Biogeochemical and physical flows

For this assessment, four subcategories have been selected: Freshwater contaminants, Marine Contaminants, Freshwater cycles and Sediment cycles.

The first subcategory was assessed through the 'Freshwater Suspended Sediment Load – SSL' which serves not only to understand potential effects on the turbidity of the estuarine waters but also as a proxy for the transference of contaminants (nutrients, metals, and other potentially hazardous elements) from the river basin to the coastal zone. The second category uses a multiparameter index known as Marine Water Quality Index - MWQI (developed by the INVEMAR in Colombia) which act as a state indicator and that is calculated based on eight (8) physic-chemical and microbiological parameters, namely, dissolved oxygen (DO), Biological Oxygen Demand (BOD), pH, Nitrates (NO3), Dissolved Inorganic Phosphorus (PO4), Total Suspended Solids (TSS), chlorophyll-a (CLA) or Dissolved and Dispersed Hydrocarbons (HPDD), and Faecal Coliforms (CTE) (INVEMAR, 2021).

The third subcategory uses an index of known as Water Regulation Index (WRI) which provides an idea of the streamflow variability and is described in detail within the 'National Water Study'

(IDEAM, 2019). Finally, the sediment cycles were measured with ‘erosion/accretion rates’ along the coast using secondary information from N. G. Rangel-Buitrago et al. (2015) and INVEMAR (2017).

3.2.2.2 Social and cultural domain

The Social and Cultural domain was assessed with the following five indicators:

3.2.2.2.1 Social benefits

This category was assessed only through one subcategory: ‘Goods and services’. The social benefits in coastal settings are easily measured through provisioning services such as fish protein for self-consumption or trade from both artisan and industrial fisheries. In the study area there could be other goods and benefits such as the use of mangrove and tropical dry-forest wood for construction or cooking, however, reports on this latter use with detail information about rate of consumption or other quantifiable figures were not found by the author. Hence, the social benefits which are intrinsically related to the ecosystem services in the study area were measured by looking at the status of the fishing stocks (i.e., Catch by stock status) as a proxy indicator of the resource availability and the sustainability of the fishing methods used by artisan and industrial fisheries along the Caribbean coast (OHI, 2022).

3.2.2.2.2 Demographics

‘Population growth’ and ‘Social class’ were used as subcategories to assess the demographic dynamics from the study area. All the municipalities within the department of the Atlántico (i.e., twenty-two municipalities and one special district) plus the municipality of Santa Catalina (i.e., Bolívar department) were included in the socio-demographic characterization. Using an oversimplified approach based on the reasoning that the increase of population in a territory normally implies greater pressures on it, the evaluation of the first subcategory uses the net growth rate (i.e., accounting for migrations, births, deaths) as an indicator. The other subcategory, 'Social class' was assessed based on the incidence of income poverty (i.e., assesses the household's ability to purchase goods and services), which is an indirect measure of poverty reported annually by the DANE (DANE, 2019, p. 2).

3.2.2.2.3 Social well-being

This category was divided in four subcategories: Subjective well-being, Food security, Water security and Health. For the first subcategory, a well-known indicator of 'Subjective well-being' was chosen. This indicator is the same used by Organisation for Economic Co-operation and Development - OECD and the Sustainable Development Goals - SDG. The second subcategory is evaluated with the indicator of 'Prevalence of food insecurity' as defined in the Nutritional Status National Survey (ENSIN 2015) (UNAL et al., 2020). For water security, specifically, the water for human consumption, this assessment used the Water Quality for Human Consumption Risk Index (IRCA) used by the Ministry of Health in Colombia. Finally, as a health indicator, the percentage of people who are affiliated to the General System of Social Security in Health (SGSSS) was used.

3.2.2.2.4 Identity

Identity was split in two subcategories: Sense of self and Sense of Place. For the former, the indicator selected was the 'Inter-census change in the ethnic population' namely, the population that recognises themselves as belonging to the following groups: Black, Afro-Colombian, Raizal[1] and Palenquero[2] population, as well as the Indigenous or Aboriginal people. The second subcategory was evaluated using an approach based on the Ocean Health Index – OHI indicators where the number of touristic attractions (including places and events) are used as a proxy for the 'sense of place'. The Lasting Special Places/traditions indicator measures the status of conservation and importance of those locations and/or traditions that contribute to the coastal related cultural identity (OHI, 2022).

3.2.2.2.5 Social resilience

The social resilience of the system is evaluated through the following subcategories: Education; Climate change adaptation; and Risk Management. The first subcategory was assessed through the 'Literacy of the adult population' indicator. This indicator measures the percentage of people who can both read and write a short simple statement on everyday life which is considered an essential skill to communicate and receive written messages and to promote critical thinking.

To assess social resilience regarding climate change, the Relative Effort Indicator (IER) was used. The IER *"measures the adaptation investment effort of a department considering its GDP compared to the national GDP and its relative climate change risk level compared to the country's*

[1] People from San Andrés y Providencia Islands
[2] People from San Basilio de Palenque

average risk level” (DNP, 2021). It is important to highlight that the IER is specifically focused on the adaptation strategies, leaving aside the mitigation aspects which are measured through a different indicator.

Additionally, an indicator of ‘Preventive risk management investment’, was calculated based on the total investments in knowledge of risk, risk reduction and governance improvement, reported for the Atlántico department[3] and Santa Catalina municipality during the 2018 period.

3.2.2.3 Economic domain

The main source of information for this domain was the official information provided by the National Administrative Department of Statistics – DANE and was complemented with other secondary sources. It is important to note that every time the local currency (Colombian Peso – COP) is converted to USD the exchange rate applied is 1USD = 2,957 COP, unless otherwise stated. The five categories that are used to assess this domain are explained below.

3.2.2.3.1 Security

Economic and financial security for the study area were assessed through the following sub-categories: Livelihood, Income Gender Gap, and Employment patterns. The ‘Livelihoods’ subcategory was assessed through an indicator of the ‘relative change of GDP from ocean-related activities’, using an approach adapted from the ‘Livelihood and economies’ goal from the OHI (OHI, 2022). The second subcategory was assessed through a ‘Gender wage gap’ indicator, which is defined by the OECD as the difference between male and female median wages divided by the male median wage. Finally, the employment patterns were measured through the ‘unemployment rate’ which is defined as “*the percentage ratio between the number of people who are looking for a job (DS) and the number of people in the labour force (PEA).”* (DANE, 2022)

3.2.2.3.2 Infrastructure

This category was divided in four subcategories: Energy supply, Tourism, Transport and Access.

[3] The total investment for the Atlántico department was preferred rather than the investments on the municipalities within the study area exclusively, considering that more than 80% of the municipalities are in the SA and some of the investments from the department are transversal, in other words, their scope is broader than a single municipality

The first subcategory was evaluated with two indicators: the share of the population with access to electricity (information provided by DANE) and the share of energy generated from renewable sources. For the latter, it is necessary to look at the national energetic matrix that, anyway, provides a fair estimation of the overall sustainability of this sector and its implications for the Caribbean region and the Atlántico's coast. Therefore, reports from the Colombian Energy Balance – BECO, the Mining and Energy Planning Unit – UPME and the DANE 2018 census were the base to estimate the following variables: percentage of houses connected to the electricity network in the study area (DANE, 2018) and Share of energy sources in the composition of supply at a national level (UPME, 2019).

In the case of 'Tourism' the hotel occupancy was used as an indicator to evaluate tourism related infrastructure. The percentage of cargo and passengers mobilized by transport mode was used as a proxy indicator to evaluate the transport-related infrastructure under the assumption that a bigger proportion of goods and people mobilized by each mode is related to a more developed and accessible infrastructure (i.e., in terms of availability and costs). Finally, the 'Access' subcategory was assessed by looking at two sub-indicators: the availability of quality port infrastructure and the road quality based on the annual reports from the INVIAS.

3.2.2.3.3 Economic well-being

Well-being cannot be measured alone in economic terms, there are other aspects such as health, knowledge, safety, subjective well-being, among others (OECD, 2020). However, this category strictly assesses the economic domain of well-being by using the following two indicators: The GINI index, associated to the 'Equality' subcategory; and the 'Household income devoted to housing costs' used to assess the 'Housing affordability' subcategory.

3.2.2.3.4 Industry

Two subcategories were used for assessing this aspect: (1) The 'Renewable Industry' that was assessed through the 'share of the Atlántico's GVA generated by sustainable industries' as an indicator. For this purpose, the sustainable activities are those from the tertiary group associated with accommodation and food services; Professional, scientific, and technical activities; Arts, entertainment, and other service activities.

The second subcategory is the ‘Extractive industry’ which was assessed with two sub-indicators. One has to do with the ratio between the GVA generated by extractive activities (i.e., Agriculture, livestock, and fishing – ALF and, Mining and quarrying – M&Q.) and the GVA of sustainable activities, under the assumption that a system where the GVA of extractive activities exceed the economic GVA from the sustainable group is going in the wrong direction towards sustainability. However, it cannot be ignored that activities such as agriculture and fishing provide the vital elements for life, and it would be neither realistic nor beneficial to expect they will disappear. In fact, the purpose of the second sub-indicator is to account for this aspect.

All the GVA information for the year 2018 and the preceding period was taken from the National Departmental Accounts - DANE (2021b)

3.2.2.3.5 Dependency

This category was divided in the ‘Resource dependency’ and ‘Resources diversity’ subcategories. The former was assessed using the ‘Relative change of overall workforce within blue economy’ indicator. While the latter used an indicator of ‘Livelihood diversification in small-scale fishing households. Information for the former was obtained from the DANE-GEIH (2018).

For the second indicator, the results from a different area with similar conditions were used. The work from Maldonado et al. (2022) was considered useful to portray a rough idea of the livelihood diversification in fishing and non-fishing households from the study area (Higinio Maldonado et al., 2022, pp. 3–4). Considering that the communities surveyed by the authors exhibit similar socio-demographic characteristics to those present in the Atlántico's coastal zone (e.g., both are in the central Caribbean within the same Environmental Coastal Unit (UAC), use of similar fishing arts, similar cultural characteristics).

3.2.2.4 Politics and governance

This domain was assessed using the five (5) categories that are explained below:

3.2.2.4.1 Organization

Society participates directly and indirectly in the management of the coastal zone through local community councils, ethnic communities, NGOs, educational institutions and civil associations. (CRA & ASOCARS, 2014), all of them can play different roles simultaneously (e.g. extractors, beneficiaries and influencers) (Newton & Elliott, 2016). The number and quality of the Civil and NGOs within the study area was used as the chosen indicator to evaluate this category that was not divided into subcategories.

3.2.2.4.2 Law and justice

This category was not divided into other subcategories and its assessment is based on information provided in Botero et al. (2020) and CRA (2020). The former, evaluated the evolution of the integrated coastal zone management in Colombia based on ten principles that include policy, law, and institutions and, tools, among others. The second document, besides providing insights on the current management strategies, contains information about the legislation and norms which are applicable for the study area.

3.2.2.4.3 Representation and power

This category was divided in two subcategories: Participation in elections and Women representation. For the former, the voter's turnout in national (i.e., president, chamber, and senate) and local (i.e., department and municipality) bodies are reported based on the records from the 'Registraduría Nacional del Estado Civil' and the Electoral Observation Mission. This indicator was chosen because it can be associated to legitimacy issues and calls into question the representativeness of those elected. Moreover, it can be related to multiple aspects of the society including: economic level, education, population age and size and psychological aspects, among others (Bedoya Marulanda & Nieto Palacio, 2020).

Woman representation was measured with a set of sub-indicators related to power and decision-making in the private and public spheres. All the information is available at the Colombian Women's Observatory. The indicators used were: Percentage of women mayors in 2019 and Percentage of women elected in the House of Representatives (Vicepresidencia de la República, 2022).

3.2.2.4.4 Legitimacy and accountability

This category, which has no associated subcategories, was evaluated with an indicator developed by the Transparency Secretariat of the Presidency of the Republic. The National Anti-Corruption Index - INAC is an *"index of indices based on objective and official data"* and its objective is to measure the degree of implementation of *"policies or tools to fight corruption, in order to give a* *holistic view of institutional capacities to confront the phenomenon"* (Secretaria de Transparencia, 2020). In other words, this indicator does not directly assess corruption within Colombian institutions, which may be present despite the existence of mechanisms to combat it. The INAC is composed by multiple variables, components, and dimensions, as shown in Figure 3.4. For more details on the methodology for the calculation including the weighting factors for each variable and component, please refer to the original reference.

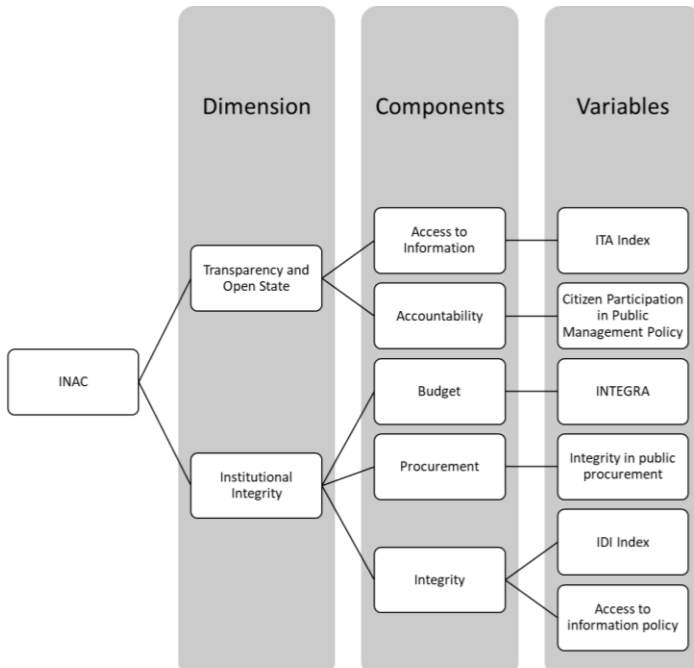


Figure 3.4. Structure and components of the INAC. Note: ITA - Transparency and Access to Information Index. INTEGRA – Integrity Index

Source: Adapted from Secretaria de Transparencia, 2020

3.2.2.4.5 Resource Management

The management of natural resources in the study area was assessed with two subcategories: Management plans and Decentralization. For the former, the assumption that a greater number of planning instruments equals greater sustainability of the system is not entirely true if one considers that, in some cases, the instruments are not effective during their implementation. However, measuring the effectiveness of individual instruments is a complex and lengthy task. Thus, for this indicator, a comprehensive list of plans that can work towards management and sustainability of the coastal zone was taken from the annex 5 in the Res. 768/2017, 17/April/2017. Based on this list, it was identified which and how many plans should exist in the study area and a percentage of implementation was determined by counting only those plans that are updated, operational or in an advanced stage of development

Another aspect that was consider relevant for the assessment of the resource management was the level of decentralization and existence of public responsibilities distribution in relation to the management of coastal space and resources. In this aspect, Botero et al. (2020) made an analysis of the decentralization and distribution of responsibilities for the coastal zone management in Colombia.

3.2.3 Sustainability score: Defining thresholds, normalization, weighting, and aggregation

Sustainability score or levels for each indicator range from one (1) to five (5) where the lowest score represents the worst condition and is described as 'Bad' and the highest score is obtained when the system presents optimal conditions and is considered 'Excellent', in-between is possible to find the 'Poor' (Score = 2), 'Satisfactory' (Score = 3) and 'Good' (Score = 4) levels.

Calculating a sustainability score for the domains, categories and indicators involves the following steps: (i) establishing sustainable or performance thresholds; (ii) rescale the data to ensure comparability across indicators (normalization); (iii) aggregate the indicators within and across subcategories and categories.

3.2.3.1 Establishing sustainability thresholds

The upper bound or ideal conditions for each indicator were determined using the following decision tree based on the methodology from Sachs et al. (2021):

1. Use of absolute quantitative thresholds defined in the SGD, OECD, IPBES, Aichi targets, among others, to establish the upper bounds (e.g., zero poverty, full gender equality, among others)
2. Where no explicit target is set for the indicator, apply the principle of 'leave no one behind' to set the upper bound to universal access or zero deprivation (e.g., Prevalence of food insecurity, Coverage of essential health services, Literacy of adult population, among others)
3. Where science-based targets exist, also known as technical optimum, those were used as the upper bound (e.g., zero greenhouse gas emissions from CO_2 as required by no later

than 2050 to stay within the 1.5°C target, or 100 percent sustainable management of fisheries).

4. For those indicators based on existent indexes, the lower, upper bounds and intermediate levels were taken from their corresponding scales (e.g., MWQI, IRCA, Freshwater streamflow variability, INAC, among others).
5. For all other indicators, values based on literature review were used as upper and lower bounds.

Each indicator distribution was censored, so that all values exceeding the upper bound scored five (5), and values below the lower bound scored one (1).

Finally, for four (4) of the indicators was difficult to define a quantitative scale and ranges for the discretization, therefore, a set of conditions based on literature reviews and expert judgment were used to assign the score. However, due to the high uncertainty and subjectivity of the qualitative approach, the indicators using that scoring method were only assessed within the intermediate categories (i.e., Poor, Satisfactory and Good). In other words, it was not possible for them to achieve an ‘Excellent’ or ‘Bad’ status.

3.2.3.2 Normalization

To make the data comparable across indicators, ‘Categorical scales’ were defined for the majority of the indicators (OECD & JRC, 2008, pp. 27–30). In general terms, what was done was to establish ranges of values (i.e., brackets) within the upper and lower limits of each variable/indicator that correspond to a score on the CCS framework scale that goes from one (1) to five (5) where 1 is ‘Bad’ and 5 is ‘Excellent’. The categorical ranges defined for each of the quantitative variables is shown in Table 3.2.

For those indicators where ‘leave no one behind’ was chosen as an optimum, a categorical scale was established based on an adaptation from Sachs et al. (2021, pp. 82–86). Not all indicators received the same brackets division but, the divisions were established in a way they reward the best performing system and penalise the worst.

Only a few indicators did not require any normalization because in their original source they were already score from 1 to 5 (i.e., Existence of policy and norms regarding ICZM; Decentralization and existence of public competencies) or because they were scored in a qualitative way (i.e., ‘Lasting special places / traditions’; ‘Percentage of goods transported by transport mode’; ‘Port infrastructure’ and ‘Quality of roads’; and ‘Civil and NGOs’). The criteria used for the qualitative evaluation of four of the indicators are explained below:

Lasting special places / traditions: Quantity and quality of touristic attractions is considered. For the system to score ‘Good’ in this indicator, there must be a representative and diverse number of attractions (e.g., material, festivities, cultural) which have a good status of preservation (e.g., clean, maintains the traditions, it is accessible for all the community).

Percentage of goods transported by transport mode: A greater share of goods and people mobilized by each mode is related to a more developed and accessible transport infrastructure (i.e., in terms of availability and costs). Also, higher scores are assigned to more resilient systems relying in more energy-efficient transport modes.

Port infrastructure and Quality of roads: The former was assessed based on the availability of port infrastructure and its importance for the economy of the system and the region. It is considered whether the port is used to the full extent of its capacities or whether there are conditions that restrict certain types of operation (e.g., need for continuous dredging, access for small barges only). In the case of road quality, it was associated with better accessibility and fuel efficiency, as well as facilities for exporting or importing products that favour the economy of the system. For this indicator, a weighted average was used where the quality of roads was given a score from 1 to 5 (very good = 5, good = 4, fair = 3, poor = 2 and very poor = 1) and then weighted according to the percentage of roads in each condition.

Civil and NGOs number: assessment based on quantity and representativeness of the organizations and institutions that can be found in the Atlántico. If besides having enough institutions representing different sectors from the society and they are recognized by the community, it can be considered a 'satisfactory' status have been achieved. Moreover, if Ostrom's design principles (Gari et al., 2017) are incorporated by this organizations, then a 'Good' condition will be achieved. On the other hand, if only a few organizations/institutions exist, and they lack legitimacy among people a 'Poor' score will be assigned.

Table 3.2. Categorical scales to normalize the scores from the quantitative indicators of all domains.

