International Hydrogen Ramp-up Programme – H2Uppp

GREEN HYDROGEN IN COLOMBIA – ENVIRONMENTAL STUDY – AKUAIPPAHY PROJECT

Executive Summary: Environmental Component

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and Energy

VIRIDI

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This statement is included in accordance with the transparency principles set out in Article 50(4) of Regulation (EU) 2024/1689.

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INTRODUCTION

The development of the AkuaippaHy project requires determining which areas of La Guajira may be suitable for the location of its infrastructure and under what environmental and territorial conditions the project could move forward. This decision depends not only on the availability of wind and solar resources, but also requires consideration of land-use compatibility, ecosystem sensitivity, the availability and sustainability of water resources, the physical conditions of the territory, the presence of ethnic communities, and the applicable regulatory and environmental pathway for each component of the H_2V/PtX value chain.

The scale and diversity of the infrastructure associated with the production, processing, storage, transportation, and potential export of H_2V and its derivatives entail different territorial interactions depending on their location. In La Guajira, these interactions are conditioned by the presence of strategic ecosystems, protected areas and other conservation designations, natural and semi-natural land cover, ethnic territories, arid conditions, limited water availability, and higher-level environmental determinants. In addition, geological, geomorphological, hydrogeological, geotechnical, climatic, and hydrological variables may either constrain or facilitate infrastructure siting.

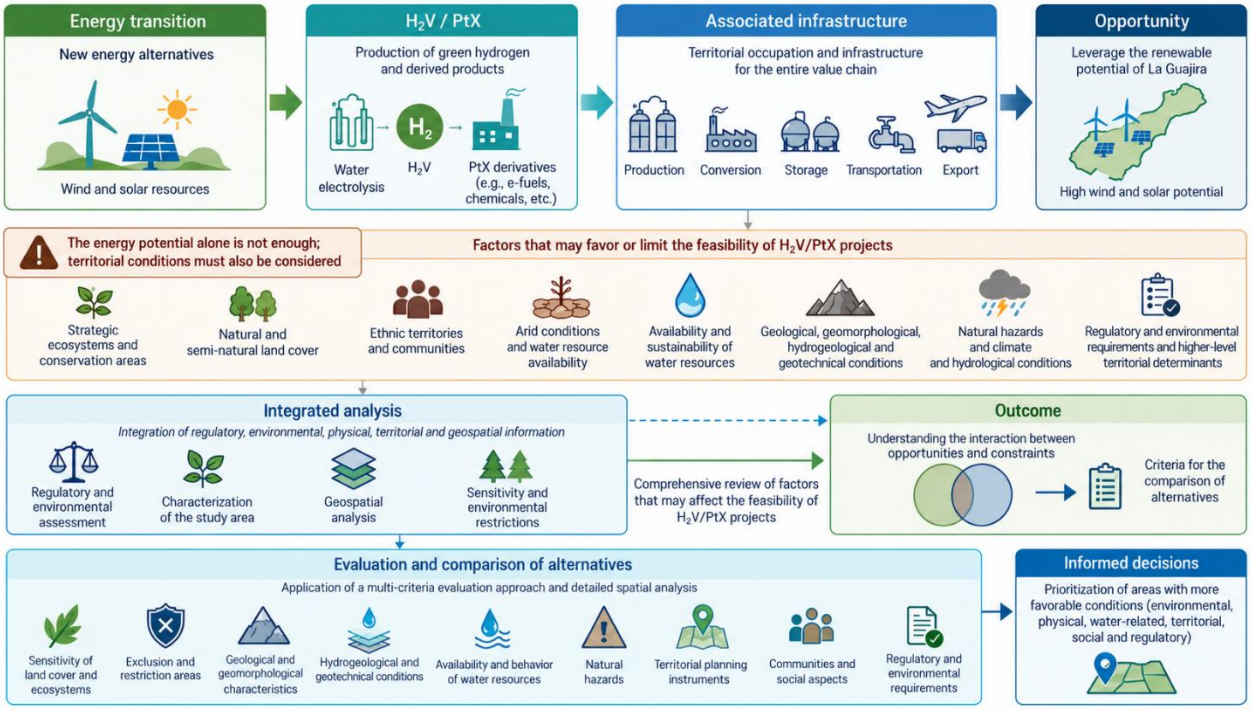
The environmental component of the consultancy was structured to examine these factors in an integrated manner and identify their differences among the alternatives evaluated. To this end, the environmental regulatory assessment, characterization of the study area, geospatial analysis, and assessment of sensitivity, constraints, and potential environmental impacts were integrated. This approach makes it possible to move beyond the isolated review of individual variables and assess how their concurrence may affect the location and configuration of the infrastructure, as well as the development pathway of AkuaippaHy.