Indicator	Measurement Unit	Justification upper or lower bounds	Worst (Lower Bound)	Best (Optimum)	Bad	Poor	Satisfactory	Good	Excellent
Land cover change (i.e., TDF)	%/y	SDG Target	1.5	0	x < -0.5	-0.5 < x ≤ -0.05	-0.05 < x < 0.05	0.05 ≤ x < 0.275	x ≥ 0.275
Shoreline hardening (or armouring)	%	Technical optimum	100	0	x ≥ 70	50 < x ≤ 70	30 < x ≤ 50	10 < x ≤ 30	x ≤ 10
Proportion of threatened species	%	Technical optimum	75	0	x ≥ 55	35 < x ≤ 55	15 < x ≤ 35	5 < x ≤ 15	x < 5
Natural Hazard Regulation	%	Technical optimum	0	100	x ≤ 30	30 < x ≤ 50	50 < x ≤ 70	70 < x ≤ 90	x > 90
Protected areas	%	Adapted Aichi targets	0	30	x ≤ 5	5 < x ≤ 10	10 < x ≤ 15	15 < x ≤ 20	x > 20
Sea-level change rate compared to global average	%	Adapted from IPCC Sixth Assessment Report	100	0	x > 50	30 < x ≤ 50	10 < x ≤ 30	0 < x ≤ 10	x < 0
Sea surface temperature change	°C	Adapted from IPCC Sixth Assessment Report	3	0	x > 2.0	1.5 < x ≤ 2.0	1.0 < x ≤ 1.5	0.5 < x ≤ 1.0	x ≤ 0.5
Atmospheric temperature change	°C	Paris Agreement	2	0	x > 2.0	1.5 < x ≤ 2.0	1.0 < x ≤ 1.5	0.5 < x ≤ 1.0	x ≤ 0.5
Rainfall change	%	Adapted from TCNCC	50	0	$\|x\|$ > 40	20 < $\|x\|$ ≤ 40	10 < $\|x\|$ ≤ 20	5 < $\|x\|$ ≤ 10	$\|x\|$ ≤ 5
Net GHG emissions per year	ton CO2e / capita	Technical optimum	20	0	x > 4	3 < x ≤ 4	2 < x ≤ 3	0 < x ≤ 2	x ≤ 0
Extreme events trends (slope)	Dimensionless	Arbitrary value	1	0	NA	x > 0.5	-0.5 < x ≤ 0.5	x < -0.5	NA
Wave Energy Flux	%	Arbitrary value	50	0	$\|x\|$ > 40	20 < $\|x\|$ ≤ 40	10 < $\|x\|$ ≤ 20	5 < $\|x\|$ ≤ 10	$\|x\|$ ≤ 5
Freshwater Suspended Sediment Load	%	Arbitrary value	50	0	$\|x\|$ > 40	20 < $\|x\|$ ≤ 40	10 < $\|x\|$ ≤ 20	5 < $\|x\|$ ≤ 10	$\|x\|$ ≤ 5
Marine Water Quality Index	Dimensionless	Index scale	0	100	x ≤ 25	25 < x ≤ 50	50 < x ≤ 70	70 < x ≤ 90	x > 90
Freshwater streamflow variability	Dimensionless	Index scale	0	1	x ≤ 0.50	0.50 < x ≤ 0.65	0.65 < x ≤ 0.75	0.75 < x ≤ 0.85	x > 0.85
Erosion/accretion rates	m/y	Benchmarking	-1.5	1.5	x ≤ -1.5	-1.5 < x ≤ - 0.2	-0.2 < x < 0.2	0.02 ≤ x < 1.5	x ≥ 1.5

Indicator	Measurement Unit	Justification upper or lower bounds	Worst (Lower Bound)	Best (Optimum)	Bad	Poor	Satisfactory	Good	Excellent
Catch by stock status	%	Technical optimum	100	0	x > 50	35 < x ≤ 50	20 < x ≤ 35	5 < x ≤ 20	x ≤ 5
Coastal population growth rate	%/y	Arbitrary value	5	0	x > 1.5	1.0 < x ≤ 1.5	0.5 < x ≤ 1.0	0.1 < x ≤ 0.5	0 < x ≤ 0.1
Incidence of income poverty	%	SDG Target	30	0	x ≥ 20	20 > x ≥ 15	15 > x ≥ 10	10 > x > 5	x ≤ 5
Subjective well-being	Dimensionless	Index scale	0	10	x < 2.5	2.5 < x < 5.0	5.0 < x < 7.0	7.0 < x < 9.0	x > 9.0
Prevalence of food insecurity	%	Leave no one behind	100	0	x ≥ 50	30 < x ≤ 50	15 < x ≤ 30	5 < x ≤ 15	x ≤ 5
Water Quality for Human Consumption Risk Index - IRCA	Dimensionless	Index scale	100	0	80.1 ≤ x ≤ 100.0	35.1 ≤ x ≤ 80.0	14.1 ≤ x ≤ 35.0	5.1 ≤ x ≤ 14.0	x ≤ 5.0
Coverage of essential health services	%	Leave no one behind	0	100	x ≤ 50	50 < x ≤ 65	65 < x ≤ 80	80 < x ≤ 95	x > 95
Inter-census change in the ethnic population	p.p.	Arbitrary value	-5	NA	x< - 2.0	-2.0 < x ≤ -0.5	-0.5 < x ≤ 0.0	0.0 < x ≤ 0.5	x > 0.5
Lasting special places / traditions	NA	NA - Qualitative	NA	NA	NA	NA	NA	NA	NA
Literacy rate of adult population	%	Leave no one behind	0	100	x ≤ 50	50 < x ≤ 65	65 < x ≤ 80	80 < x ≤ 95	x > 95
Relative Effort Indicator - IER	Dimensionless	Technical optimum	0	1	x ≤ 0.40	0.40 < x ≤ 0.6	0.6 < x ≤ 0.8	0.8 < x ≤ 1	x > 1
Preventive risk management investment	%	Arbitrary value	0	60	x < 15	15 < x ≤ 30	30 < x ≤ 45	45 < x ≤ 60	x > 60
Relative change of ocean-related activities' GDP	Dimensionless	Adapted from OHI	0	1	x < 0.50	0.50 < x ≤ 0.70	0.70 < x ≤ 0.85	0.85 < x ≤ 0.95	x > 0.95
Gender wage gap	p.p.	Technical optimum	40	0	x > 20	14 < x ≤ 20	8 < x ≤ 14	0 < x ≤ 8	x = 0
Unemployment rate	%	Adapted SDG Index	26	0.5	x > 10	7.5 < x ≤ 10	5 < x ≤ 7.5	2.5 < x ≤ 5	x ≤ 2.5
Access to electricity	%	Leave no one behind	0	100	x ≤ 20	20 < x ≤ 40	40 < x ≤ 60	60 < x ≤ 80	x > 80
Share of energy generated from renewable sources	%	WEO 2021 – NZE	20	88	x ≤ 20	20 < x ≤ 40	40 < x ≤ 60	60 < x ≤ 80	x > 80

Indicator	Measurement Unit	Justification upper or lower bounds	Worst (Lower Bound)	Best (Optimum)	Bad	Poor	Satisfactory	Good	Excellent
Relative change in occupancy rate in commercial accommodation	p.p.	Adapted from EC ETIS 2016	50	0	∣x∣> 50	30 <∣x∣≤ 50	15 <∣x∣≤ 30	5 <∣x∣≤ 15	∣x∣≤ 5
Percentage of goods transported by transport mode	NA	NA - Qualitative	NA	NA	NA	NA	NA	NA	NA
Port infrastructure	NA	NA - Qualitative	NA	NA	NA	NA	NA	NA	NA
Quality of roads	%	Technical optimum	0	100	x ≤ 30	30 < x ≤ 50	50 < x ≤ 70	70 < x ≤ 90	x > 90
GINI Index	Dimensionless	Benchmarking	0.7	0.25	x ≥ 0.55	0.45 < x ≤ 0.55	0.35 < x ≤ 0.45	0.25 < x ≤ 0.35	x ≤0.25
Household income devoted to housing costs	%	Benchmarking	70	20	x > 40	30 < x ≤ 40	20 < x ≤ 30	15 < x ≤ 20	x < 15
Percentage of GVA generated by activities/sectors relying on Renewable resources	%	Arbitrary value	0	70	x < 25	25 < x ≤ 45	45 < x ≤ 65	65 < x ≤ 75	x > 75
Ratio Extractive / Renewable activities	Dimensionless	Arbitrary value	2	0.2	x > 1.75	1.25 < x ≤ 1.75	0.75 < x ≤ 1.25	0.25 < x ≤ 0.75	x < 0.25
Relative change in GVA from 'Agriculture, livestock and fishing'	Dimensionless	Adapted from OHI	0	1	x < 0.50	0.50 < x ≤ 0.70	0.70 < x ≤ 0.85	0.85 < x ≤ 0.95	x > 0.95
Relative change of overall workforce within blue economy	Dimensionless	Adapted from OHI	0	1	x < 0.50	0.50 < x ≤ 0.70	0.70 < x ≤ 0.85	0.85 < x ≤ 0.95	x > 0.95
Livelihood diversification in small-scale fishing households	Dimensionless	Technical optimum	0	1	x < 0.15	0.15 < x ≤ 0.30	0.30 < x ≤ 0.45	0.45 < x ≤ 0.60	x ≥ 0.60
Civil and NGOs number	Dimensionless	NA - Qualitative	NA	NA	NA	NA	NA	NA	NA

Indicator	Measurement Unit	Justification upper or lower bounds	Worst (Lower Bound)	Best (Optimum)	Bad	Poor	Satisfactory	Good	Excellent
Existence of policy and norms regarding ICZM	Dimensionless	Benchmarking	0	5	x = 1	x = 2	x = 3	x = 4	x = 5
Voter turnout	%	Leave no one behind	0	100	x ≤ 20	20 < x ≤ 40	40 < x ≤ 60	60 < x ≤ 80	x > 80
Percentage of women in politics	%	SDG Target	0	50	x ≤ 15	15 < x ≤ 25	25 < x ≤ 35	35 < x ≤ 45	45 < x ≤ 55
National Anticorruption Index (INAC)	Dimensionless	Index scale	0	100	x ≤ 25	25 < x ≤ 50	50 < x ≤ 75	75 < x ≤ 95	x > 95
Existence operative instruments for the management of natural resources	%	Leave no one behind	0	100	x ≤ 25	25 < x ≤ 50	50 < x ≤ 75	75 < x ≤ 95	x > 95
Decentralization and existence of public competencies	Dimensionless	Benchmarking	0	5	x = 1	x = 2	x = 3	x = 4	x = 5

Source: the author. Note: NA is written in those indicators that were evaluated using a qualitative approach.

3.2.3.3 Weighting

The general idea behind the CCS framework is that every subcategory, category, and domain are equally important. Therefore, it would not be necessary to assign weights to the different variables. However, in terms of scale and availability of information in the system, there are some differences. For this reason, a method of weighting the scores according to the area within each administrative division and the population was adopted. In other words, in those cases where the information available is disaggregated at the municipal or department level, those jurisdictions with a larger area or population will have more weight in the final score.

In terms of population, Santa Catalina only possesses 0.58% of the total within the study area and the inhabitants in Barranquilla accounted for nearly half of the population, the share from the other municipalities is presented in Table 3.4. Regarding area distribution, Table 3.3 shows that the area within Santa Catalina jurisdiction corresponds to 23% and 2% of the total marine and terrestrial study area. Both values, area, and population proportion, are equivalent to the weighting factor used for the aggregation of the information in the cases where it was needed (e.g., Sea-level change, Coverage of health services, IRCA, among others).

Table 3.3. Share of the study area belonging to Santa Catalina (Bolívar).

Domain	Total Study Area (Ha)	Only Santa Catalina (Ha)	CCS weight based on area
Marine	165,514	38,374	23%
Terrestrial	224,068	5,323	2%
Total	389,582	43,697	11%

Source: the author

Table 3.4. Share of the population by municipality within the study area

Municipality	Total inhabitants 2018	CCS weight based on inhabitants
Baranoa	62,382	2.52%
Barranquilla	1,206,319	48.72%
Campo de La Cruz	22,879	0.92%
Candelaria	15,982	0.65%
Galapa	60,708	2.45%
Juan de Acosta	20,999	0.85%
Luruaco	28,175	1.14%
Malambo	128,203	5.18%
Palmar de Varela	28,932	1.17%
Piojó	6,608	0.27%
Polonuevo	18,197	0.73%
Ponedera	23,848	0.96%
Puerto Colombia	49,264	1.99%
Sabanagrande	32,334	1.31%
Sabanalarga	93,261	3.77%
Santa Catalina	14,563	0.59%

Municipality	Total inhabitants 2018	CCS weight based on inhabitants
Santo Tomás	29,829	1.20%
Soledad	603,999	24.40%
Suán	11,940	0.48%
Tubará	17,377	0.70%

Source: the author

3.2.3.4 Aggregation

To define sustainability in its different domains, the framework relies on a bottom-up approach where the sustainability score is first assigned to the indicators from each subcategory. The score of each subcategory is calculated as the ‘median’ of its composing indicators and so on. This means, each domain will have a sustainability score calculated as the ‘median’ of the five categories that belong to it.

Unlike what was proposed by P. de Alencar et al. (2020), an overall score for the system was defined for the present case study. Now, understanding that none of the domains is superior or inferior to the others, the final score of the system corresponds to the lowest score within its four domains. The final score of the system corresponds to the lowest score within its four domains. For example, if the ‘Economy’, ‘Socio-cultural’ and ‘Environmental’ domains are scored five (5), but the ‘Governance’ is scored two (2), then the overall sustainability for the system will be two (2).

3.2.4 Communication

For science-communication with stakeholders from different levels and contexts (e.g., decision makers, academy, public in general) the sustainability score from each category, domain and the system in general is represented in a bull-eye-like figure using a different colour matching each level of sustainability as shown in Figure 3.5.

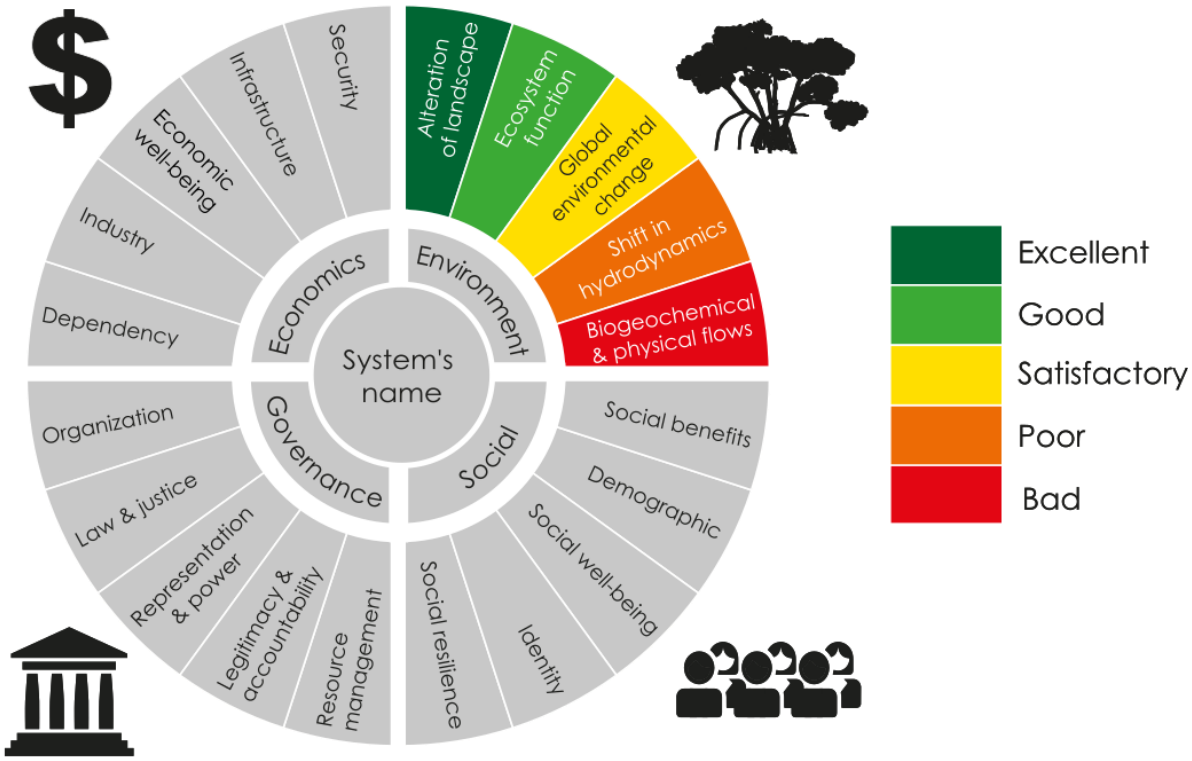


Figure 3.5. The CCS graphical representation

Source: Maria Esther Ollivier (2022)

4 CIRCLES OF COASTAL SUSTAINABILITY

This chapter presents the information corresponding to each of the indicators chosen to evaluate the sustainability in the Magdalena River-mouth socio-ecological system. The indicators are divided by domain, category and subcategory following the CCS framework.

4.1 INDICATORS

4.1.1 Environmental and Ecological domain

4.1.1.1 Category 1 - Alteration of landscapes

4.1.1.1.1 Subcategory 1 - Land

The chosen indicator was the rate at which land cover has changed in the last two decades (2000-2018) focusing in particular on the change of Tropical Dry Forest which is one of the most important and threatened ecosystem in the study area (Juanita et al., 2019).

In the Atlántico, there is a reduction in the areas corresponding to crops. Those areas have been replaced or occupied by the expansion of urbanised or artificialized territory as well as the increase of forest and natural areas (see Table 4.1). It is important to note that there is a difference of 474 Ha between the total area in 2018 and the area in 2002. This difference could be due to the distinct characteristics of the products used for the Corine Land Cover (CLC) classification but also with changes along the coastline (e.g., formation of a coastal in the municipality of Tubará and beach accretion in some stretches of the littoral).

Table 4.1. Land cover by major groups in the 2002 and 2018 years according to the Corine Land Cover methodology adapted for Colombia.

Group	2000-2002		2018	
	Ha	%	Ha	%
1. Artificial surfaces	16,109.65	7.00%	20,604.79	8.94%
2. Agricultural areas	157,412.54	68.42%	142,975.33	62.05%
3. Forests and semi-natural areas	32,726.43	14.22%	46,839.14	20.33%
4. Wetlands	9,996.84	4.35%	7,032.20	3.05%
5. Water bodies	13,830.34	6.01%	12,964.03	5.63%
Total	**230,075.81**	**100%**	**230,415.48**	**100%**

Source: the author with information from IDEAM, 2022

Despite this apparent ‘positive trend’ in the last two decades, the analysis from mangrove and tropical dry forest (TDF) ecosystem shows a contrasting reality. In the case of the TDF, more than half of the baseline cover was lost (i.e., 3,728 Ha - 56,2%) between 1986 and 2016, accounting for an average yearly loss of -1.87% of TDF cover. The TDF was replaced by agricultural, urban, and mining areas. In the future, it is expected that urban areas will increase in 55% by 2027 leading to a further loss of 32% of the existing TDF and 52% of the scrublands (Aldana-Domínguez et al., 2018) In general, these losses in the study area have been associated to little extent to natural causes but, mainly, to anthropogenic driven hydrodynamic changes and illegal logging, both related to urban sprawl and economic activities such as agriculture and cattle ranching (Aldana-Domínguez et al., 2018; Chacon et al., 2020; Villate Daza et al., 2020).

In line with the SDG 15 targets and understanding the study area has suffered mayor transformations in the last 30 years, the condition for this indicator was defined based under the following assumptions: (i) a progressive cover loss represents a negative scenario; (ii) maintaining the current proportion of land cover is satisfactory and (iii) recovery of the Tropical Dry Forest, even if slow, is the desired scenario.

4.1.1.1.2 Subcategory 2 - Shoreline armouring

A higher proportion of 'armoured coastline' is not only synonymous with greater landscape alteration but may reflect other underlying disturbances such as loss of natural hazard protection, lack of coastal planning and management, longshore transference of problems, among others.

In the Caribbean coast, the construction of hard infrastructure has been the preferred management strategy to control erosion. A growing coastal population and the political and economic pressures have boosted the construction of this structures in the last three decades. (N. Rangel-Buitrago et al., 2018, p. 62) Specifically, in the Atlántico’s department, there are a total of sixty-two structures with a length of 10,242 m which are grouped as follows:

Table 4.2. Shore protection structures along the Atlántico’s shoreline.

Structure	N	Length (m)
Groin	31	2,123
Breakwater	0	0
Seawall, Revetments, Ripraps	12	523
Others	19	7,596
Total	*62*	*10,242*

Source: adapted from N. Rangel-Buitrago et al. (2018, p. 63).

In the Table 4.2 ‘Others’ could include dunes stabilization, Posidonia and/or mangroves (natural and artificial), cliff stabilization, tyres, and jetties from which a length of 6km correspond to the mangrove protection in the ‘Cienaga de Mallorquin’. Hence, the total length of the hard protection structures corresponds to nearly 6% (i.e., 4.2 Km approx.) of the total shoreline length in the Atlántico (i.e., approx. 71 Km).

The structures in the Bolívar department were not considered for this assessment given most of them are around Cartagena, outside the study area.

4.1.1.2 Category 2 - Ecosystem function

4.1.1.2.1 Subcategory 1 - Biodiversity loss

The species that inhabit the ocean and coastal areas have a vital role in shaping the existing coastal environment. *“They are valued for their beauty and inherent right to exist, as well as their role in supporting productive habitats that provide many benefits for people”* (OHI, 2022).