The assessment considered exclusion and restriction areas; the sensitivity of land cover and ecosystems; geological and geomorphological characteristics; hydrogeological and geotechnical conditions; water resource dynamics; natural hazards; land-use planning instruments; the presence of ethnic communities; and the applicable regulatory and environmental requirements. On this basis, areas that are incompatible with the project or subject to greater restrictions were identified, as well as areas with relatively more favorable conditions for further evaluation of the alternatives.

The study therefore provides a technical basis for comparing the location alternatives and for identifying, at an early stage, the factors that may influence territorial occupation, infrastructure design, water resource management, engagement with communities, and the permitting pathway. Its value lies in reducing uncertainty at this stage of project development and identifying the aspects that will require further assessment before subsequent decisions are made regarding the project's configuration.

This Executive Summary presents the main findings of the comparative assessment of the AkuaippaHy alternatives and describes the environmental, physical, water-related, territorial, social, and regulatory conditions that differentiate them. The methodological foundations, information sources, spatial analyses, and detailed results for each component are presented in the technical documents supporting the assessment.

Figure 1 Integrated approach for the identification and comparison of alternatives for the AkuaippaHy project



Source: Prepared by the authors with the support of artificial intelligence tools, based on technical information provided by Óptima Consultores S.A.S. (2026).

1 Determinants, Constraints, and Reference Framework

The Environmental Regulatory Assessment identified the regulatory instruments, territorial determinants, environmental constraints, and institutional responsibilities that may influence the structuring of the AkuaippaHy project. The review covered cross-cutting environmental regulations and instruments related to renewable energy generation, hydrogen, land use, water resources, marine and coastal planning, biodiversity, waste, hazardous materials, climate change, risk management, and infrastructure associated with the production and potential export of PtX derivatives.

The regulatory review was organized into an applied matrix that made it possible to relate each instrument to its competent authority, scope of application, obligations, enabling, restrictive, or procedural nature, binding character, and level of influence on the different project phases. Based on this structure, three levels of constraint (low, medium, and high) were established according to the capacity of each instrument to enable, condition, or restrict decisions related to the project's location, design, scale, schedule, and permitting pathway.

This classification assesses the influence of the instruments on project decisions rather than solely their legal nature. The assigned levels make it possible to identify matters requiring early attention; however, they do not replace the specific analysis of the obligations, prohibitions, permits, or institutional responsibilities applicable to each infrastructure component and location alternative. Table 1 presents the consolidated results by regulatory category.

Table 1 Cross-cutting and consolidated analysis of the levels of constraint by regulatory category

Regulatory category	Level of constraint	Main influence
Energy and hydrogen	Low – Medium	Acts as an enabling framework for the project, although the technical and regulatory conditions applicable to energy infrastructure, grid interconnection, and transportation must be defined.
Environmental regulation and licensing	High	Determines the applicable environmental assessment, licensing, and permitting pathway for the different project components.
Water resources and marine and coastal environment	High	Influences the source and availability of water, the technological solution for water supply, wastewater discharge management, and the location of associated infrastructure.
Air quality	High	Influences the design and the applicable emission prevention and control measures.
Land use and territorial planning	Medium – High	Conditions territorial compatibility and site selection.
Forestry, soils, and biodiversity (fauna)	High	May impose restrictions on location and, where a prohibition or applicable protection regime exists, exclude certain areas.
Waste and hazardous materials (HAZMAT)	High	Requires the definition of applicable management, storage, transportation, treatment, and disposal conditions throughout the project life cycle.
Climate change	Medium – High	Requires the incorporation of mitigation, adaptation, and resilience criteria.
Risk management	High	Influences location, design, and operation.
Communities and socioeconomic component	High	Influences territorial engagement, social management, and the scheduling of project activities.
Sectoral institutions	Medium	Requires coordination among authorities and a clear sequence of procedures, permits, and decisions.

Source: Prepared by the authors based on the consolidated regulatory assessment developed as part of this study. Óptima Consultores S.A.S. (2026).

When comparing the results, it can be observed that the energy framework and sectoral planning establish general conditions for project development. However, the main constraints are associated with the environmental, water-related, territorial, biotic, and social components, as well as risk management. These conditions may occur simultaneously within the same area or affect the same infrastructure component, potentially modifying the favorability of an alternative, the permits required, or the timeframes necessary for its development.

In the case of AkuaippaHy, these aspects should be considered from the initial stage of alternative comparison, particularly those classified as high or medium-high. These include environmental licensing, water supply and management, territorial compatibility, ecosystem and land-cover sensitivity, risk management, and the presence of communities. Their early identification will make it possible to prioritize areas with more favorable conditions and establish the issues that will require more detailed analysis during environmental and institutional structuring and the definition of the permitting pathway.

1.1 Energy Policy, Planning, and Regulation Applicable to H_2V/PtX

The analysis of the energy framework highlights a strategic condition that is favorable to the development of H_2V/PtX projects in Colombia, particularly their integration with the renewable energy potential of La Guajira. The Hydrogen Roadmap recognizes hydrogen as a strategic energy vector and establishes guidelines to promote its development. However, its scope is primarily advisory and, by itself, does not establish an operational licensing and permitting regime or binding technical

standards for the different stages of hydrogen production, storage, transportation, and industrial use. For this reason, its influence on the project is classified as **Low**, as it primarily serves as a public policy and sectoral guidance framework.

National energy planning has an indirect influence and, in some aspects, applies by analogy, as existing instruments are primarily focused on the conventional electricity and energy system, and there is still no comprehensive planning framework specifically addressing the full range of infrastructure required for H_2V/PtX value chains. This situation is particularly relevant for projects integrating renewable energy generation, electrolysis, derivative production, storage, transportation, port infrastructure, and export, since the integration of these components must be assessed based on the sectoral instruments currently available.

The energy framework serves as a strategic enabler but does not, by itself, authorize project development. The main findings are summarized in Table 2.

Table 2 Summary of the Energy Framework for H_2V/PtX Projects

Aspect analyzed	Implications for the H_2V/PtX project
Energy and hydrogen policy	Recognizes H_2V and its derivatives as alternatives for diversifying the energy mix and contributing to decarbonization. However, its scope is primarily advisory and does not replace the authorizations required for project development.
Energy planning	Instruments applicable to renewable energy generation and guidelines for hydrogen production and use are in place. However, there is currently no single instrument integrating all stages of the value chain, from energy generation to the storage, transportation, and potential export of the resulting products.
H_2V/PtX-specific regulation	Regulation is still under development and does not address all stages of the value chain with the same level of detail. Therefore, applicable provisions and regulatory gaps must be reviewed for each project component.
Permits and licensing	Permits and authorizations will depend on the works, activities, and location of each alternative. Therefore, the applicable energy, environmental, territorial, and sectoral requirements must be reviewed jointly.

Source: Prepared by the authors based on the review of the energy and regulatory framework applicable to H_2V/PtX projects. Óptima Consultores S.A.S. (2026).

***Note:** The organization and synthesis of the information were supported by artificial intelligence tools and technically reviewed by Óptima Consultores S.A.S.*

1.2 Territorial Planning and Land Use

The territorial planning analysis reviewed the 15 municipalities in the department of La Guajira: Albania, Barrancas, Dibulla, Distracción, El Molino, Fonseca, Hatonuevo, La Jagua del Pilar, Maicao, Manaure, Riohacha, San Juan del Cesar, Uribia, Urumita, and Villanueva. For each municipality, the applicable territorial planning instruments were reviewed and assessed in relation to higher-level environmental and territorial determinants.