A total of 2,325 species were found within the study area from which 110 correspond to observations in the department of Bolívar and 2,215 in Atlántico. From the total, thirty species (1.26%) are considered as threatened (i.e., they are listed in the Resolution 1912/2017) and are distributed in eight classes as shown in Figure 4.1. This simplistic approach (i.e. using the proportion of threatened species) gives a sense of the biodiversity loss status, however, it is strongly recommended to estimate and use the Red List Index for a more accurate assessment, especially considering that Colombia has been experiencing a declining trend in the latter indicator going from 0.76 in 2001 to 0.74 in 2018 (OECD).

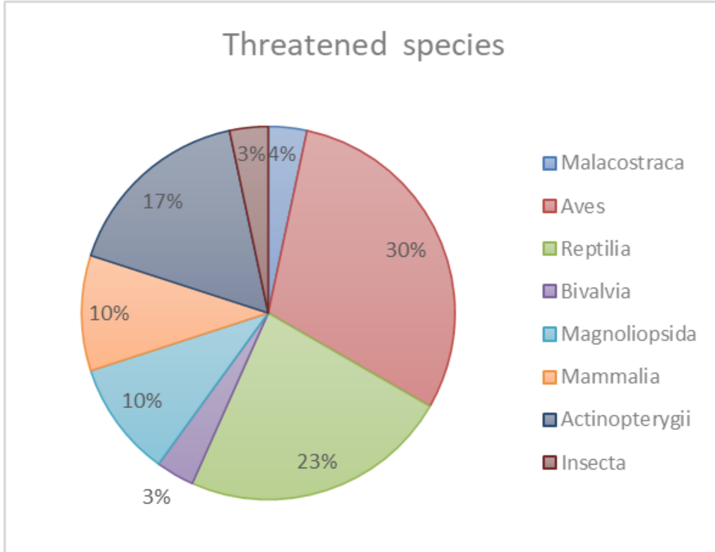


Figure 4.1. Classes distribution of threatened species in the study area.

Source: the author with information from GBIF.org (2022)

4.1.1.2.2 Subcategory 2 - Natural hazard regulation

This indicator assesses the amount of protection provided by marine and coastal habitats against natural hazards in coastal areas that people value. As explained in the OHI. The maximum score would indicate that these habitats are all still intact or have been restored to the same condition as in the baseline year. The lowest score would indicate that these protective coastal habitats are completely absent, while a low score indicates that these habitats have declined significantly (OHI, 2022).

Between 1985 and 2018, mangrove cover loss in ‘Cienaga del Totumo’ and ‘Cienaga de Mallorquin’ was 316 Ha altogether, going from nearly 800 ha in the baseline year (i.e. 1985) to less than 500 Ha in 2018 which indicates an overall change of -9.6 ha/year (i.e. -1.20% / year) (see Figure 4.2). In terms of coastal protection, this change can be interpreted as if the current natural hazard regulation services are only 60% of what they used to be in 1985. In other words, two fifths of the natural protection were lost in roughly three decades.

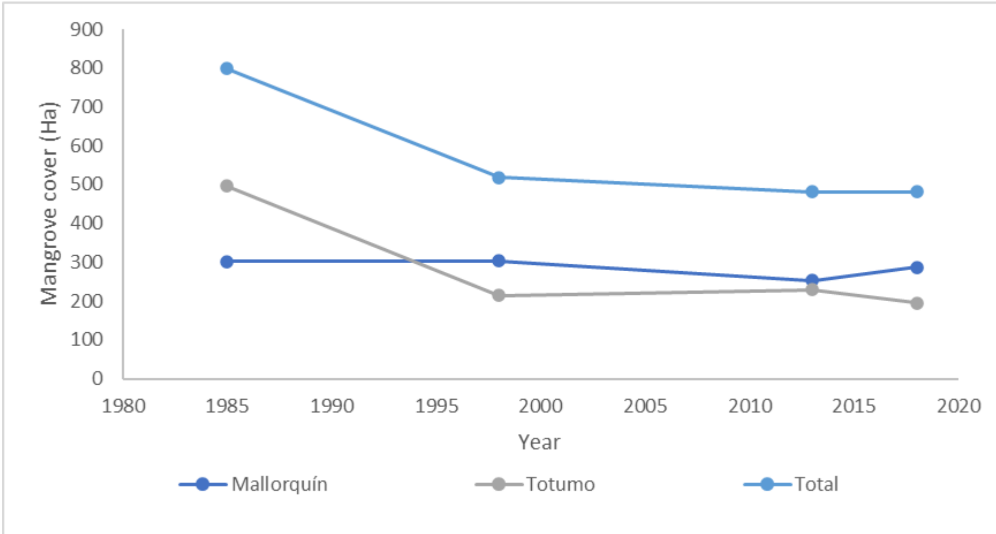


Figure 4.2. Mangrove cover change in the Mallorquín and Totumo swamps between 1985 to 2018

Source: the author with information from Villate Daza et al. (2020)

4.1.1.2.3 Subcategory 3 - Biodiversity protection

Aichi Target 11 establishes that *"By 2020, at least 17 per cent of terrestrial and inland water areas and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascape." (CBD, 2012)* Using this target as a satisfactory condition allows to define what is better (i.e., more protected areas than the target) or worse (i.e., insufficient to achieve the target) for the system.

To evaluate this subcategory the 'proportion of protected areas within the study area' was selected as indicator. In the Atlántico department there are a total of eight protected areas covering 7,226 Ha of land. From those, only 4,861 Ha are within the study area (see Table 4.3), meaning that less than 3% of the land is under some category of protection. In terms of marine protected areas, no register was found by the time this study was conducted.

Table 4.3. Protected areas within the study area.

Category	Name	Area (Ha)
Regional Protective Forest Reserves	El Palomar	772.3
Civil Society Nature Reserve	Los Charcones	42.99
Civil Society Nature Reserve	Los Mameyales	31.1
Regional Natural Parks	Los Rosales	1,393
Regional Districts of Integrated Management	Palmar del Tití	2,622

Source: the author with information from RUNAP (2022)

4.1.1.3 Category 3 - Global Environmental Change

4.1.1.3.1 Subcategory 1 - Climate change

The study area is located within the 'Central Coast' hydroclimatic region defined by the IDEAM. The reference climate used in the TCNCC correspond to the 1976-2005 period in agreement with the CMIP5 global models. The Representative Concentration Pathways (RCP) for Colombia are the RCP 4.5 and 6.0 in which the Atmospheric Temperature (T), Precipitation (P) and Sea Surface Temperature change are based for the present study (IDEAM, PNUD, et al., 2017a, 2017b).

- Sea level change

"Thermal expansion, ocean dynamics and land ice loss contributions will generate regional departures of about ±30% around the GMSL rise. Differences from the global mean can be greater than ±30% in areas of rapid vertical land movements, including those caused by local anthropogenic factors such as groundwater extraction" (H.-O. Pörtner et al., 2019). A deviation within this range (10-30%) of the local SLR compared to the GMSL will be considered satisfactory, not because it is a favourable situation, but because, at least, it follows global trends which cannot be controlled on a local scale (i.e., there are no local actions that can stop global sea level rise). Conversely, if the local increase is lower or higher than the range of global variation, these are assumed to be positive and negative conditions, respectively.

The Economic Commission for Latin America (CEPAL, by its Spanish acronym) estimated a SLR rate of approximately 2.8 mm/y and 3.6mm/y for the Caribbean during the 2010-2040 and 2040-2070 periods, respectively (CEPAL, 2015). Now, based on CEPAL’s projections, the IDEAM (2017b) estimated the SLR for the study area (see Table 4.4), if compared to the global mean sea level (GMSL) rise rate in 2100 for the RCP 4.5 scenario (i.e. 7 mm/y) (Oppenheimer et al., 2019, p. 352), the local rates are 20% higher.

Table 4.4. Sea-level rise in 2040, 2070 and 2100 for the Atlántico and Bolívar departments.

Period	Atlántico		Bolívar	
	Δ SLR (mm/y)	SD	Δ SLR (mm/y)	SD
2010-2040	2.39	0.15	2.39	0.14
2041-2070	5.47	0.40	5.40	0.41
2071-2100	8.47	0.58	8.33	0.59

Source: IDEAM, PNUD, et al. (2017b). Note: it is not clear which RCP scenario was used for this projection, however, it is assumed that it was the RCP 4.5 same as for Sea Surface Temperature – SST

- Sea surface temperature change

"Seagrass meadows (...) will face moderate to high risk at temperature above 1.5ºC global sea surface warming. Coral reefs will face very high risk at temperatures 1.5ºC of global sea surface warming. Intertidal rocky shores are also expected to be at very high risk (transition above 3ºC) under the RCP8.5 scenario. These ecosystems have low to moderate adaptive capacity, as they are highly sensitive to ocean temperatures and acidification. The ecosystems with moderate to high risk (transition above 1.8ºC) under future emissions scenarios are mangrove forests, sandy beaches, estuaries and salt marshes" (Bindoff et al., 2019) Hence, temperature rise below 1.5ºC is considered a positive scenario and above this value is negative.

The analysis conducted by A. C. Torregroza-Espinosa et al. (2021) shows a significant inter-annual increasing trend (i.e. Mann-Kendall Test p ≤ 0.05, Sen-slope between 0.005 and 0.038, t between 0.225 and 0.308) between 2003-2017 with mean monthly SST of 27.6 ± 1.5 °C at Bocas de Ceniza and 27.6 ± 1.3 °C at the Caribbean sea. With a similar pattern observed in other areas of the study region (A. C. Torregroza-Espinosa et al., 2021). Now, according to the projections from the TCNCC, the central Caribbean SST could experience an increase around 0.5, 0.9 and 1.4 °C by 2040, 2070 and 2100, respectively, under the RCP 4.5 scenario. This means, the SST is expected to reach temperatures of 27 ± 0.71°C, 27.5 ± 0.71 °C and 27.75 ± 1.06 °C (INVEMAR, 2017).

- Atmospheric temperature change

The Paris Agreement goal was to limit global warming to well below 2 and preferably to 1.5 degrees Celsius, compared to pre-industrial levels. Hence, 1.5 degrees Celsius was used for the satisfactory condition. A lower temperature change is considered positive, while values above it represents worse conditions. According to the evaluated scenarios, the atmospheric temperature in the study area could increase in 1.1°C by 2040 and, by the end of the XXI century, it could be 2.2 °C higher.

- Precipitation change

Using the same categorical scales from the TCNCC ‘Climate Change Scenarios’ document, the variation in precipitation can be classified as: Severe Deficit (<-40%), Deficit (-39% and 11-%), Normal (-10% and 10%), Excess (11%-39%) and Severe Excess (> 40%) (IDEAM, PNUD, et al., 2017b). Based on these ranges, system sustainability scores were defined.

The climate change scenarios suggest that average precipitation in the Atlántico can be reduced in -7.39% between 2011-2040, -9.52% between 2041-2070 and can be -11.26% by the end of the XXI century. However, the study area presents differences with municipalities such as Barranquilla and Santa Catalina having changes ranging from -10 to +10 % that are considered ‘Normal’. The rest of the municipalities could have a deficit of rainfall with variations between -20 to -10% and more intense effects could be experienced in the southern municipalities of the Atlántico with changes between -30 to -20% (i.e. Ponedera, Sabanalarga, Manatí, Candelaria, Campo de la Cruz, Santa Lucía and Suán). (IDEAM, PNUD, et al., 2017b)

- Climate Net Greenhouse Gas (GHG) emissions

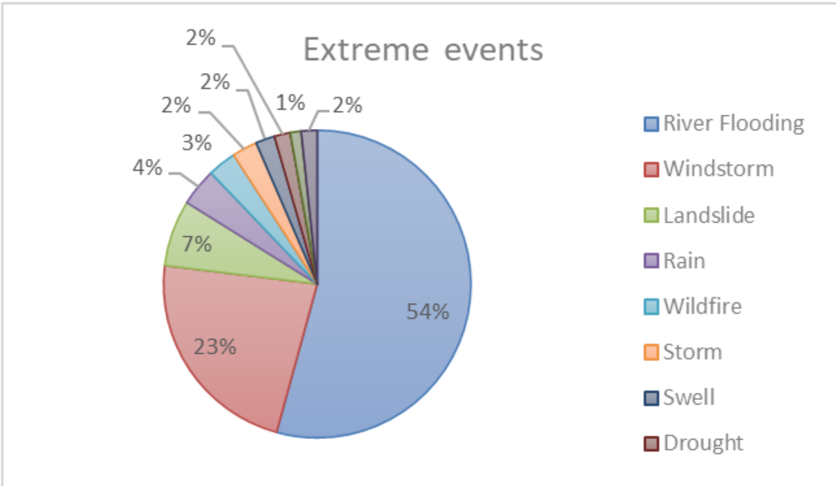
Colombia generates only 0.4% of the GHG global emissions. In terms of per capita emissions Colombia that accounts for 4.2 ton CO2e which is a similar magnitude of the emissions from countries such as Congo (4.08), Liberia (4.02) and Uruguay (4.34). In 2012, the Atlántico emitted 7,420,000 ton CO2e and absorbed 77,700 ton CO2e which represents 7,342,000 ton CO2e of net emissions, from which 85% correspond to CO2 emissions (i.e., The majority of the emissions are associated to the combustion of fuels for power generation (i.e. 43.2%), followed by the manufacturing industry (i.e. 22.0 % of the emissions) and the transport activities (i.e. 15.5%) (IDEAM et al., 2016). Considering that the total population in the Atlántico for 2012 was 2,315,361 inhabitants (DANE, 2018), the Atlántico emitted and estimate of 3.2 ton CO2e/capita which is less than the national and global average (4.6 ton CO2e / capita). However, it is not enough to achieve the Paris Agreement target of limiting global warming to 1.5°C above pre-industrial levels and to reach net-zero carbon dioxide CO2 emissions globally by 2050. In order to achieve this goal, net per capita emissions should be approximately 2.3 tons CO2 by 2030 and 0 by 2050 (UNEP, 2021).

4.1.1.3.2 Subcategory 2 - Natural change

The frequency of extreme events between 1980 and 2015 was used as an indicator in this subcategory. Due to the high uncertainty from this indicator, only intermediate levels or scores were assigned. A positive slope ($x>0.5$) indicates a rising number of extreme events per year, and it is considered a negative condition. A negative slope ($x<-0.5$) shows an opposite condition, namely, declining extreme events which is consider a positive condition.

The IDEAM, PNUD, et al. (2017a) reported a total of 1,135 extreme hydro-meteorological events between 1929 and 2015 in the Atlántico. A considerable proportion of them corresponded to

Flooding (54%), Windstorms (23%) and Landslides (7%). The remaining 16% involve events such as wildfires, storms, swells, droughts, torrential floods, among others (see



Event	No.
River flooding	616
Windstorm	257
Landslide	79
Rain	45
Wildfire	34
Storm	30
Swell	23
Drought	19
Torrential flood	13
Electric storm	9
Heat Wave	3
Tornado	3
Flash floods	1
Huricane	1
Storm surge	1
Fog	1

Figure 4.3. Proportion of hydro-meteorological events reported in Atlántico between 1929 and 2015.

Source: Adapted from IDEAM et al. (2017a)

Now considering only the frequency of extreme hydro-meteorological events that occurred between 1980 and 2015, the reports showed a rising number per year with a maximum of eighty-two events in 2012 when a record of windstorms were registered (i.e., 54) added to 19 river flooding events and other type of events. However, it is important understand that data on number of events has some constraints and the affirmation that disasters occur more frequently today than in the beginning of the century cannot be inferred with total accuracy from the information showed in Figure 4.4. In fact, what the figure is showing is the evolution of the registration of natural disaster events over time. Despite these constraints and under the assumption that records have been more accurate in the last 3 decades and they will be more accurate in the future, it can be said with a high degree of uncertainty, that extreme events had a rising tendency between 1980 and 2015.

The aforementioned matches the IPCC projections which indicate that increases in pluvial/river flooding are expected with a high confidence in the northwest of South America (IPCC, 2021). This suggests that the incremental trend in the number of disasters is not far from reality.

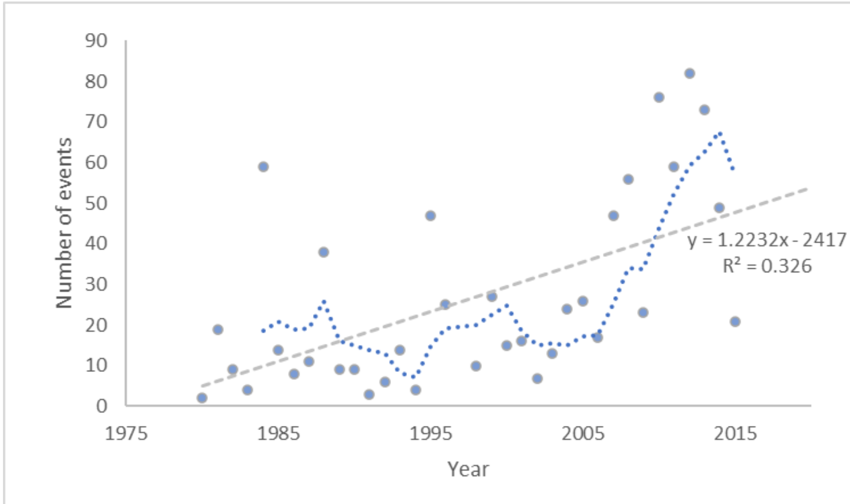


Figure 4.4. Extreme hydro-meteorological events reported between 1980 and 2015. Note: the dotted line corresponds to the 5-year moving average and the dashed line correspond to a linear regression forecasted until year 2020.

Source: the author.

4.1.1.4 Category 4 - Shifts in hydrodynamics

The chosen indicator to evaluate this subcategory was the Wave Energy Flux – WEF. An arbitrary selection of relative variation ranges was used based on the same criteria as for changes in precipitation. This assumes that extreme changes in reference conditions can have unexpected and undesirable consequences for the system. (e.g., erosion/accretion processes).

The study from Orejarena-Rondón et al. (2022) with information from 1978 until 2017, showed evidence of an initial increase of WEF until the period between 1988-1992. From that period onwards, the WEF shows a declining trend. Moreover, the same study indicates that from all the buoys analysed in the Caribbean, the ones in front of Barranquilla are among the group with the highest long-term decrease in WEF with values ranging from 11 to 12% for the whole analysed period (1958-2017) which translates to a decrease percentage of 0.15 – 0.20 % per year.

4.1.1.5 Category 5 - Biogeochemical and physical flows

4.1.1.5.1 Subcategory 1 - Contaminants

Within the study area there are fluvial and coastal waters both impacted by different activities developed along the basin and in the coastal zone. Therefore, to better understand the contamination processes in the study area it was decided to evaluate both: (i) the fluxes from the Magdalena River represented by the Suspended Sediment Load (SSL) indicator and (ii) the anthropogenic contamination of the coastal waters due to the activities developed in the coastal areas for which the Water Quality Index was selected.

- Freshwater Suspended Sediment Load (SSL)

Under the same rationale of the WEF indicator, consequences of changing conditions in relation to a baseline include beach erosion/accretion, decreased primary productivity, water quality deterioration, siltation, among others.

The Magdalena River contributes to 97% (142.6 x 10^6 t/y) of the average SSL discharged to the Caribbean coast. SSL discharged had increasing trend between 1972-2010, however, this trend was not significant when applying the Mann-Kendall Test (MKT). During the first decade of the century, the SSL in the Magdalena River decreased a 4% yet the MKT indicated a significant increasing trend (see Table 4.5) (Restrepo López et al., 2017). On the other hand, some authors have mentioned an SSL increase between 33-48% when comparing the mean load from the 1984–2000 period with the observed inter-annual mean in a more recent period (i.e., 2005–2010). Overall, in the latter there was an increase of 44 Mt/y of SSL (J. D. Restrepo et al., 2018).

Table 4.5. Monthly average, Maximum and Minimum SSL, trend significance and Sen's slope in the Magdalena River at Calamar Gauging station between 1972 and 2010.

Period	SSL (x10^3 t/d)	SSLmax (x10^3 t/d)	SSLmin (x10^3 t/d)	Significant trend (MKT $p < 0.05$)	Sen's slope (x10^6 t/yr. y)
1972-2010	390.87	1.56	46.83	no	0.84
1972-1999	143.70	NA	NA	no	1.55
2000-2010	137.90	NA	NA	yes	14.29

Source: Adapted from (Restrepo López et al., 2017)

- Marine/Estuarine Water Quality Index (MWQI)

The MWQI was assessed in eleven stations using the physicochemical parameters from the sampling campaigns conducted during dry and wet season in 2018. Overall, the coastal waters of the Atlántico depicted an 'Acceptable' condition during both dry and wet season (i.e., 51.8 and 65.9, respectively). When looking at the results by station, the MWQI exhibits a heterogeneous distribution along the Atlántico's coast. During the dry season, more than 60% of the stations presented quality equal or below 'acceptable'. The wet season did not show any station with 'optimal' conditions, however, 70% of the stations presented an 'adequate' quality (Gallo Vélez et al., 2022).

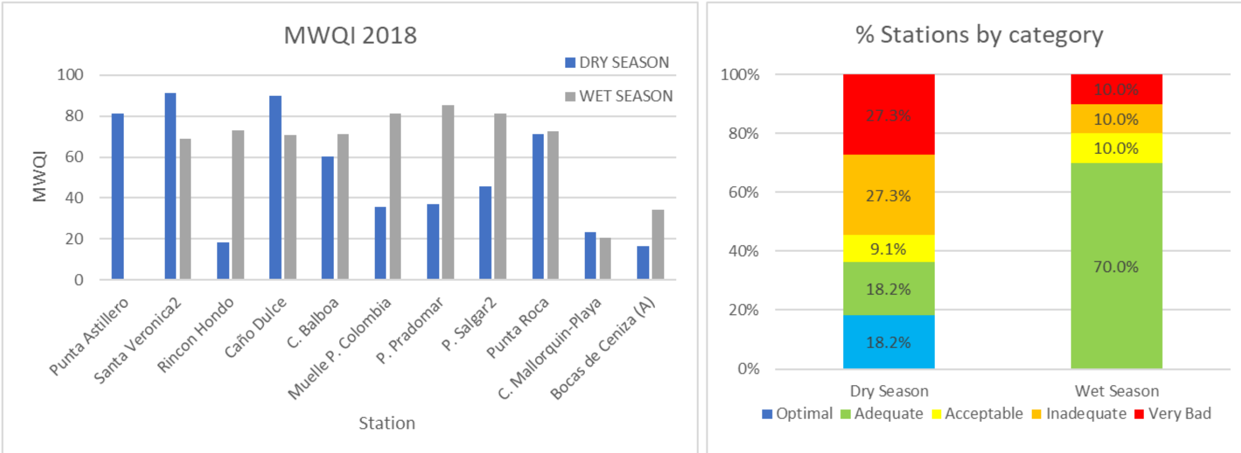


Figure 4.5. Coastal Water Quality Index (MWQI) calculated for eleven stations along the Atlántico's coast.

Source: Gallo-Vélez et al., 2022

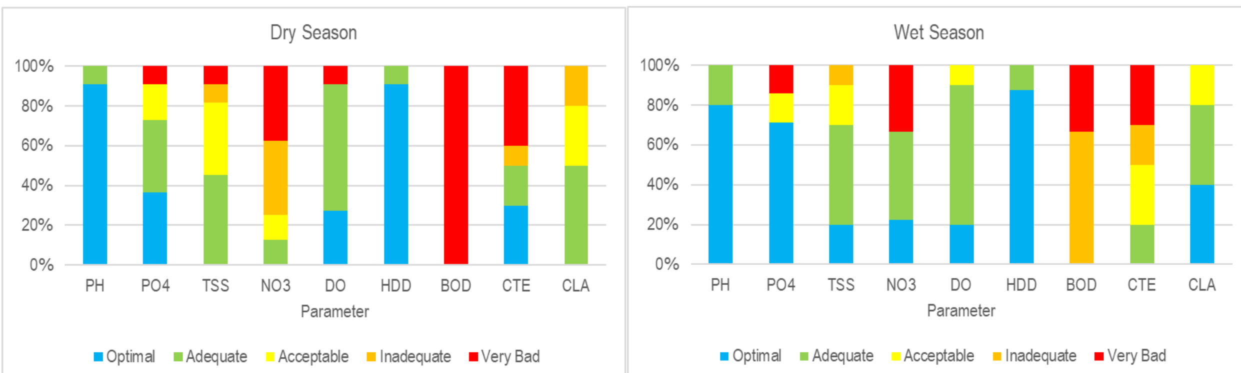


Figure 4.6. Proportion of measurements from each measured parameter by quality category.

Source: Gallo-Vélez et al., 2022

4.1.1.5.2 Subcategory 2 - Freshwater cycles

In the same way it happens with SSL, the main contributor of freshwater in the Caribbean basin is the Magdalena River (i.e., 205.1 km^3/y or 26% of the entire fluvial discharge). The average streamflow between 1942 and 2015 has been 7,154 m^3/s with high interannual variability due to the El Niño (dry phase) and La Niña (wet phase) events when the streamflow can be lower than 5,000 m^3/s or higher than 10,000 m^3/s, respectively (see Table 4.6). Additionally, there is a strong intra-annual variability due to the hydrological cycles that exhibit a dry period (Jan-Apr), transition period (May-Aug) and rainy period (Sep-Nov) (Juan Camilo Restrepo et al., 2014; J. D. Restrepo et al., 2021).

Moreover, Juan Camilo Restrepo et al. (2014) sustains that during the first decade of the century there were significant positive flow trends (MKT $p<0.1$) in the Magdalena River where the streamflow experienced an even steeper increase compared to data pre-2000. For example, the mean annual water discharge of 6,335 m^3/s during the 1941–1999 period increased to 7,392 m^3/s for the 2000–2010 period. (See Table 4.6).

Table 4.6. Average stream in the Magdalena River during normal, El Niño and La Niña years.

Period	Avg. Monthly Streamflow (m3/s)	Qmax (m3/s)	Qmin (m3/s)	Significant trend (MKT p <0.05)	Sen's slope (m3/s. y)
1941-2010	6,497.21	16,913	1,520	yes	17.26
1941-1999	6,334.9	NA	NA	no	10.20
2000-2010	7,391.6	NA	NA	yes	493.70

Source: Adapted from Juan Camilo Restrepo et al. (2014)

As defined in the ENA 2018, *“the water regulation index (WRI) is an indicator associated with the natural regime of the basins that qualitatively classifies the water retention and regulation capacity, by means of the shape of the average daily flow duration curve (ADC), to indicate the areas with the most stable runoff and the occurrence of extreme flows.”* (IDEAM, 2019, p. 65). To account for more localized conditions of freshwater cycles, this index was used to complement the data from the Magdalena River. At a local level, the Water Regulation Index (WRI) for the three basins integrating the study area is 0.77 (IDEAM, 2019).

4.1.1.5.3 Subcategory 3 - Sediment cycles

The erosion/accretion rates along the Atlántico shoreline were selected as a state indicator for this subcategory. The maximum erosion rates in the Atlántico are on the western side of the Magdalena River-mouth at Puerto Colombia, Cienaga de Mallorquin and Rincon Hondo with erosion rates varying between- 20 to -40 m/y. High erosion rates are also present in the municipality of Santa Catalina, more specifically in the area known as Galerazamba. The remaining stretch of coast presented stability (-0.2 to +0.2 m/y) or moderate erosion (-0.2 to -1.5 m/y) (see Figure 4.7) Overall, the TCNCC reported that erosion rate in the department of the Atlántico was -0.65 m/y between 1986-2016. (INVEMAR, 2017; N. G. Rangel-Buitrago et al., 2015).

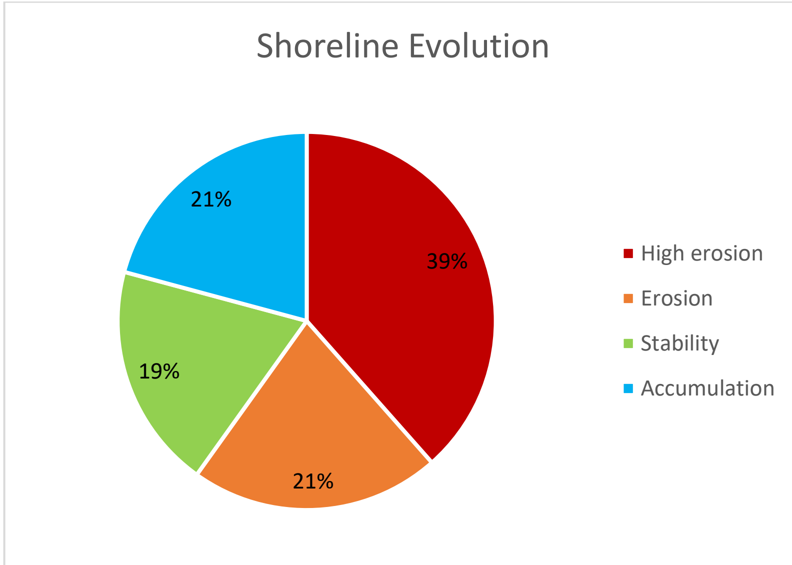


Figure 4.7. Coastal evolution categories for the 1983-2013 period in the study area

Source: Author with information from N. G. Rangel-Buitrago et al. (2015)

4.1.2 Social domain

4.1.2.1 Category 1 - Social benefits

The sustainability of this category is measured through the sustainability of the fishing methods and the health of the targeted species using an approach adapted from the Ocean Health Index where a high score indicates that the demand for fishing is being met using sustainable methods.

According to the most recent report from the Sea Around Us project which assessed the stock status in the waters of the Colombian Caribbean, the shared of catches from stocks of a given status, measured in biomass (3-year running average values) are the following: 30% come from rebuilding stocks while the other 70% comes from collapsed stock. Catches of fish under the over-exploited, exploited and developing status were zero (Page et al., 2020).

4.1.2.2 Category 2 - Demographics

4.1.2.2.1 Subcategory 1 - Population growth

Using an oversimplified approach based on the reasoning that the increase of population in a territory normally implies greater pressures on it, the qualification of this indicator was done thinking that a net growth rate (accounting for migrations, births, deaths) closer to or below zero represents a positive situation for the system.

In 1985, the population was 1.25 million inhabitants from which 93% lived in urban areas while the other 7% lived in small, populated centres or dispersed along the rural area. Between 1985-2005, the study area population increased in more than 800,000 thousand people reaching a total number of 2.17 million inhabitants by 2005, representing an increasing rate of approximately 41,000 people per year (i.e., 3.1%/y). This change came with a slight reduction of the rural population (i.e., passing from 7.1% in 1985 to 5.3% in 2005) and more people living in the urban areas (i.e., 94.7% in 2005).

Overall, the period between the 2005 and 2018 census showed slower increasing trends with an average increment of 28,000 people per year. Between those years the population increased a 17% (i.e., 1.3%/y) corresponding to more than 371,000 inhabitants, reaching a total of 2.5 million inhabitants that were located mainly in the urban areas (i.e., 94.5%) while only a 5.5% of the population lived in the rural and dispersed areas. Those percentages are slightly different when excluding the population in Barranquilla (i.e., 90% and 10% of the population is in urban and rural areas, respectively). Additionally, the projections from DANE show that the population is expected to increase by 24% by 2035 surpassing the 3 million inhabitants (i.e., 1.4%/y) (see Figure 4.8).

The census in 2018 also showed that the Atlántico's population is concentrated near the mouth of the Magdalena River in 'Bocas de Ceniza'. More specifically in the Barranquilla Metropolitan Area, formed by the city of the same name and the municipalities of Soledad, Malambo, Galapa and Puerto Colombia, which altogether accounted for 80% of the total population within the study area. Looking at the distribution in rural and urban settings, the vast majority of BMA inhabitants lived in urban areas (i.e., only 1.1% lives in rural or dispersed areas). Outside the BMA the percentage of people living in urban and rural/disperse areas correspond to 76.5% and 23.5%, respectively.

One aspect worth considering in the population dynamics is the pulse due to the internal and international migration. In the case of the international migration, between 2014 and 2019 a total of 145,805 Venezuelans arrived to Barranquilla and, considering the 2018 year only, this number was 41,763 people (Oviedo Arango, February/2020). Regarding the internal migration, the main flow is from and to the municipalities of the BMA and its surroundings.

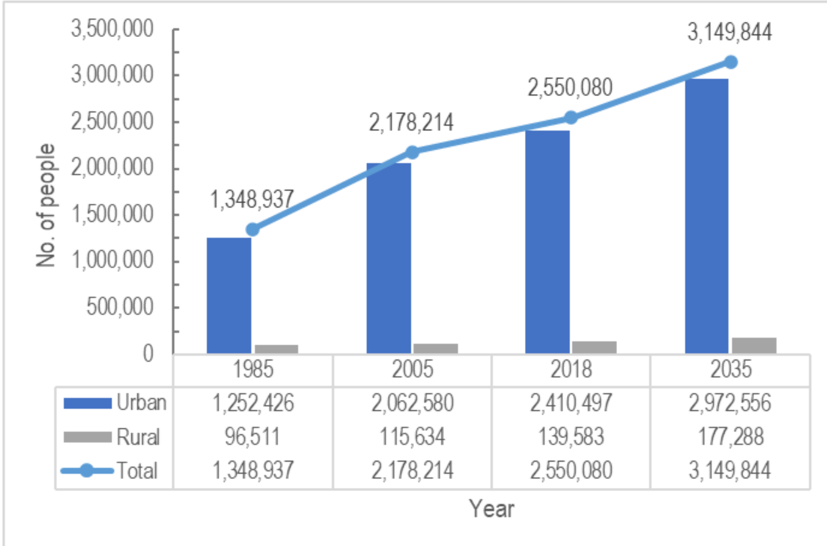


Figure 4.8. Population growth between 1985 and 2035. The 1985 and 2035 values are projected while the 2005 and 2018 values are from the corresponding census.

Source: the author with information from DANE (2018)

4.1.2.2.2 Subcategory 2 - Social class

This subcategory was assessed through an indicator called 'Incidence of income poverty'. In 2018 the Poverty Income Threshold for the Atlántico and Bolívar departments were 3.2 USD/day and 2.9 USD/day (current prices), respectively. With those thresholds, the incidence of income poverty was estimated in 24.2% for the Atlántico and 36.2% in Bolívar, while the national average was 27.0%. In terms of the money gap to obtain a household income above the poverty threshold, the Atlántico (i.e., 6.6%) showed better conditions than the national average (i.e., 9.8%) and Bolívar (i.e., 12.5%). During the same year, the minimum wage per month was 264 USD (current prices) which is above the 'Household average income per capita' registered in both departments, in other words, the average income (per capita) of the households in Atlántico and Bolívar was less than the minimum legal wage. Moreover, the same figure was below the national average (see Table 4.7).

Table 4.7. Income poverty and average income per capita in the Atlántico and Bolívar in 2018. All the income figures in USD are given per month. (Exchange Rate 1 USD = 2,957 COP)

Department	Income Poverty Incidence (%)	Poverty Income Threshold (USD current prices)	Income poverty gap (%)	Household average income per capita (USD current prices)
Atlántico	24.2	96.5	6.6	220.1
Bolívar	36.2	88.4	12.5	165.9
National	27.0	87.1	9.8	229.8

Source: the author with information from DANE (2022)

4.1.2.3 Category 3 - Social wellbeing

4.1.2.3.1 Subcategory 1 - Subjective well-being

This subcategory was assessed through the 'Subjective well-being scale' measured in Colombia by the DANE that uses the same approach from the OECD and the SDG. It involves asking the respondents (people aged 15 and over) to rate their lives on a scale from 0 (not at all satisfied) to 10 (completely satisfied).

The results from the ECV – DANE 2018 shows that the 'Life satisfaction' was higher in the department of Atlántico with a score of 8.32 (i.e., 0.06 points above the national average of 8.26), while Bolívar with a score of 7.95 had the lowest score among the departments of the Caribbean Region which had an average life satisfaction score of 8.24 points.

4.1.2.3.2 Subcategory 2 - Food security

The 'Prevalence of food insecurity' was chosen as the indicator to evaluate this subcategory. According to data reported in the ENSIN 2015, the prevalence of food insecurity in the Caribbean region (i.e., 65.0%) is the highest in Colombia being 10.8 p.p. higher than the National average (i.e., 54.2%). More specifically, in the departments of Atlántico and Bolívar this figure corresponded to 58.8% and 68.5% for the same year.

Despite not being disaggregated at departmental or regional level, other important findings from the ENSIN 2015 were that: 1. There is a higher prevalence of food insecurity in rural and disperse areas when compared to the urban centres (i.e., 64.1% for the former) 2. Households where the breadwinner belong to Indigenous or afro descendent ethnicity presented higher prevalence of food insecurity (i.e., 77.0% and 68.9%, respectively) than the average national figure. 3. Variables such as education, wealth and gender were also associated to high percentages of food insecurity for more vulnerable groups.

4.1.2.3.3 Subcategory 3 - Water security

The Water Quality for Human Consumption Risk Index – IRCA has been measured in Colombia regularly, hence, this index was chosen as an indicator for the water security subcategory. The IRCA reported for the municipalities within the study area (i.e., nineteen in the Atlántico and one in Bolívar) during the 2018, shows that most of them had appropriate conditions for water to be consumed, namely, they present 'No Risk' (i.e., 70% of the municipalities). In 'Medium' risk were 20% of the municipalities. Followed by one municipality with 'low risk'. Only one municipality, namely, Santa Catalina in Bolívar department had water whose consumption was 'Unsafe for public health' (see Figure 4.9).

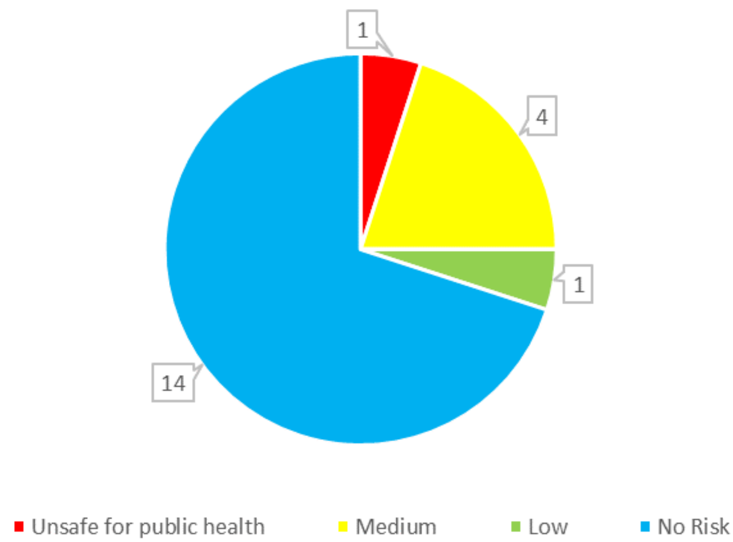


Figure 4.9. Share of municipalities by IRCA Level. Note: 'High' risk is not shown in the pie-chart because no municipality presented this risk level in 2018.

Source: the author with information from Minsalud (2020)

4.1.2.3.4 Subcategory 4 - Health

In this subcategory the 'Coverage of essential health services' is used as indicator. The higher the percentage of affiliated, the higher the number of people that will have access to essential health services (e.g., reproductive, maternal, new-born and child health, infectious diseases, non-communicable diseases)

In the Atlántico and Bolívar departments, the number of people with Affiliation to the General System of Social Security in Health (SGSSS) in 2018 was 2,352,000 people (i.e., 91.6%) and 1,952,000 people (i.e., 93.5%), respectively. Which was slightly lower than the national average for the same year of 93.6%. In the case of the non-affiliated the figures were 8.3% for the Atlántico and 6.3% for the Atlántico. Regarding the affiliation scheme, both departments showed that more than half of the population are being subsidize and, in the case of the Bolívar department, that figure accounted for nearly three quarters of the population in the SGSSS (see Figure 4.10).

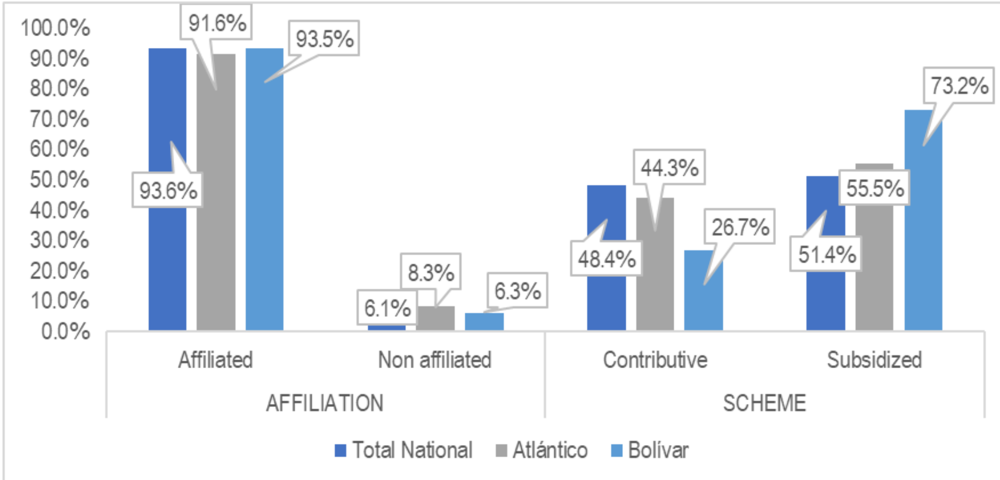


Figure 4.10. Affiliation to the SGSSS in Colombia and the Atlántico and Bolívar departments during 2018.