The results show that land-use compatibility for industrial infrastructure associated with H_2V/PtX projects varies among municipalities and cannot be determined solely based on the municipal land classification. The POT, PBOT, and EOT define permitted, conditional, or prohibited land uses. Their application must be coordinated with environmental determinants such as POMCA, protected areas, conservation designations, and conditions associated with risk management. These determinants may restrict intervention or exclude certain areas when applicable prohibitions are established, regardless of the land use defined by the municipal planning instrument.

The analysis established that territorial conditions vary among the municipalities assessed. For the location of industrial infrastructure associated with PtX projects, San Juan del Cesar, Villanueva, Riohacha, Albania, and Fonseca presented the most favorable results, with medium to high levels of compatibility.

As a complement to this municipal comparison, a spatial analysis of the constraints present throughout the territory was conducted. This analysis integrated information on land classification and land use, environmental determinants, POMCA, protected areas, other planning designations, and areas subject to hazard and risk conditions. The overlay of these layers made it possible to differentiate exclusion areas, areas subject to high constraints, and areas where intervention is subject to medium constraints.

It is important to clarify that these results represent an approximation at the municipal scale and do not mean that the entire territory of municipalities with higher compatibility is available for the project. Area selection must be complemented by a more detailed spatial assessment to rule out incompatible areas and identify sectors with fewer environmental and territorial constraints.

1.3 Environmental Management, Licensing, and Institutional Coordination

Project management involves environmental, energy, territorial, maritime, cultural heritage, and risk management authorities. The participation of each authority will depend on the location, works, and activities included in the selected alternative. Table 3 summarizes the entities that should be considered from the project structuring stage.

Table 3 Entities to be Considered in the Structuring of H_2V/PtX Projects

Entity	Subject	Relationship to the projects	Applicable regulations
Ministry of Environment and Sustainable Development (MADS)	Environmental policy and regulation	Defines national environmental policy and regulations. Its guidelines should be considered for matters such as biodiversity, water resources, climate change, and environmental land-use planning.	Decree 3570 of 2011
Ministry of Mines and Energy (MME)	Energy and hydrogen policy	Provides guidance on sectoral policy and regulatory development related to hydrogen and the energy transition. Its decisions may influence incentives, technical conditions, and the integration of the project with the energy sector.	Decree 381 of 2012; Law 2099 of 2021; Decree 1476 of 2022
Ministry of the Interior – DANCP	Prior consultation	Determines whether and when prior consultation is required and, where applicable, coordinates its implementation. This process should be incorporated into the project schedule when potential direct impacts on ethnic communities are identified.	Decree 2353 of 2019
UPME	Energy planning and electricity interconnection	Provides information for energy planning and, where applicable, manages applications for the allocation of transmission and connection capacity to the National Interconnected System. Its participation will be relevant both for renewable energy generation and for the PtX plant's electricity demand.	Decree 1258 of 2013; CREG Resolution 075 of 2021 and amendments thereto
CREG	Electricity sector regulation	Establishes rules related to connection to and access to electricity networks. These provisions should be reviewed if the project requires the consumption, generation, or delivery of electricity through the National Interconnected System.	Law 143 of 1994; Decree 1260 of 2013; CREG Resolution 075 of 2021 and amendments thereto

ANLA	Environmental licensing under national jurisdiction	Depending on the legal allocation of responsibilities and the characteristics of each component, it participates in the assessment, authorization, and monitoring of environmental licenses, permits, and other environmental instruments, with implications for design, scheduling, and environmental management obligations.	Decree 3573 of 2011; Decree 1076 of 2015
Corpoguajira	Regional environmental permits and licensing	Acts as the regional environmental authority in La Guajira and, within its jurisdiction, processes licenses, permits, and concessions related to water use, wastewater discharges, emissions, forestry use, and watercourse occupation, among others.	Law 99 of 1993, Article 31; Decree 1076 of 2015
UNGRD and Territorial Risk Management Councils	Risk management	Risk management instruments and guidelines constitute an input for infrastructure siting and design. The participation of national and territorial entities will depend on the hazards identified and their respective areas of jurisdiction.	Law 1523 of 2012
DIMAR	Marine and coastal areas	Becomes involved when alternatives include works or occupation of beaches, foreshore areas, maritime waters, or other assets under its jurisdiction.	Decree-Law 2324 of 1984
ICANH	Archaeological heritage	Administers procedures related to the Preventive Archaeology Program and interventions involving archaeological heritage, where applicable to the project.	Law 1185 of 2008; Decree 1080 of 2015, as amended by Decree 138 of 2019
Territorial authorities	Land-use planning and land use	Municipalities and districts define land uses and restrictions through their territorial planning instruments. The compatibility of each alternative should be verified before selecting project areas.	Law 388 of 1997

Source: Prepared by the authors based on the regulations cited in the table. Óptima Consultores S.A.S. (2026).

***Note:** This identification is preliminary. The competent authorities and applicable procedures must be confirmed once the location, works, and activities comprising each alternative have been defined.*

1.4 *Water Resources and Marine-Coastal Planning*

Water supply is one of the aspects that should be assessed from the initial comparison of H_2V/PtX alternatives. Demand will depend on the project's configuration and capacity, the processes associated with derivative production, and the possibilities for water recirculation or reuse. Therefore, estimated requirements should be compared with available supply, existing uses, and the behavior of potential water sources. In La Guajira, this analysis should be conducted for each potential source and should consider both water availability variability and the conditions established in the planning and management instruments for water resources (IDEAM, 2023; Decree 1076 of 2015).

For each alternative, a preliminary water balance should be developed identifying the water supply source, required flow rate, quality conditions, losses, recirculation opportunities, and effluents generated. When continental water sources are considered, their availability and the possibility of obtaining the corresponding water concession must be verified. If seawater intake and desalination are considered, the treatment plant should be complemented by intake and conveyance infrastructure, energy consumption, and brine management. Although this option may reduce dependence on continental water sources, its

feasibility will depend on the environmental and technical conditions of the selected area. Improper brine disposal may locally alter salinity and affect receiving ecosystems (UNEP, 2021).

Infrastructure located along the coastline or in marine areas must also be compatible with the planning and management instruments applicable to coastal environmental units, restrictions associated with sensitive ecosystems, and the authorizations required for the occupation of beaches, foreshore areas, or maritime waters (Decree-Law 2324 of 1984; Decree 1120 of 2013, incorporated into Decree 1076 of 2015). Likewise, discharges into marine water bodies must comply with the conditions established in the corresponding permit and the parameters set forth in Resolution 883 of 2018.

Accordingly, the water supply source should not be assessed in isolation. Its analysis should include the required infrastructure, supply continuity, effluent management, and the environmental and territorial constraints associated with each alternative. Table 4 summarizes the main factors assessed.

Table 4 Water Resource and Marine-Coastal Aspects to Be Reviewed for Each Alternative

Aspect	Information required	Application
Continental water sources	Available supply, seasonal behavior, existing uses, water quality conditions, and existing concessions.	Determines whether a surface water or groundwater source could meet project demand without disregarding other existing uses and constraints.
Water demand and balance	Process requirements, total flow rate, losses, recirculation, reuse, and required water quality.	Allows comparison of water-use efficiency and determination of the actual water supply requirements of each alternative.
Seawater intake and desalination	Intake location, treatment capacity, conveyance, energy consumption, and volume of brine generated.	Determines the additional infrastructure and operational requirements associated with this water supply source.
Effluents and brine	Flow rate, composition, treatment, discharge point, receiving water body conditions, and disposal alternatives.	Identifies the constraints and management measures associated with industrial discharges and the desalination process.
Marine-coastal compatibility	POMIUAC zoning, sensitive ecosystems, protected areas, existing uses, and maritime jurisdiction.	Allows incompatible areas to be ruled out and the permits or authorizations required for coastal or marine infrastructure to be identified.
Supply continuity	Seasonal variations, extreme events, operational failures, storage capacity, and backup sources.	Allows assessment of the reliability of each alternative and the measures required to maintain project operations.

Source: Prepared by the authors based on IDEAM (2023), Decree-Law 2324 of 1984, Decrees 1120 of 2013 and 1076 of 2015, Resolution 883 of 2018, and UNEP (2021). Óptima Consultores S.A.S. (2026).