Source: the author with information from ECV-DANE, 2018

4.1.2.4 Category 4 - Identity

4.1.2.4.1 Subcategory 1 - Sense of self

This subcategory relies on the 'Inter-census change in the ethnic population' for its evaluation. The results from the Census and Quality-of-Life ECV-2018 survey shows that the percentage of the population that self-recognizes as part of an ethnic group is estimated to be 6.4% in the department of the Atlántico and 11.0% in Bolívar. In both cases the 'Black, Afro-Colombian, Raizal and Palenquero - NARP' population are predominant. At the national level, this groups account for nearly 15% of the population (i.e., 6,576,777) (DANE, 2021a).

The change, measured in percentage point (pp), in the proportion of Indigenous and NARP people between 2005 and 2018 shows a decrease in the representation of NARP people and an increase in the proportion of Indigenous people. Specifically, the NARP population had a change of -0.6 pp and -0.8pp in Atlántico and Bolívar, respectively. In the case of Indigenous people, the change was 0.4 pp and 0.2 pp, respectively (See Figure 4.11).

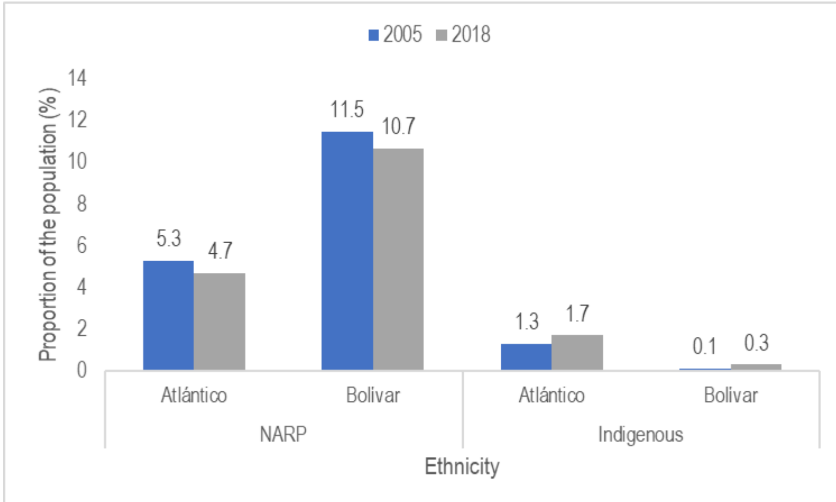


Figure 4.11. Proportion of NARP and Indigenous people in the Atlántico and Bolívar departments – Comparison between 2005 and 2018 census.

Source: the author with information from DANE (2021a)

4.1.2.4.2 Subcategory 2 - Sense of place

As explained in the OHI the lasting special places are coastal areas that can be considered culturally significant. Having this type of places (e.g. landmark, monument, marine protected area, etc) *"can help ensure its existence, provide valuable ecosystem services and preserve cultural heritage and identity" (OHI, 2022)*.

The tourism development plans that were elaborated for the departments of Atlántico and Bolívar have an inventory of tourist attractions among which are places of importance, representative buildings, landmarks, festivities, etc. For the Atlántico, in 2011 there were a total of 407 attractions (i.e. 57% material tourist attractions, 21% festivities and events, 16% natural sites and 6% intangible heritage) with the city of Barranquilla having the largest number (CITUR, 2014).

In the case of Santa Catalina (Bolívar), the main sites of interest are the Totumo mud volcano, Cocos Island, the swamps of La Redonda and El Totumo, the beaches of Galerazamba and Loma Arena, the salt flats of Galerazamba, among others, for a total of 10 tourist attractions (CITUR, 2012).

Among the events that stand out in this area is the Carnival of Barranquilla, which was declared national heritage in 2002 and, subsequently, in 2003 was declared as 'Intangible Cultural Heritage' of Humanity by the UNESCO. Thus, it is the most important festival in the region and in Colombia and attracts locals as well as national and foreign visitors.

All the above reflects a strong connection between the inhabitants of this region and their traditions, showing a sense of belonging that is not always reflected in the way the locals take care of those material attractions and natural sites whose beauty is outshined by deterioration or environmental problems such as the presence of rubbish or unfavourable sanitary conditions (CITUR, 2012, 2014).

4.1.2.5 Category 5 -Social resilience

4.1.2.5.1 Subcategory 1 - Education

This subcategory was assessed using the 'Literacy rate of adult population' as an indicator. Literacy is essential to communicate and receive written messages, to promote critical thinking. It is the basis for learning many trades and professions, reduces poverty and child mortality, contributes to economic growth, among many other benefits. Therefore, the ideal scenario is one where all (or almost all) the population is literate. Data from the Census 2018 shows that literacy levels are high in Colombia and, moreover, in the departments within the study area. The percentage of the population aged 15 years or over who can read was 96.4% in the Atlántico and 92.2% in Bolívar. However, a comparison between urban and rural/disperse areas reveals some disparities, i.e., while the literacy rates in the urban areas were 96.8% (i.e., Atlántico) and 94.5% (i.e., Bolívar), in both cases, the same figure for the rural/disperse areas was 10 p.p. less.

4.1.2.5.2 Subcategory 2 - Climate change adaptation

Investment in climate change adaptation was measured through an indicator specifically developed for this purpose by SISCLIMA Financial Management Committee. The indicator is called Relative Effort Indicator – IER.

The MRV System reported investments in the order of USD 18.62M and USD 7,610 for the Atlántico and Santa Catalina, respectively, during 2018. Altogether, those investments represented a 2.2% of the national investment (USD 860.55M) in adaptation and mitigation strategies to climate change. Regarding the source of funding, more than half of the investment in the Atlántico (i.e., 53.6%) came from private sources, followed by the public investment (i.e., 44.3%). The Relative Effort Indicator – IER shows that Bolívar made more investments in adaptation than expected (INER = 2.2), while the Atlántico did not manage to allocate enough resources according to its GDP, risk level and adaptation needs (INER = 0.4) (DNP, 2021).

4.1.2.5.3 Subcategory 3 - Risk management

This subcategory was evaluated by looking at the 'Preventive risk management investment'. The Atlántico and Santa Catalina invested a total of USD 13.561M during 2018 which divided by the total population (i.e., 2,564,643 inhabitants) gives a Per Capita Expenditure on Risk Management – PCERM of USD $5,288 per person. Table 4.8 shows in detail to which strategies (i.e., disaster response, knowledge of risk, risk reduction or governance improvement) the funds were allocated. Overall, in the Atlántico and Santa Catalina, $6.4 USD million (i.e., 46.9% of the total) of the risk management funds were used in preventive strategies.

Table 4.8. Risk management funds during 2018 for the Atlántico and Santa Catalina (Bolívar).

Domain	Total actions	Total investment (USD)	Distribution by type measure (%)			
			Disaster response	Knowledge of risk	Risk reduction	Governance
Atlántico SA	186	$ 10,857,000,000.00	54.4	0.7	3.2	41.8
Atlántico department	228	$ 13,561,000,000.00	53.1	9.0	4.3	33.6
Bolívar (Santa Catalina)	2	$ 7,021.00	100.0	0.0	0.0	0.0

Source: the author with information from DNP (2021). Atlántico SA: only municipalities within the study area. Values reported as current prices in 2018 and converted from local currency using an exchange rate of 1USD = 2,956 COP

4.1.3 Economic domain

4.1.3.1 Category 1 - Security

4.1.3.1.1 Subcategory 1 - Livelihoods

For this category, the chosen indicator was the 'Relative change of GDP from ocean-related activities'. The Atlántico and Bolívar GDP in 2016 were USD 11.4 million and USD 11.2 million[4]. From these, the coastal-related activities (i.e., Fishing and Aquaculture, Accommodation and Services, Water-borne transport and, Travel agencies) contributed to an average of 5.4%, being the most important the 'Accommodation and Services' sharing nearly four fifths of the total. Table 4.9 shows the percentage of GDP associated to each activity.

As seen in Table 4.9, the ratio between the Gross Domestic Product – GDP of 2016 and the 5-year average GDP (i.e., 2011-2015) for the coastal-related activities shows values above 1 (i.e., all activities and both departments). This means that in the latter period, the revenues from the coastal related activities have increased on average in 40% when compared to the preceding 5-

[4] Current prices in 2016. Exchange rate 1 USD = 2,957 COP

year period. Moreover, the GDP of activities such as the water-borne transport in the Atlántico has doubled in the same time span.

Table 4.9. Coastal-related-activities shared of the GDP, 5-year average between 2011-2015 and GDP for the year 2016. Values are given in billion COP as constant prices (Reference year 2015).

Domain	Activity	Share in Department GDP (%)	5-year average (Billion COP)	GDP 2016 (Billion COP)	Ratio Current Year / Reference period
Atlántico	Fishing and aquiculture	0.01%	COP 2.35	COP 3.72	1.6
	Accommodation and services	4.02%	COP 1,199.51	COP 1,359.66	1.1
	Water-borne transport	0.01%	COP 2.35	COP 4.65	2.0
	Travel agencies	0.58%	COP 167.85	COP 197.16	1.2
Bolívar	Fishing and aquiculture	0.74%	COP 185.94	COP 244.59	1.3
	Accommodation and services	4.42%	COP 1,259.02	COP 1,459.17	1.2
	Water-borne transport	0.06%	COP 14.52	COP 21.39	1.5
	Travel agencies	0.89%	COP 254.95	COP 293.88	1.2

Source: the author with information from DANE Departmental national accounts (2016)

4.1.3.1.2 Subcategory 2 - Gender

The Gender subcategory in economic terms was evaluated through the ‘Gender Wage Gap’ indicator. To achieve sustainability in the environmental, social, and political domain it is necessary to achieve gender equity, *“evidence indicates that women's inclusion in the labour market would not only increase Gross Domestic Product (GDP), but also reduce poverty and inequality”* (ONU Mujeres et al., 2020, p. 24).

Between 2017 and 2018 Barranquilla experienced an improvement in terms of women income in relation to the men's going from 71.5% to 76.9% (i.e., an increase of 5.4 percentual points - p.p.). However, this is not enough in terms of gender equity, especially if considering that Barranquilla presented the biggest inequality among the group of thirteen cities assessed with 7.9 pp. less than the other 12 (i.e.,84.8%). The capital of Bolívar (i.e., Cartagena) shows slightly better equality conditions with women earning 81.2% of the men's average income during 2018 that is 3.6 pp. less than the national average. (DNP, 2019). Thus, the gender wage gap in 2018 for Barranquilla, Cartagena and Colombia was estimated at 23.1 pp, 18.8 pp and 15.2 pp, respectively.

4.1.3.1.3 Subcategory 3 - Employment Patterns

This subcategory relies on the ‘Unemployment rate’ as the main indicator for its assessment. Information about other indicators is provided for contextualization purposes.

Historic data from DANE shows an increasing trend on the indicators of pressure over the labour market and occupation, namely, Overall Participation Rates – TGP and Employment rate – TO, since 2001 until 2018 in the Atlántico department. On average, the proportion of people old enough to work who is in fact working or looking for a job was 58.2%, in 2018 the proportion was 63.3%. The employment rates exhibited a similar behaviour with an average of 52.1% and 58.4% during the 2018. As it is logical, the increasing trends from the occupation indicator are matched by unemployment rates exhibiting a downward trend with a peak of unemployment in 2003 (i.e., 15.5%) and consequent lower levels until reaching a minimum of 7.4% in 2017, followed by a slight increase of 0.3pp to reach 7.7% in 2018. On average, the unemployment rates were 10.5% during the study period (see Figure 4.12).

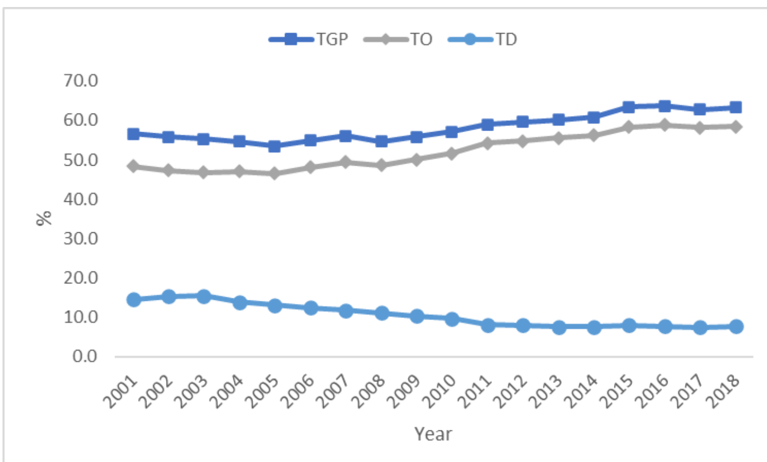


Figure 4.12. Employment patterns in the Atlántico (2001-2018). Overall participation rate – TGP, Employment rate – TO and Unemployment rate – TD.

Source: DANE, 2022

4.1.3.2 Category 2 - Infrastructure

4.1.3.2.1 Subcategory 1 - Energy supply

This subcategory was evaluated with two sub-indicators: (i) Share of electricity generated from renewable sources and (ii) Share of households with access to electricity.

Overall, the primary energy supply (i.e., the one that is taken directly from natural resources) in Colombia is mainly associated to fossil fuels (oil and coal) sharing 77% of the total. The other 23%

is composed by hydroelectric energy, gas, and other non-conventional renewable energy sources. By 2018, the share of energy sources in the composition of supply at a national level was as follows: Diesel fuel 21%, Gasoline 17%, Electricity 17%, Natural Gas 16%, Firewood 8% and other sources 21% (e.g. coal, bagasse, coke, jet fuel) (UPME, 2019).

Now when it comes to electric energy, Colombia has one of the cleanest energy generation matrices in the world with 68% generated from hydroelectric power, however, in terms of non-conventional renewable energy sources - FNCE, the country is lagging behind (Carlos Paniagua & Duarte Pérez, 2021, p. 1). In 2010, the Ministry of Mines and Energy established a goal of 3.5% and 6.5% of the total installed capacity for the SIN coming from FNCE by 2015 and 2020, respectively. (UPME, 2015, p. 26) Although, by 2018 less than 1% corresponded to FNCE in the SIN. It is expected that in the following years, this value will reach nearly 10% due to the implementation of new incentives for energy traders (Carlos Paniagua & Duarte Pérez, 2021, p. 8). Finally, in terms of overall electricity connectivity per household, disregarding their location in rural or urban settlements , 85.8% of the total households has access to electricity (DANE, 2018).

According to the International Energy Agency – IEA, to maintain temperature rise below 1.5°C, is necessary to get the world on track for a Net-zero emission scenario which will require, among others, to achieve the following targets:

- All the population has access to electricity by 2030
- The share of fossil fuels from the total energy supply is less than 62% in 2030 and less than 22% in 2050
- The share of renewables in electricity generation should be 61% by 2030 and 88% by 2050 (this percentages include wind and solar power generation).

4.1.3.2.2 Subcategory 2 - Tourism

The ‘relative change in hotel occupancy rates’ was the chosen indicator to evaluate this category. According to the reports from the Colombia Tourism Information Centre – CITUR, in 2018 the total number of rooms, beds and employees of tourist accommodation and lodging service providers in the Atlántico department were 9,339; 16,425 and 12,708, respectively. The average hotel occupancy was 51.4% in 2017 and 53.9% in 2018 meaning there was an increase of 2.5pp between the evaluated periods. Due to the lack of historic information, it was not possible to calculate the 5-year average for the reference occupancy because the platform where the information was available (i.e., CITUR Atlántico) was released in 2017, therefore, the uncertainty of this indicator is high.

In 2018, 162,361 international passengers arrived in commercial flights and 1,067,791 national passengers arrived using the same transport mean. These figures were measured during the best year for the national tourism industry that received 4.2 million non-resident visitors (including Colombians and foreigners) reaching a hotel occupancy of 55.46% (MinCIT, 2021).

4.1.3.2.3 Subcategory 3 - Transport

The indicator for this subcategory corresponds to the 'Percentage of goods transported by transport mode'. The Atlántico moves most of its cargo and passengers by terrestrial mode (62% and 83%, respectively). The air-borne transport is only important for passengers given that in terms of cargo it mobilizes less than 1% of the total, hence, terrestrial vehicles are followed by sea transport (23% of the cargo) and inland waterways freight transport (15%) (COLOMBIA. Ministerio de Ambiente y Desarrollo Sostenible, 2015, p. 34). As inferred from the Table 4.10, the Atlántico does not have access to a railway network however, there is the idea, on a very early stage of development, of building a regional train that in the future could connect the main cities in the Caribbean region, namely, Cartagena, Barranquilla and Santa Marta (Gobernación del Atlántico, 2020, p. 261).

Table 4.10. Volume of cargo and number of passengers mobilized by transport mode in the Atlántico

Mode	Cargo volume		Number of passengers	
	Ton/month	%	Quantity	%
Plane	2,592.00	0.11%	1,207,115.00	16.94%
Road (trucks, vehicles)	1,412,163.00	62.00%	5,918,374.00	83.06%
Inland waterway	336,597.00	14.78%	ND	ND
Maritime	526,418.00	23.11%	ND	ND
Total	2,277,770.00	100.00%	7,125,489.00	100.00%

Source: COLOMBIA. Ministerio de Ambiente y Desarrollo Sostenible (2015, p. 34)

Thus, the department is well connected to different modes of transport, however, there is a heavy dependence on land transport by trucks which rely on fossil fuels as a source of energy. A more sustainable transport infrastructure would require not only a diversification of transport modes (railways or higher share of the maritime and fluvial waterways for both cargo and passengers) but also less dependence on fossil fuels.

4.1.3.2.4 Subcategory 4 - Access

This subcategory is evaluated with two sub-indicators. The first one is focused on the waterborne transport access and the second one focuses on the quality of the roads for the terrestrial transport and connectivity.

When it comes to maritime transport, in Colombia there are three main port areas (i.e., Caribbean region, Pacific region, and Magdalena River) that mobilised 170.5, 26.5 and 2.4 million tons, respectively in 2018. Specifically in the department of Atlántico is located the Port of Barranquilla, a multipurpose port (i.e., containers, dry and liquid bulk cargo) which, despite being the one that moves the least cargo of the continental Caribbean ports (i.e. only 5.5% of the national cargo), its main importance lies in being a maritime and fluvial port, which allows the connection with other cities in the interior of the country through the main fluvial artery of Colombia: the Magdalena River in whose basin 80% of the national GDP is generated. Barranquilla's Port contributes to 5% of the GDP for the city and 3% of the departmental GDP and generates around 17,500 direct and indirect jobs (Patiño M., 2019; Puerto de Barranquilla, 2021; SuperTransporte, 2019). Therefore, in terms of access to the maritime and fluvial transport the study area is privileged, however, the transport through the Magdalena waterways is underexploited due to technical constraints (e.g., siltation, draft, width, among others).

Regarding terrestrial transport, the Atlántico has a high level of interconnexion with the national highways (i.e., 69km within the department). Overall, the department has a road density of 0.79 km / km^2 and its road network consists of 2,616 km of road distributed as follows: the primary departmental network account for 13% of the total; the secondary network comprises nearly a quarter; and the tertiary network with a total of 1,670 km corresponds to more than half of the department roads (see Table 4.11) (Gobernación del Atlántico, 2020). Despite presenting one of the highest road densities among Colombia's departments, the state of the road network does not match the importance of the department and the level of interconnection considering that only 11% of the primary non-leased[5] network is paved, while the remaining 89% are unpaved roads. Regarding the quality, nearly 35% of the non-leased network reported to be 'Adequate' and the remaining roads had 'Good' or 'Excellent' conditions by 2019 (INVIAS, 2022)

Table 4.11. Road network composition in the Atlántico department.

Network	Maintained by	Total km
Primary	Department	338.95
Secondary	Department	606

[5] Roads overseen by INVIAS

Network	Maintained by	Total km
Tertiary	Department	356.26
Tertiary	Municipality	1,314.48
Total (km)		***2,616***
Area Atlántico (km²)		***3,386***
Road density (km / km²)		***0.77***

Source: the author with information from Gobernación del Atlántico (2020)

4.1.3.3 Category 3 - Economic wellbeing

4.1.3.3.1 Subcategory 1 - Equality

Income inequality was measured through the well-known GINI coefficient that shows an overall decreasing trend between 2002 and 2018 in all geographic scales (departmental and national). In the Atlántico, the coefficient decreased steadily in the evaluated period going from 0.530 in 2002 to 0.443 in 2018 representing, roughly, a 16% drop in the inequalities. Over the same period, Bolívar department exhibited a similar trend passing from 0.533 in 2002 to 0.472 in 2018, which translates into a 11% decrease of income inequalities. Besides the slight differences in absolute values between both departments (i.e., Bolívar is slightly higher than Atlántico), the main difference lies on the behaviour exhibited during the earliest 5 years of the record when Bolívar had an initial sharp plunge reaching one of the lowest values being 0.476 in 2003 (i.e. even lower than the Atlántico) and a sudden rise that led to an all-record maximum of 0.543 in 2008. The behaviour in the Atlántico did not show any sharp changes along the same period but a steady decrease until 2016 when it reached an all-record minimum of 0.432 followed by a slight increase in the following 2 years. In both departments, the GINI coefficient has always been below the national average which in 2018 was 0.517 (see Figure 4.13).

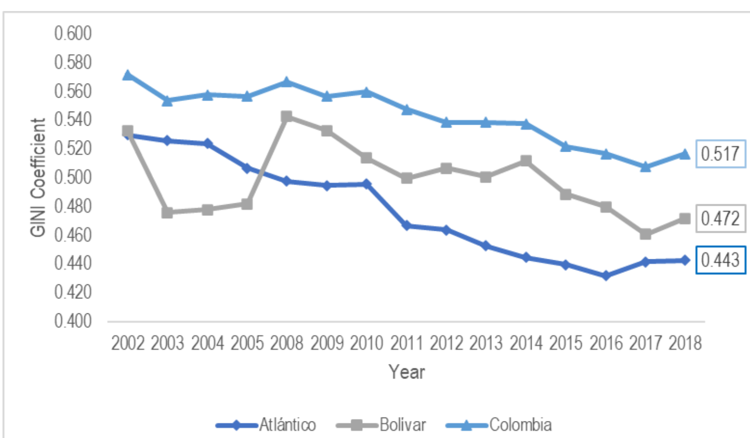


Figure 4.13. GINI Coefficient in Atlántico, Bolívar, and Colombia (2002-2018).

Source: the author with information from DANE (2018)

4.1.3.3.2 Subcategory 2 - Housing

This subcategory is evaluated based on the household income devoted to housing costs. If the average cost of rent reported by Torres Ramírez (2012) in the Caribbean region is adjusted for inflation, the current price by 2018 would be USD 91 which is equivalent to nearly 35% of the minimum wage for the same year (264 USD). In terms of 'household income' to 'rent expenditure' ratio, in 2008 this value ranged between 10-11% of the household monthly income. However, it was as high as 60% of the monthly income for people earning equal or less than the minimum wage (Torres Ramírez, 2012, pp. 7–8). More recent data from the Household Budget National Survey shows that in Barranquilla, Cartagena and Colombia, the Household income devoted to housing costs, including paying public services, was 31.4%, 30.8% and 28.7%, respectively (DANE, 2017).

4.1.3.4 Category 4 - Industry

The main activities within the 'Blue Economy' in the Atlántico's department are presented in Table 4.12. Other important economic activities which are not part of the 'Blue Economy' are Commerce, transport, and communications (CTC); Corporate Services (CS), Social Services and Others (SSO); and the manufacturing industry (MI) which generated nearly three quarters of the Atlántico's GVA corresponding to 25 billion COP in 2018. Hence, the Atlántico's GVA main contribution came from the tertiary sector or service activities, followed by the secondary sector activities, and little representation of the primary sector or extractive activities. Each of these major activity groups accounted for 65.3%, 33.2% and 1.5% of the departmental GVA in 2018, respectively (see Figure 4.14) (Gallo Vélez et al., 2022)

Table 4.12. Main activities of the blue economy in the Atlántico department.

Activity	Description
Fishing & Aquaculture	In 2018, only 83.5 ton of fishing production were reported at the 2 unloading sites monitored by the AUNAP (i.e. 'Las Flores' & 'Tajamar Occidental'), on the other hand, aquaculture production was estimated at 3,969 ton in the same year (Roca-Lanao et al., 2018; SEPEC, 2021).
Tourism	For the Atlántico, the number of international and domestic arrivals was 631 thousand and 4.2 million, respectively, between 2016 and 2019 (MinCIT, 2021).
Shipyards	As of 2019, there were 42 shipyards and 16 repair facilities in Colombia, some of which are located in Barranquilla, where, in addition to repairs, small vessels such as patrol vessels, tugboats, pusher craft, barges and river boats, among others, were manufactured (CONPES 3990, 2020).
Off-shore oil & gas and alternative energies	Barranquilla aims to play a strategic role by becoming an 'offshore platform for logistical development' and an 'energy hub' in the Colombian Caribbean. Although exploration and exploitation activities do not take place directly off the Atlántico coast, at least for the time being (A. Castellanos et al., 2017; Oxford Business Group, 2017; WECP, 2020). Additionally, the "Offshore Wind Roadmap for Colombia" proposes two areas

Activity	Description
	of interest, off the Atlantic coast, for the potential deployment of 2 wind farms which have a combined area of 900 km2 and a nominal reference capacity of 3600 MW. (Renewables Consulting Group, 2022)
Marine bioprospecting	Only a few studies to identify potential uses of the biological diversity in the Caribbean, not specifically in the Atlántico's marine area, have been conducted such as the ones from (F. Castellanos et al., 2019; Jutinico-Shubach et al., 2021; Quintero et al., 2018)
Maritime transport	In the department of Atlántico is located the Port of Barranquilla which contributes to 5% of the GDP for the city and 3% of the departmental GDP and generates around 17.500 direct and indirect jobs (Patiño M., 2019; Puerto de Barranquilla, 2021; SuperTransporte, 2019).

Source: Adapted from Gallo Vélez et al. (2022)

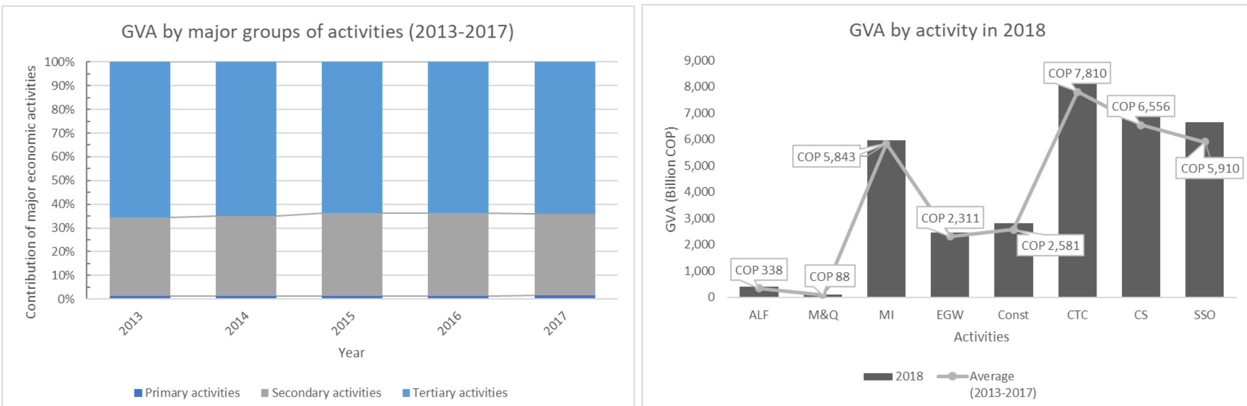


Figure 4.14. Gross Value Added (GVA) contribution of major groups of activities (left) and GVA by activity in 2018 (right) in the Atlántico's department. *Current prices (Reference 2015). Does not include Santa Catalina (Bolívar). Note: ALF - Agriculture, livestock, and fishing; M&Q - Mining and quarrying; EGW - Electricity, gas, and water; Cons – Construction.

Source: the author with information from DANE (2021b)

4.1.3.4.1 Subcategory 1 - Renewable

The share of GVA generated by activities/sectors relying on Renewable was used to assess this sub-category. The activities from the tertiary group associated with 'Accommodation and Food services'; Professional, scientific, and technical activities; Arts, entertainment, and other service activities, were the ones considered to be reliant (or have the potential to be) on renewable resources, adding up for a total of 32.6% of the department's GVA (i.e., 3.53 million USD).

4.1.3.4.2 Subcategory 2 - Extractive

This subcategory was assessed through two sub-indicators: (i) The ratio between Extractive and Renewable activities and (ii) the relative change in GVA from 'Agriculture, livestock and fishing' (ALF).

From all the economic activities, it is assumed that primary and secondary groups rely directly and indirectly, respectively, in extractive activities and both accounted for 34.6% of the Atlántico's GVA during 2018 (i.e., 3.81 million USD). Hence, the ratio of Extractive GVA between Sustainable GVA is 1.08 or, in other words, the GVA from extractive industries is nearly 10% more than the one produced by sustainable activities. Finally, when dividing the GVA from the ALF activities in 2018 (i.e., 133,000 USD) by the 5-year average value between 2013 and 2017 (i.e.,117,000 USD) the ratio was 1.14. In other words, the GVA from the Agriculture, livestock, and fishing industry in the evaluated period 2018 grew by 14% compared to the reference period, showing positive trends for this activity in economic terms.

4.1.3.5 Category 5 - Dependency

4.1.3.5.1 Subcategory 1 - Resources

In this subcategory, the chosen indicator corresponds to the ‘Relative change of overall workforce within blue economy’.

The conditions in the capital cities from the Atlántico and Bolívar (i.e., Barranquilla and Cartagena, respectively) provide an overall picture of the urban workforce in the study area. Despite the slight differences in percentual points among the share of jobs by activity, both cities present a similar behaviour. The activities that were assumed to be related to coastal jobs were ‘Retail, hotels and restaurants - RHR’, which provided nearly 30% of the jobs; ‘Transport, storage and communications – TSC’ providing between 10.9%-15.8% of the occupied workforce and, ‘Agriculture, livestock and fishing-ALF’ which represents less than 1% of the jobs by 2018 (see Figure 4.15) (DANE – GEIH 2018). This figures, however, might not reflect the conditions for the rural population of the study area outside BMA (i.e. 94,100 people approx.)[6], where no information regarding workforce occupation was available (DANE, 2018).

[6] Working age population (PET) living strictly in rural areas outside BMA. PET from urban areas outside BMA assumed to have similar patterns as Barranquilla.

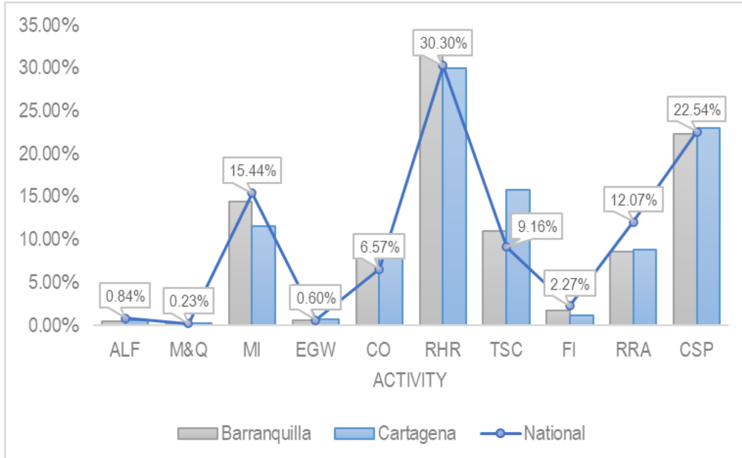


Figure 4.15. Percentage of the average urban workforce by economic activity in Barranquilla, Cartagena, and Colombia – Year 2018. Note: M&Q -

Source: the author with information from DANE – GEIH 2018

In terms of the relative change of coastal jobs, the ratio between the evaluated period (i.e., year 2018) and the reference period (i.e., 2013-2017) were 1.05 and 1.01 for Atlántico and Bolívar, respectively. This numbers, indicate that compared to the reference period, there has been an increase of 1% to 5% of the jobs generated in the blue sector. These values might not be considered important and, in fact, could be associated to the variability of the jobs in this sector. In any case, what can be inferred from these numbers is that the coastal jobs in 2018 remained close to the trend of the last five years.

4.1.3.5.2 Subcategory 2 - Diversity

The diversity subcategory is evaluated based on the 'Livelihood diversification from small-scale fishing households. The results from a survey conducted in Barú (Bolívar department) shows some of the main activities of non-fishing households which include tourism, production and sale of handicrafts, construction, and sale of food. In the case of fishing households, the main activities were fishing, transport, watch keeping and fishing-related activities such as selling fish and renting fishing gear. In terms of income, the proportion derived from the primary activity for households with more than one economic activity was higher on the non-fishing type (i.e., on average derived 90% of their income from the main economic activity), while in the fishing households this figure was 78%.

Finally, *"according to the Simpson Diversity Index, fishing households diversified their income significantly more than non-fishing households. Households did not exhibit large diversity of* *income in the main economic activity; however, secondary economic activity tended to be more diverse within households."* (see Figure 4.16) *(Higinio Maldonado et al., 2022, p. 11).* It is important to stress that these results are just an approximation and, by no means represents the reality of the study area considering that regardless the similarities between Barú's and Atlántico's coastal communities, there are conditions which could promote different dynamics such as land availability, vicinity to urban centres, existence of manufacturing industry, among others.

Variables	Non-fishing Mean (SD)	Fishing Mean (SD)	Means difference
Number of economic activities	1.160 (0.021)	1.709 (0.022)	-0.549 (***)
Proportion of income from the main activity	0.899 (0.005)	0.783 (0.006)	0.115 (***)
Proportion of income from the main activity when household has more than one activity	0.714 (0.009)	0.627 (0.005)	0.088 (***)
Simpson Diversity Index (for the main activity of household members)	0.131 (0.007)	0.267 (0.007)	-0.136 (***)
Simpson Diversity Index (for household members with more than one economic activity)	0.370 (0.009)	0.459 (0.005)	-0.089 (***)

* p<0.10, ** p<0.05, *** p<0.01

Figure 4.16. Labour income diversity for fishing and non-fishing households in Barú (Bolívar).

Source: Higinio Maldonado et al. (2022, p. 12)

4.1.4 Politics and governance domain

4.1.4.1 Category 1 -Organization

Despite the existence of organizations and institutions legally established and recognized by local authorities, there is widespread lack of legitimacy on the part of community members, either because of the low visibility of the institutions or because they are not acknowledged as being representative of the community's interests. There are also a large number of sectoral leaders. (CRA & ASOCARS, 2014, pp. 426–427). Table 4.13 presents the number and type of organizations that were registered in the Atlántico department and the year to which the information corresponds.

Table 4.13. Number of organizations by type.

Stakeholder type	Number	Year
Local community councils - JAC	545	2021
Ethnic communities	2	2021
NGO	305	2015
Educational institutions	291	2019
Civil associations	167	2014

Sources: ANT, 2021; CRA, 2014, 2015; Mintic, 2022

4.1.4.2 Category 2 - Law and justice

In terms of policies aimed at coastal management, Botero et al. acknowledge that Colombia has a public policy represented in the PNAOCI and the PNOEC, however, their implementation is in the initial stages and that there are no evaluation and monitoring mechanisms in place for those responsible from executing the policy. Hence, a score of three (3) out of five (5) is assigned to this aspect. In terms of norms and regulations, the same authors mention that the Colombian regulatory framework has an integrated sectoral approach and recognises the differences that exist in the coastal zone, but clarify that the current regulations are not specifically oriented towards the *"management of the coastal/maritime public domain"*, which is why this aspect receives a score of 2 out of 5. (Botero et al., 2020, p. 60)

Although the above assessment has a national scope, the conditions of the study area are not very different, taking into account that the littoral and marine areas are under the jurisdiction of the national government at the planning level and that, in environmental matters, although the regional autonomous corporation is the competent authority within the study area and the UAC Río Magdalena - Atlántico sector, no regulations with a direct focus on the coastal/marine area had been introduced until 2020. (CRA, 2020, pp. 36–39)

4.1.4.3 Category 3 - Representation and power

4.1.4.3.1 Subcategory 1 - Participation in elections

Voters turn-out is a well-known indicator to evaluate people's participation at the national and local level. For the study area, the voter turnout in national elections during the first decades of the 21st century (i.e., each four years between 2002-2018) has been low, with rates below 50% in all years in the case of presidential elections, and even lower numbers in the case of legislative bodies in Colombia (i.e., senate and chamber). The elections in 2018 had the highest voter turnout (i.e., 46.7%) in the evaluated period, even though less than half of the population participated. On the other hand, the presidential elections from 2014 exhibited the highest abstention rate in the Atlántico with less than a quarter of the electorate taking part in the elections (see Figure 4.17).

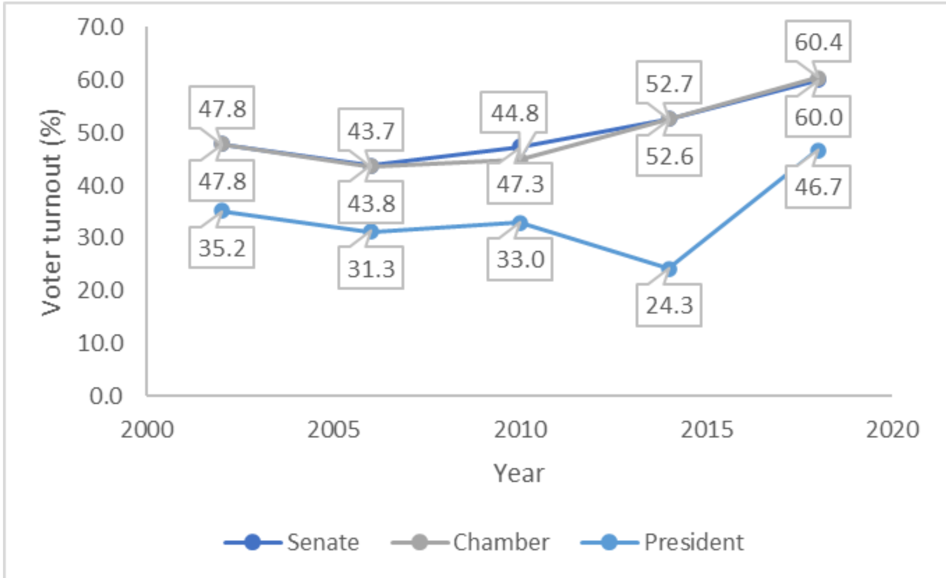


Figure 4.17. Historic voters' turnout in national elections (2002-2018)

Source: the author with information from Registraduría Nacional del Estado Civil.

In the case of local elections and taking the 2019 scenario as an example, it is observed that electoral turnout is higher (see Figure 4.18) and that the abstainers dropped, on average, to 25.0% in all municipalities within the study area, except for the city of Barranquilla where almost half of the people refrained from voting.

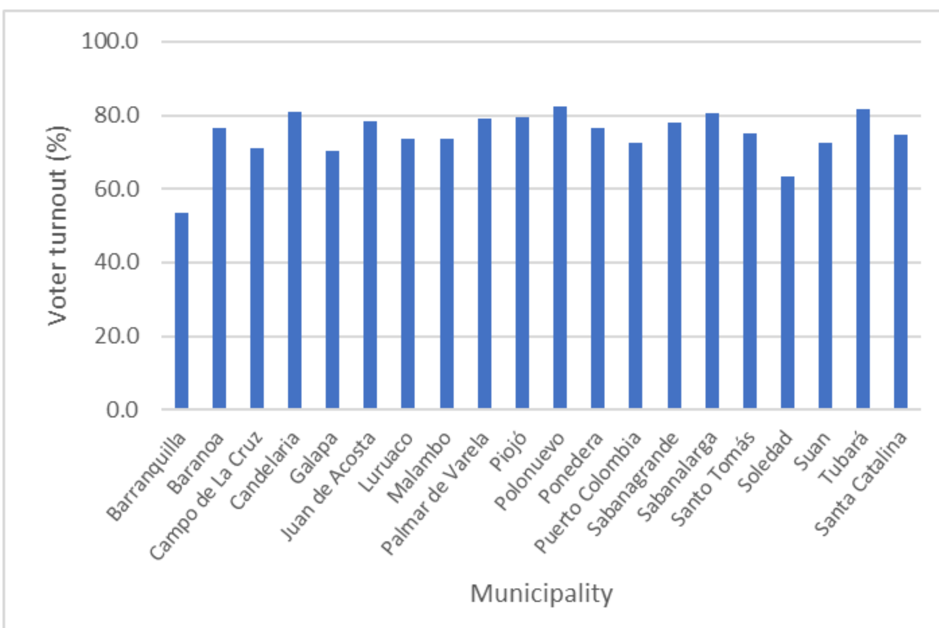


Figure 4.18. Voter turnout (%) by municipality in the local elections from 2019.

Source: the author with information from MOE, 2019

4.1.4.3.2 Subcategory 2 - Women representation

The Convention on the Elimination of All Forms of Discrimination against Women - CEDAW define the effective participation of women in the political and public life as the right *" (a) To vote in all elections and public referenda and to be eligible for election to all publicly elected bodies; (b) To participate in the formulation of government policy and the implementation thereof and to hold public office and perform all public functions at all levels of government; (c) To participate in non-governmental organizations and associations concerned with the public and political life of the country."* (MOE, 2018, p. 7)

Regardless of the norms that have been implemented in Colombia to improve women's representation in the political arena, the national and local (department and municipalities) reality is that women's participation is still low. This is suggested by the percentage of women mayors elected in Atlántico in 2019 (i.e. 17.4%); or that out of 7 governors elected in the last two decades (2000-2020) only 1 (14.3%) has been a woman; to reinforce this point, the Percentage of women elected in the House of Representatives 2018 for the Atlántico was 42.8% (MOE, 2018; Vicepresidencia de la República, 2022).

4.1.4.4 Category 4 - Legitimacy and accountability

Colombia has an index to evaluate the capacity of the state to fight corruption. The INAC for the department of Atlántico and its capital city Barranquilla, was 70.4 and 82.36 for the 2020 year. Despite not being optimal, these values indicate a high degree of implementation of the anticorruption strategies. Comparing the 2020 scores with the preceding year 2019, it is seen that in Barranquilla there was an increase in both dimensions, transparency, and integrity, of 7.29 and 3.06 points, which translates into a better INAC score. In the case of the department, there was a negative variation of -5.20 points with respect to 2019, this value is mainly associated to an important fall in the 'Institutional Integrity' component (see Table 4.14).

Table 4.14. INAC for Colombia, Atlántico, and Barranquilla - 2019 and 2020 period.

Entity	Year	INAC	Dimension 1 Transparency and open state	Dimension 2 Institutional Integrity
Barranquilla City Hall	2019	77.6	88.66	70.23
Barranquilla City Hall	2020	82.36	95.95	73.29
Atlántico government	2019	74.2	79.2	70.8
Atlántico government	2020	70.4	85.74	60.17

Entity	Year	INAC	Dimension 1 Transparency and open state	Dimension 2 Institutional Integrity
Average Colombia	2019	75.47	66.95	74.92
Average Colombia	2020	78.19	79.24	77.49

Source: the author with information from (Secretaria de Transparencia, 2022)

4.1.4.5 Category 5 - Resource Management

4.1.4.5.1 Subcategory 1 -Management instruments

After reviewing some of the most important instruments for the management of natural resources it was established that less than 20% of the job has been done. In general terms, integrated management plans for basins, wetlands and the coastal zone are lacking either the formulation or the implementation, meaning they were not operative until 2020. Instruments with a narrower scope, meaning those sectorial plans (e.g., mangrove management; water use and quality; and protected areas management) are in a further stage of development and implementation, however, there is still a considerable number of non-existent instruments (e.g., Water resource management plans). Details about the percentage of implementation from each instrument are presented in Table 4.15.

Now, the issues are not only in terms of quantity but also in the quality of the instruments. The most important instrument envisioned to manage the resources and activities in the coastal zone is the ‘Integrated Management and Development Plan for the Coastal Environmental Unit of the Magdalena River, Canal del Dique complex - Lagoon System of the Ciénaga Grande de Santa Marta’ (hereinafter POMIUAC - RM), however, it is not yet operative. The formulation of the POMIUAC-RM has been slow and difficult considering the complexity involved in coordinating studies with the other CARs and the absence of detailed baseline information on the marine areas (CRA, 2016) and this process is expected to continue during the period 2020-2023[7] without a clear panorama of when the POMIUAC Rio Magdalena will be effectively adopted and implemented (CRA, 2020).

4.1.4.5.2 Subcategory 2 -Decentralization of power

[7] As of November 2021, there is an institutional version of the POMIUAC-RM which was approved by the ‘Joint Commission’ of the UAC. This version must be consulted with the ethnic communities (Consulta Previa) before its approval and implementation. Thus, the POMIUAC RM is in Phase 4. 'Formulation and Adoption' within the phases established in numeral 2.2.4.2.2.3.4 of Decree 1076 of 2015.

Despite being promulgated by the national constitution, there is no decentralization of power when it comes to coastal management. Most of the decisions are taken at central level in the institutions based in Bogotá. Only a few steps have been taken towards this decentralization (i.e., Law 1617 / 2013 granting special powers to municipalities that are declared as *"special districts"* which is the case of Barranquilla). The decree 1120/2013 is specifically focused on the coastal areas and assigns responsibilities to a *"Joint Commission"*, however, it is only in regards environmental matters. The Maritime General Direction is responsible for the beaches, low tide land and territorial waters but not as an environmental or police authority. The only norm that can be really considered as an advance in decentralization of power is the Decree 1766/2013 which creates the Local Committees for Beach Organization. (Botero et al., 2020, p. 49). For all the above reasons, Botero et al. state that Colombia has *"an ICM-oriented public responsibility distribution scheme with coordination mechanisms"* and assign it a score of 3.

Table 4.15. Natural resource planning or management instruments and percentage of implementation within the jurisdiction of the Corporación Autónoma Regional del Atlántico (CRA).

Instrument	Notes	How many should be implemented	How many are currently operative	Percentage of implementation
Strategic plans for macro-basins	PEM Magdalena-Cauca River was formulated in 2018 and its implementation started in 2019	1	1	100%
Integrated Coastal Zone Development and Management Plan - POMIUAC	POMIUAC Rio Magdalena is in stage F4	1	0	0%
River basin development and management plans - POMCA	Direct to Caribbean (F0), Mallorquin Basin (F4) and Low Magdalena River - LM (F4)	3	0	0%
Aquifer environmental management plans	None of the three main aquifers (Sabanalarga-Tubará, Magdalena River, and Barranquilla-Puerto Colombia in the area have management plans)	3	0	0%
Territorial plans for adaptation to climate change	The Atlántico has an "Integrated Territorial Climate Change Management Plan for the Atlantic Territory 2040"	1	1	100%
Mangrove management plan	Adopted by the Resolution 00923 from 2018. "By which the integrated management plan for mangrove ecosystems in the department of Atlántico is adopted."	1	1	100%
Delimitation of water courses	The only water bodies with a defined water round are Luruaco, Tocagua, Mallorquín, Guajaro and Cisne.	17	5	29%
Forest management plans	El Palomar Protected Forest Reserve Management Plan	1	1	100%
Water resource management plans	In 2020 there were 317 users of the water resource in the Atlántico's jurisdiction, however, only 41 had approved programmes and projects for efficient water use and water saving	317	41	13%
Water use regulations	The water bodies in the jurisdiction have Quality objectives set by Resolution No. 00258 of 2011 for the period 2011 - 2020.	1	1	100%

Instrument	Notes	How many should be implemented	How many are currently operative	Percentage of implementation
Regulation of water discharges	Status of the Sanitation and Wastewater Management Plan - PSMV from the Municipalities within the Atlántico until 2020	23	13	57%
Climate change national adaptation plan	Established since 2012	1	1	100%
Protected areas management plans	The protected areas within the Atlántico are: DMI Luriza, DRMI Palmar del Tití, DRMI Banco- Totumo - Bijibana, PNR Rosales, RNFP El Palomar, RNSC Los Mameyales, RNSC Los Carchones	7	7	100%
Management plans for RAMSAR areas	There are five wetlands belonging to RAMSAR sites of the "Sistema Delta Estuarino Ciénaga Grande De Santa Marta" (i.e., Mallorquín, Manatíes, Ciénaga Luisa, Larga and Paraíso) none of them have a management plan	5	0	0%
Administrative regulations on resource bans	Not existent	1	0	0%
Exclusive zones for artisanal fishing	Not existent	1	0	0%
Average implementation within the study area		***384***	***72***	***19%***

Source: the author with information from CRA, 2020 and Res. 768/2017, 17/April/2017

4.2 SCORING

For the assessment of the Magdalena River-mouth a total of fifty-two indicators were chosen. Their distribution among the four domains of the CCS framework is represented in Figure 4.19. The 'Economy' and 'Environmental' domains have the highest number of indicators both with sixteen (16), followed by the 'Society' domain containing twelve (12) indicators. Finally, the complexity of measuring 'Governance' is reflected in the small number of indicators (i.e., only 8).

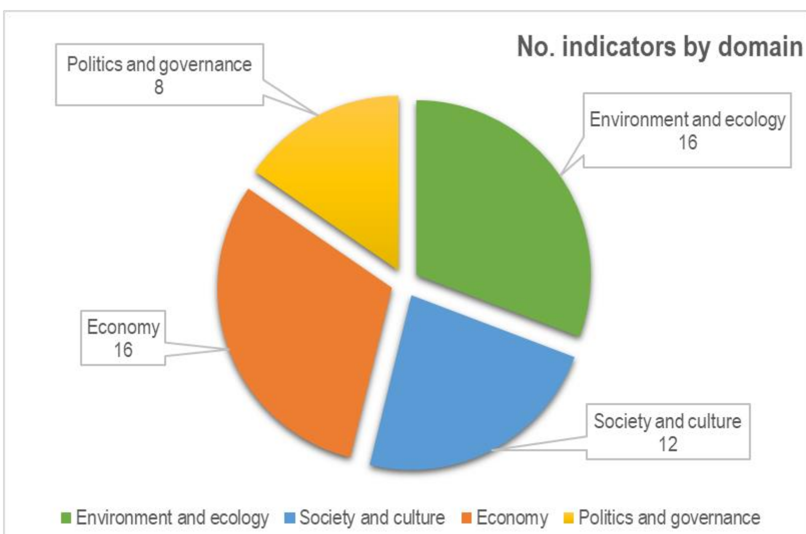


Figure 4.19. Number of indicators by domain.

Source: the author.

Using the information presented for each indicator and taking as a reference the categorical scales defined in the methodology (see Table 3.2), a sustainability score was defined for all the indicators that were aggregated by subcategory and, subsequently, by category to obtain the results shown in Table 4.16.

The domain with the higher number of indictors scoring 'Bad' was the Environmental domain with four out of 16 (i.e., Land Cover Change, Protected areas, Atmospheric temperature change and Freshwater suspended sediment load) followed by the Socio-cultural domain with three indicators in the same sustainability level (i.e., Incidence of Income poverty, Prevalence of food insecurity and Relative Effort towards climate change adaptation).

On the contrary, the Economy domain presented only one indicator scoring 'Bad' (i.e. Gender wage gap) while having the most indicators in the 'Excellent' sustainability level, a total of 5 out 16 (i.e. Relative change of ocean-related activities; Access to electricity; Relative change in occupancy rate in commercial accommodation; Relative change in GVA from 'Agriculture, livestock and fishing'; Relative change of overall workforce within blue economy). Finally, most of the indicators from the Governance domain stayed in the middle scores of the sustainability scale, namely, five out of 8 score 'Satisfactory'. Only one of the indicators in this domain (i.e., Operative instruments for natural resources management) was scored as 'Bad'.

Overall, the highest proportion of the indicators (i.e., sixteen out of 52 – 31%) received a 'Satisfactory' score, while the lowest proportion correspond to the indicators that scored 'Excellent' (8 out of 52 – 15%) (see Figure 4.20).

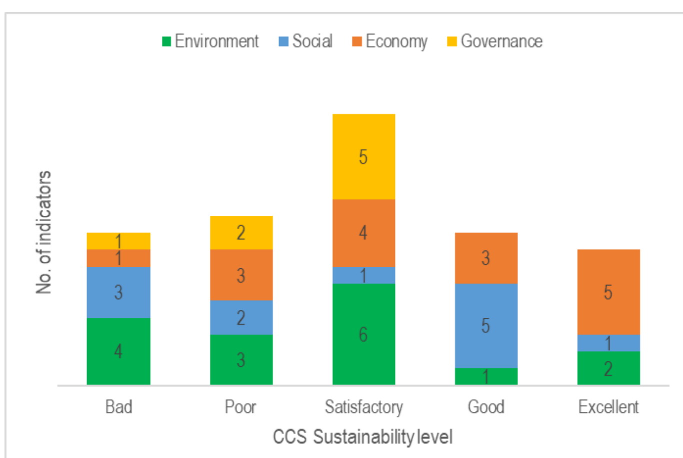


Figure 4.20. Number of indicators by sustainability level

Source: the author

Regarding the categories, only the 'infrastructure' received the highest sustainability score (i.e., 'Excellent – 5'). None of them reached the lower extreme of the sustainability scale, (i.e., 'Bad – 1').

After 'Infrastructure', the categories with the highest sustainability level are 'Social well-being', 'Identity' and 'Social resilience' from the social domain and 'Dependency' in the economic domain. The three of them received a score of 'Good – 4'. More than half of the categories (i.e., eleven categories) received a 'Satisfactory – 3' score. Finally, the categories that received the lowest score are those with a 'Poor – 2' level of sustainability. They correspond to 'Societal benefits' and 'Demographics' in the social domain; 'Resource management' from the governance domain and, 'Security' within the economy domain. The predominance of medium scores within categories is reflected in the scores of the domains that were evaluated as 'Satisfactory', except for the 'Social' domain that exhibits a 'Good' level of sustainability. In consequence, the MRm-SES was found to have a 'Satisfactory' condition (see Figure 4.21).

Table 4.16. CCS scores by category and domain for the Magdalena River-mouth.

Domain	Score	Label	Category	Score
Environment and Ecology	3	Satisfactory	1. Alterations of landscapes	3
			2. Ecosystem function	3
			3. Global environmental change	3
			4. Shifts in hydrodynamics	3
			5. Biogeochemical and physical flows	3
Society and culture	4	Good	1. Societal benefits	2
			2. Demographics	2
			3. Social wellbeing	4
			4. Identity	4
			5. Social resilience	4
Economy	3	Satisfactory	1. Security	2
			2. Infrastructure	5
			3. Economic wellbeing	3
			4. Industry	3
			5. Dependency	4
Politics and governance	3	Satisfactory	1. Organisation	3
			2. Law and justice	3
			3. Representation and power	3
			4. Legitimacy and accountability	3
			5. Resource management	2

Source: the author.

The results from Table 4.16 are transformed into the graphical representation of the CCS framework that can be seen in Figure 4.21.

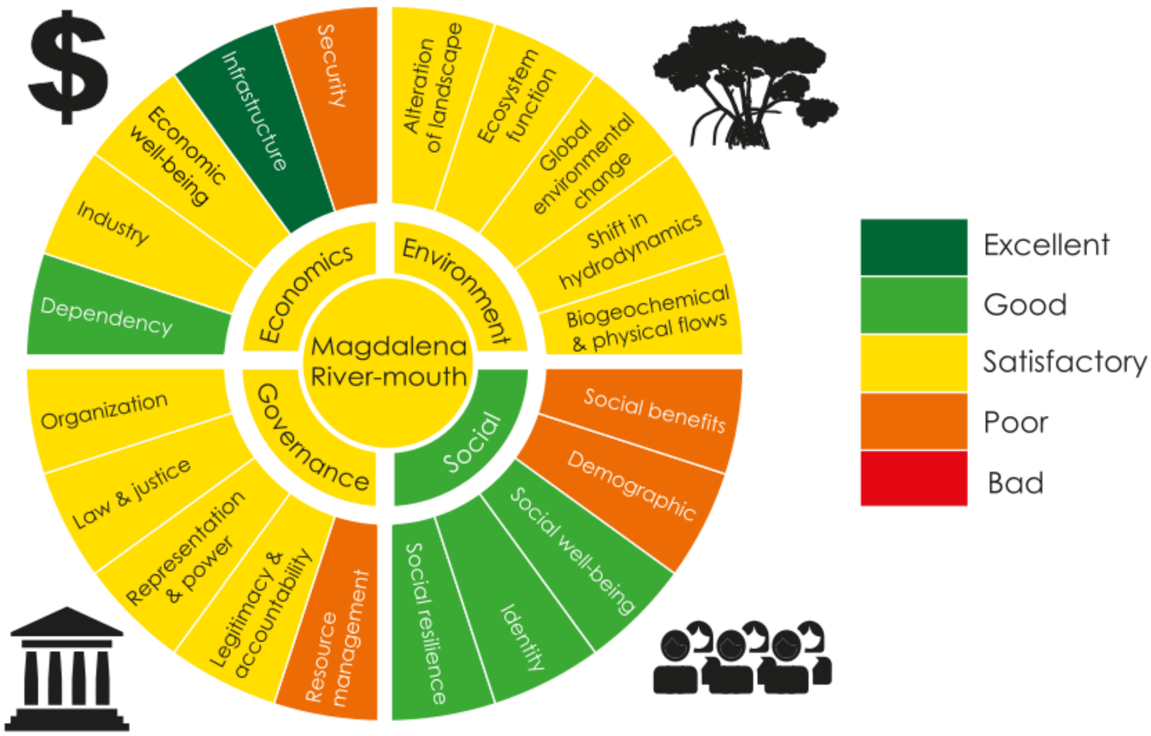


Figure 4.21. CCS score for the Magdalena River-mouth socio-ecological system

Source: adapted by the author using the original design from María Esther Ollivier (2022)

5 DISCUSSION

5.1 THE MAGDALENA RIVER-MOUTH SUSTAINABILITY ISSUES

While the CCS framework focuses on a category-by-category analysis, looking at the results of the lower divisions (i.e., sub-categories and indicators) or 'de-constructing the score' (OECD & JRC, 2008) has the advantage of providing a clearer understanding of what elements of the system have driven it to the current state.

Let us start by reviewing the categories that scored the worst, i.e., those that were rated as 'Poor' and 'Bad':

5.1.1 Environmental domain

This domain shows five categories in 'Satisfactory' conditions. However, these outcomes should be analysed with caution. When looking at the subcategories and indicators, the panorama for this domain changes and nearly half of the indicators (i.e., 7 out of 16 or 44%) were assigned a 'Bad' or 'Poor' level. These indicators were distributed in four (4) of the five (5) categories composing the domain. Among the seven indicators more than half are associated to ExUP (i.e., Atmospheric temperature change, Trends in extreme events, Freshwater SSL, and erosion/accretion rates) while only the three remaining can be managed within the study area, namely, they are EnMP (i.e., Land cover change, protected areas and net GHG emissions per year).

Looking at the above, clues begin to emerge as to what strategies could be pursued to improve the sustainability of the system. Regarding temperature increase there are no exclusive local measures that can be effective in stopping temperature change given it is associated to the GHG emissions at the global scale, therefore, a greater and immediate commitment to reduce GHG (especially methane) is required from the world's main generators through their Nationally Determined Contributions (NDC) that, so far, are not enough to limit temperature rise below 1.5 degrees Celsius by the end of the century (Shukla et al., 2022).

Despite absolute GHG emission are significantly lower than other areas in the region and the world, this does not mean that GHG emissions in the study area should not be considered for management. Compared to emissions in South America and the Caribbean (i.e., 9.2 t CO_2e), emissions in the study area are lower but not ideal. The ideal sustainability scenario will be one in which net GHG emissions are zero by mid-century and to achieve this goal radical transitions need to be implemented including reduction of the overall fossil fuel use, the deployment of low-emission energy sources, switching to alternative energy carriers, and energy efficiency and conservation (Shukla et al., 2022). Better yet, the positive effects could spill over or depend on other categories (e.g., reducing the use of fossil fuels requires an electricity grid that is dependable, resilient and relies little on fossil fuels, which would be reflected in infrastructure). In addition, investment in energy transition projects could create job opportunities to replace jobs in a the oil and gas industry that could reach a global peak by 2028 (Rifkin, 2019)

At this point, it is important to note that Colombia has an energy matrix with a good level of sustainability (almost 70% is generated from renewable sources) (Carlos Paniagua & Duarte Pérez, 2021) that can become more resilient with the promotion and development of non-conventional renewable energies such solar, hydrogen and onshore and offshore windfarms (Renewables Consulting Group, 2022; UPME, 2019) However, Colombia's main challenge is therefore How to adapt and/or build new infrastructure to allow an energy transition of the transport and industry sector, which are the main consumers of fossil fuels in the country? (UPME, 2019).

5.1.2 Social and cultural domain

In the ‘Society and Culture’ domain there were two categories whose score was ‘Poor’: The ‘Social benefits’ and the ‘Demographics’.

Social benefits

The former is composed by the ‘Goods and Services’ subcategory, evaluated through the ‘Catch by fish stock status’ indicator which showed that nearly three quarters of the catch came from species that are under the status of Collapsed or Over-exploited. The stocks have reached this status due to the mismanagement from both artisan and industrial fisheries, pollution and to climate changes (WWF, 2020). For this reason, marine management measures such as the creation of protected areas and/or special management areas are required, but above all the participation of the communities in the formulation of management measures and in the appropriation of the governance of the resources is required (Future Ocean et al., 2021; WWF, 2020). Precisely as a response to this need for management that involves the communities, in Colombia, the formulation of ‘Consensual Fisheries Management Agreements - ACMP’ is being carried out with 9 pilot communities along the Caribbean coast (Saavedra-Díaz et al., 2015).

Therefore, it is expected that there will be a monitoring of the compliance and effectiveness of these agreements to know their effects in the short and medium term and to evaluate their replicability with the other fishing communities including those within the study area.

It should be noted that in common-pool resources management, the same as in the case of climate change, measures must go beyond the local scale to reach a regional or even global scale. For the MRm-SES, this implies the management and governance of the Caribbean Large Marine Ecosystem (CLME). To this end, regional and sub-regional agreements have been worked out to develop an integrated regional approach to governing shared Living Marine Resources (sLMR) of the CLME and Adjacent Regions (known as CLME+). However, the implementation of these programme, projects and initiatives has not been exempt from challenges (e.g., institutional, capacity building, leadership, awareness, legal, political, social capital and socio-cultural constraints) during its 5 years of implementation (Fanning et al., 2021). Again, it would be necessary to monitor the implementation of the SAP to evaluate its effects on the fish stocks in the CLME+ region.

Demographics

The second category is formed by the ‘Population growth’ and the ‘Social class’ subcategories, which received a score of ‘Poor – 2’ and ‘Bad – 1’, respectively.

There is a common consensus that increasing population could impose higher pressures on earth’s and, therefore, coastal habitats. However, this is not the only nor the most crucial factor. For example, in some cases, rising living standards have been considered equally or even more important than population growth in terms of environmental impacts (i.e. consumptions and productions patterns will be responsible for 70% increase in consumption per capita while only 30% will be attributable to population growth) (UN-DESA, 2021, p. 16). Hence, what a priory seems to be a straightforward assessment where population growth stabilization (i.e., net growth = 0) is the optimal condition, becomes more complex situation.

One thing is sure: *“population growth is a major driver of the increasing demand for food”* and the current food production is not sustainable. Therefore, to avoid the impacts from a growing population it is paramount to move to sustainable practices that *“preserve biodiversity and that help to mitigate climate change and adapt to its environmental and other impacts, while also* *ensuring access to safe, sufficient, affordable and nutritious food and the enjoyment of a diversified, balanced and healthy diet for all"* (UN-DESA, 2021, p. 95).

Looking at the Income Poverty, the results for the study area are 'Bad-1'. In the department of Atlántico one (1) out of five (5) people are in monetary poverty and in Bolívar this figure is about one (1) out of three (3) people. This social and economic problems have direct consequences in the sustainability and management of the resources because people who strongly rely in extractive activities such as fishing have no choice but to keep fishing, even beyond the sustainable thresholds, to survive (Future Ocean et al., 2021) At the end, they are doing it to satisfy their most basic needs and, as Maslow suggested in 1943 and 1970, *"one must satisfy the lower-level deficit needs before progressing on to meet higher level growth needs"* (M. Elliott et al., 2017).

Hence, alternative sources of income and incentives for habitat preservation and recuperation could improve the ecosystem health while providing alternative livelihood opportunities. An example of the application from these strategies can be found in the Cispatá Bay in Colombia where the conservation of eleven (11) thousand hectares of mangrove is helping to tackle climate change while providing alternative sources of income for the locals. It is expected that *"For the 12,000 people who depend on the mangroves for food, firewood and livelihoods, the sale of carbon offsets will provide a degree of financial security as well as the initial funding needed to develop a sustainable ecotourism program and improve fishing practices in the region" (Conservation International)*. In the MRM-SES these strategies could be implemented in areas such as Cienaga de Mallorquin and Cienaga del Totumo.

Thus, if we assume an optimistic scenario in which 1 hectare of mangrove could provide a direct livelihood for at least 1 person, and if we consider that a recovery of up to 90% of the original mangrove cover in the study area (i.e., which is the minimum percentage required to reach an 'Excellent' condition according to Table 3.2), the mangrove forests within the MRm-SES could be a source of income for around 720 people (i.e. 720 hectares out of a baseline of 800). This is without considering the indirect benefits that could be obtained in the future from activities such as ecotourism or better fishing yields. While these assumptions are clearly optimistic and oversimplify economic dynamics that are not necessarily linear (i.e., it is possible that 1 ha is not sufficient to provide income for one person), they serve to illustrate the fact that habitat restoration, a measure of the environmental domain, could have positive effects on the socio-cultural domain.

5.1.3 Economic domain

The worst category in this domain was the ‘Security’ that was found to have a ‘Poor’ condition. The category was divided in three subcategories (i.e., livelihoods, gender, and employment patterns). The main issue in this category are the high rates of unemployment and the disparities in gender wage gap which received a score of 1 and 2 meaning ‘Bad’ and ‘Poor’ conditions, respectively.

The unemployment can put a strain on the household and public finances, additionally it can impact individuals and diminish their career prospects. The unemployment rates in the study area are high compared to other countries (e.g. Czech Republic, Iceland and Japan with figures lower than 3%) (OECD), however, they are considered among the lowest compared to other cities in Colombia (Galvis-Aponte et al., 2019). The unemployment rates in the study area have decreased in the last years due to a lower participation rate, an increased in the occupation or both. One aspect that is not considered in the present assessment is the informality of the jobs, which is associated to the quality of the employment (Galvis-Aponte et al., 2019).

In the case of the Gender Wage Gap, it has been associated to multiple factors: economies incapable of generating enough formal jobs, the women's dominant role in domestic jobs and caregiving, the maternity wage penalty, the presence of gender norms limiting women's employment, discrimination and poor working conditions for women (Iregui-Bohórquez et al., 2021, p. 76; ONU Mujeres et al., 2020).

5.1.4 Governance domain

In the ‘Politics and governance’ domain the ‘Resource management’ subcategory received a ‘Poor – 2’ score, mainly due to the inexistence of key instruments for the management of natural resources being the POMIUAC – RM the most important among them.

The lack of an integrative plan for the use of the resources from the different stakeholders present in the coastal zone hampers its sustainable development because, in the best-case scenario, promotes sectorial view where each individual/stakeholder seeks to maximise their benefit without considering the implications it can have for other actors, for the environment and even for themselves eventually.

Despite presenting poor conditions, it is expected that once the POMIUAC-RM is formulated and implemented, it will lead to an improvement of the system. A monitoring of the implementation process (i.e., activities conducted, resources assigned, among others) and a constant evaluation of the system's evolution, for example, by using the some of the indicators presented in this assessment, will be required in order to identify, since the very early stages of implementation, the positiveness of the outcomes and/or which adjustments are required to make the POMIUAC more effective in achieving its goal.

5.2 MANAGEMENT APPLICATION OF THE CCS

In a general sense, the score received by each category serves as an element to prioritise and understand the type of management actions required for the study area such that those categories where the score was 'Bad', or 'Poor' require urgent attention and greater efforts for recovery/improvement. Categories with a 'Satisfactory' status are those with favourable conditions for achieving a higher level of sustainability through the application of prevention strategies and/or where less effort can lead to greater improvement of the system. Finally, categories with a 'Good' or 'Excellent' status do not require any immediate action other than preventing deteriorating conditions.

Considering the abovementioned, the aspects with a compelling condition or where more efforts are required to improve the sustainability of this System would be: 'Social benefits' and 'Demographics' in the 'Social' domain; the 'Economic Security' in the Economy domain; and within the 'Governance' domain the 'Resources management'. In many of the other categories there does not seem to be an urgent need for intervention because their status is 'Satisfactory' or 'Good'. However, this simplistic analysis would hinder the ultimate aim of this framework, which seeks a holistic understanding of the system that could lead to more effective management proposals.

Thus, from a management point of view, when interpreting the results, one should not be drawn into the sectoral approach that has proven to be ineffective in resolving the problems of complex systems such as those found in the coastal zone (Future Ocean et al., 2021). Although the graphic representation of the CCS makes it possible to easily identify those categories with the worst performance, it is necessary to establish the interactions that exist among them in order to foresee changes (both positive and negative) that would result from an alteration in the status of one or more of the categories.

Take for example the category of ‘Ecosystem function’ which is composed of three subcategories: (i) Biodiversity Loss (ii) Services and (iii) Biodiversity protection. What would happen if the existing relicts of Mangrove along the study area were lost? Directly this would imply a loss of Natural Hazard Protection. However, indirectly this change would be reflected in other categories, for example, in a Business As Usual scenario, the likely compensation strategy for this loss of protection would be the construction of rigid coastal protection works (N. Rangel-Buitrago et al., 2018), i.e., there would be coastal rigidification that would affect the landscape. Furthermore, mangroves are nurseries for many species of fish, and their loss could be reflected in a reduction of the fishing stocks affecting the livelihoods of a vulnerable portion of the population (i.e., the artisan fishers). Also, a natural attraction that serves to invite tourism and is related to the ‘Sense of Place’ would be lost, and so on and so forth, other connections and consequences could be established. So, what initially was a change related to the status of the Environmental domain, ends up extending to the ‘Socio-cultural’ and ‘Economic’ domains.

But in the same way those connections could multiply the effects of a negative impact, they can be used to design measures that contribute to improve various aspects from the system. Continue with the same ecosystem: mangrove restoration and preservation and the definition of a protection status and strategies for the areas where these ecosystems are located, bring multiple benefits. In total, those two measures could have a potential impact (i.e., direct, or indirect) in, at least, a quarter of the indicators. In practical terms, whether that positive impact is strong enough to produce a significant change in the sustainability of the system as measured in the CCS (i.e., indicator, subcategory, categories) will depend on the scale at which the measures are applied as well as their scope (i.e., integral measures can tackle more aspects than those with a sectorial approach).

Managing ExUP and EnMP

As mentioned above, the system is subject to pressures from both external and internal sources. Some examples of measures that could be implemented to counteract the problems arising from each type of pressure and improve the sustainability of the system are listed below:

ExUP:

It is important to stress that the implementation of these measures is not the responsibility of local managers and institutions in all cases, but that the MRm-SES would benefit from their implementation. What is expected is a willingness to participate on the part of decision-makers, the community, and other stakeholders.

- Investment in climate change adaptation measures
- Local strategies to reduce the net GHG contribution in the area, this could be through the recovery and preservation of ecosystems that serve as carbon sinks (e.g. mangroves and tropical dry forest), coupled with improved energy efficiency and promoting a more diverse energy matrix that is less dependent on fossil fuels (e.g. reducing incentives or tax exemptions for hydrocarbon exploration and exploitation and instead redirecting this money to renewable energy).
- At the level of the Magdalena River Basin, a coordination mechanism is required between the different CARs with jurisdiction in the Magdalena River Basin so that they can act jointly to solve problems such as deforestation and pollution.

EnMP:

These are the measures that could be implemented at the local level

- Designation of new conservation areas under a concept that does not necessarily prohibit their use but promotes a more responsible approach that preserves biodiversity and important habitats.
- Involve the opinions and ancestral knowledge of the communities located within the study area when designing and implementing management measures.
- Work towards the early formulation, updating and/or implementation of the POMIUAC-RM or other strategic plans for resource management in the study area.

The above list is not considered exhaustive, and it is suggested that complementary tools such as the DPSIR framework be used to establish tailored measures for the system at a later stage.

5.3 THE CCS FRAMEWORK: OPPORTUNITIES FOR IMPROVEMENT

The CCS framework and representation aim at being a tool for policy analysis and public communication but, moreover, to be an effective call for action. *"Indicators are useful in identifying trends and drawing attention to particular issues. They can also be helpful in setting policy priorities and in benchmarking or monitoring performance".* Perhaps one of the advantages of the chosen graphical representations is that, up to certain extent, it deals with one of the major issues from composite indicators which is mascaraing some issues that draw a simplistic analysis and leads to wrong conclusions (OECD & JRC, 2008, pp. 13–14). This is done by showing the overall score for the system and each domain while maintaining and showing the results for each category. In this way, is possible to identify what are those aspects that need to be at the centre of the discussion because more effectiveness and actions are required to improve their sustainability.

Initially, the distribution of indicators shows a higher concentration in the "Economic" and "Environmental" domains that share 62% of the total number. However, it is necessary to reiterate that the CCS aggregation method ensures that the sustainability of all domains will be obtained from five categories each. Hence, at the domain and category levels, all have the same weight.

One aspect that differentiates this study from the one from P. de Alencar et al. (2020) is the attempt to include a semi-quantitative approach to score the sustainability of each category, reducing the bias that comes from an application of qualitative criteria which can be interpreted in different ways by different evaluators, coastal managers, decision makers, etc. Additionally, the graphical representation suffered major transformations such as the inclusion of the domains and system within the graphic, as well as the use of a more widespread and intuitive colour scale (i.e., traffic-light colours rather than the EU water framework directive colours). Finally, the original framework was tested in Spain but, its application in this study shows that it can be adapted to other latitudes.

Despite of its advantages, there are still aspects that could improve the reliability of the results and some questions that arise after the application of the CCS framework in the MR-SES, those are:

- The CCS framework, as applied here, fundamentally relies on secondary information; therefore, it is important to define the degree of confidence of the information presented for each indicator. That is adapting a similar system as the one used in the IPCC or the IPBES reports (IPBES, 2018, p. 36) (e.g. medium confidence, very likely, high confidence, high confidence, etc.). Moreover, this degree of confidence should consider not only the quality of the sources employed but also the spatial scale of the information in relation to the system being evaluated (i.e., municipal level is more accurate than national level).
- To improve the utility of the results by drawing more accurate conclusions, it would be necessary to explore the implication of the different normalization and aggregation methods for the indicators. For example, what are the statistical implications of incorporating qualitative

and/or quantitative variables? If the variables are quantitative what is the best aggregation (i.e. linear, geometric or non-compensatory multi-criteria approach aggregation) (OECD & JRC, 2008; Papadimitriou et al., 2019)? Would it be worth to assign weights within the indicator and subcategory levels? All those questions will require a detailed statistical analysis which was outside the scope of the present study. The importance of this point can be illustrated by comparing the results of Magdalena River-mouth using the arithmetic and geometric means (i.e., linear, and geometric aggregation, both allow compensability) for the aggregation of the indicators, subcategories, and categories. The aggregation with the geometric mean results in a system with apparent worse conditions for three of the four domains even though the scores of the individual indicators remained unchanged. (See Figure 5.1).

This may seem like a numerical triviality, but its implications from a management point of view can be important. An aggregation method that allows the compensation of low scores with high scores could lead to masking problems within the different categories of each dimension, giving the erroneous idea that none of the categories requires immediate attention and that the current management is giving results, if not good, at least satisfactory.

On the contrary, an aggregation method that overly penalizes all categories, resulting in very low levels of sustainability for many of them, could prevent the clear identification of those areas where intervention is truly needed. In other words, it would not help in the prioritization of management measures and resources. Moreover, it could even lead to inaction.

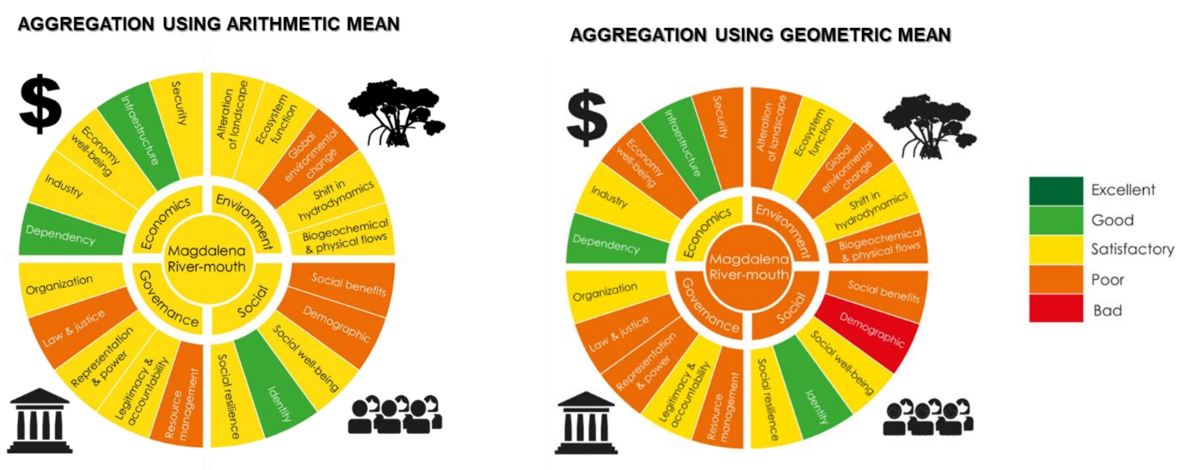


Figure 5.1. Comparison of the CCS results using different aggregation methods (i.e., arithmetic mean - left and geometric mean - right) for the Magdalena River-mouth system.

Source: the author.

- What will or could happen in the future? Or how is the system compared to previous states? Is it better/worse? Is there an identifiable trend that suggests the system is improving? What change in the system settings could lead to a potential improvement or, on the contrary, to a potential detriment? Is it likely that all domains will improve or deteriorate simultaneously? Could Artificial Intelligence (Bayesian or Neural Networks) help foresee changes in some of the categories and domains? Answering all these questions will require the application of multiple socio-ecological methods such as 'Future Analysis'. As explained by Reinette Biggs et al. (2022, p. 151) "*The combination of participatory, narrative approaches and the ability of futures analysis to interact with more quantitative predictions make these methods particularly well suited to questions raised in the management and prioritisation of social-ecological landscapes, and for ultimately developing policies to manage these systems".*
- Once an initial assessment of the sustainability of the system has been made and the areas requiring further attention have been identified, the CCS can benefit from using other frameworks (e.g., DPSIR or DAPSIWRM) to identify tailored responses/measures for the system's needs.

Last but not least, due to time constraints, this assessment was applied to the main mouth of the Magdalena River in Bocas de Ceniza and it can provide a general picture of the sustainability in Colombia's main river delta, however, it is important to investigate what could be the implications of including the other two compartments of the Magdalena River deltaic system (i.e., 'Canal del Dique' and 'Cienaga Grande de Santa Marta') considering the particularities from both areas (e.g. Black, Afro-Colombian, Raizal and Palenquero – NARP population is present in higher proportion and there is presence of 'Collective Territories'[8] or the CGSM is the largest RAMSAR area in Colombia and many local communities rely on it for its livelihoods).

[8] Territories belonging to Black communities who are given collective title to the places they have ancestrally inhabited. These territories are under a special legal status which implies, among other things, that any management or intervention measure that is proposed within these areas must be consulted and approved by the community.

6 CONCLUSIONS

Overall, the sustainability of the Magdalena River-mouth SES can be classified as ‘Satisfactory’. The 'Environmental and Ecological' domain exhibited ‘Satisfactory’ conditions. In the case of the 'Social and Cultural' domain, three categories (i.e., ‘Social well-being’, 'Identity' and ‘Social resilience’) were rated as having 'Good' conditions, the rest of the categories were rated as 'Poor'. The 'Economic' domain was the only one where a category reached an ‘Excellent’ status. Finally, none of the 'Governance' categories exceeded the 'Satisfactory' level and the ‘Resource management’ category had ‘Poor’ conditions.

A total of fifty-two indicators, distributed into twenty categories and four domains, were chosen to evaluate the sustainability of the system. The indicators were distributed like this: sixteen (16) indicators each for the Environment and Economic domains, twelve (12) indicators in the Social domain and eight (8) indicators to evaluate the Governance domain. The categories that presented the worst conditions from each domain were: ‘Social Benefits’ and ‘Demographics’ in the Social domain; ‘Security’ in the Economy domain and Resource management in the Governance domain.

Based on the sustainability score received by the indicators and the categories, some management measures can be considered. In general terms they involve: Preserving and restoring habitats; tackle sources of pollution and excessive sediment; local contributions to curve climate change through reduction of net GHG and adaptation measures to climate change; participation of local communities in the management design and implementation.

The main advantage of using the CCS framework to assess coastal socio-ecological systems is that it provides a holistic view of the conditions in the system. Moreover, it gives equal weight to the four (4) dimensions of sustainability reinforcing the concept that a truly sustainable system can only be achieved when all the domains present the same level of sustainability. The graphical representation is another strong aspect of this framework because it allows the communication of the results with stakeholders from different spheres (academia, politics, community, organizations, etc.).

Among the drawbacks of the framework, it is possible to mention the necessity of many different information that, most of the time, is dispersed and it has to be collected from different institutions.

Moreover, sometimes information is available, but it is not easily accessible. Another inconvenient of this framework is the fact of being currently in its development changes, that means that some aspects of the methodology can change in the future. Finally, a critical aspect for the application of the CCS is the selection of the set of indicators which, could be subject to bias if the selection is done by an individual and not by a multidisciplinary group.

This assessment can be complemented and improved by defining the uncertainty of the information used; reviewing the normalization and aggregation methods; using complementary socio-ecological methods/tools like 'future analysis' and DPSIR to define tailored measure for the system. Finally, it is suggested to include the other compartments (i.e., CGSM and Canal del Dique) of the Magdalena River delta.

Results and expected impact

Finally, it is expected that the results from the present research can be used share with the academic community and decision-makers from the study area as follows (see Table 6.1):

Table 6.1. Results and expected impacts of the research.

Target group	Output	Addressed to / Recipients
Academia	Master thesis dissertation	University of Bologna
	Manuscript 1 - Land-based pollution in the Magdalena River delta: A socio-ecological assessment.	Ocean & Coastal Management | Environmental Management | Frontiers | Marine Pollution Bulletin
	Manuscript 2 - Integrated Assessment of the Socio-ecological system in the Magdalena River Delta (Colombia)	Environmental Science and Policy | Ocean & Coastal Management | Journal of Environmental Management | Science of the total environment | Estuarine, Coastal and Shelf Science
Academia / General public	Poster or oral presentation in international congress/seminar	Sustainability Research & Innovation Congress 2022 | Future Earth Conference | WACOMA Symposium 2022
Decision makers	Executive summary - Concise document for decision-makers and stakeholders written in the local language (i.e., Spanish)	Corporación Autónoma Regional del Atlántico (CRA) | EPA Barranquilla Verde

Source: the author

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