1.5 Solid and Liquid Waste Management

The regulatory assessment made it possible to differentiate four main areas of waste management: integrated solid waste management, hazardous waste management, generator responsibility, and waste recovery and minimization strategies. The first three present a High level of constraint, while waste recovery and minimization strategies present a Medium-High level of constraint.

Integrated solid waste management requires planning, for each project stage, for source segregation, temporary storage, transportation, recovery, and final disposal, including the management of construction and demolition waste (CDW). At this stage, the regional capacity available to manage each waste stream must still be verified. If such capacity is insufficient, off-department management alternatives and their logistical and economic implications will need to be assessed.

Hazardous waste (RESPEL) may include reagents, catalysts, solvents, oils, sludge, and contaminated materials. Before defining the waste management logistics, the availability and capacity of authorized waste management operators must be confirmed, as well as the applicable storage, transportation, treatment, and disposal conditions for each waste stream.

The critical issue is not only the amount of waste generated, but also the possibility of managing it through specialized and traceable systems. Therefore, the strategy should be defined during project design and should distinguish between waste streams that can be managed within the region and those that would require interregional solutions. Table 5 summarizes the aspects that should be verified.

Table 5 Summary of the Main Constraints Associated with Waste Management

Management area	Analysis result	Implication for the project	Level of constraint
Integrated solid waste management	The available regional capacity must be verified for each waste stream and project phase.	May increase logistical requirements and management costs and may require solutions outside the department.	**High**
Hazardous waste (RESPEL)	The availability of authorized waste management operators must be confirmed before defining the management logistics.	May require transportation of waste to other regions and specific conditions for storage, transportation, treatment, and final disposal.	**High**
Generator responsibility and traceability	Comprehensive documentation and monitoring of generated waste are required.	Requires ensuring traceability and contracting authorized waste management operators throughout the management of the different waste streams.	**High**
Waste recovery and minimization	Waste generation must be reduced, reuse and recovery promoted, and strategies incorporated for special waste streams such as WEEE.	Helps reduce dependence on external infrastructure and optimize the project's environmental management.	**Medium-High**

Source: Prepared by the authors based on the regulatory assessment conducted as part of the study and Decree 1076 of 2015. Óptima Consultores S.A.S. (2026).

1.6 Hazardous Materials (HAZMAT)

The management of hazardous materials constitutes a highly relevant component in the development of H_2V/PtX projects. The regulatory assessment identified four main areas of constraint, all classified as **High**: storage and handling of hazardous substances, transportation of hazardous materials, contingency plans, and chemical risk management. This classification reflects the fact that HAZMAT management is not merely an operational requirement, but rather a component that must be incorporated from the early stages of project structuring and design.

The potential exposure of environmental and social receptors to accidental events requires risk analyses with a level of detail appropriate to the technological and territorial configuration ultimately adopted by the project.

The level of constraint associated with HAZMAT depends on the substances involved, safety and risk management requirements, and the logistical conditions of the territory. The comparison of alternatives should consider safe storage, specialized transportation, emergency prevention and response, and technological risk assessment, in coordination with the project's environmental permitting pathway. Table 6 summarizes the main management aspects.

Table 6 Summary of the Main Constraints Associated with Hazardous Materials (HAZMAT) Management

Management area	Analysis result	Implication for the project
Storage and handling	Management conditions require consideration of storage areas, tanks, pressure vessels, ventilation, secondary containment, leak detection, safety distances, and fire protection systems.	Directly influences the design and configuration of facilities and safe operating protocols.
Transportation of hazardous materials	Land transportation and, potentially, maritime transportation require specific technical and operational conditions, route definition, and emergency measures.	May constrain logistics, transportation routes, and the time and costs associated with the supply and transportation of substances.
Contingency plans	Prevention and response mechanisms, drills, institutional coordination, and specialized equipment are required.	Influences the project's preparedness for emergencies and the capabilities required to respond to accidental events.
Chemical and technological risk management	Requires the assessment of risk scenarios, establishment of preventive and mitigation measures, and identification of potential impact areas.	May influence location, design, safety measures, worker and community protection, and the content of the applicable environmental studies.

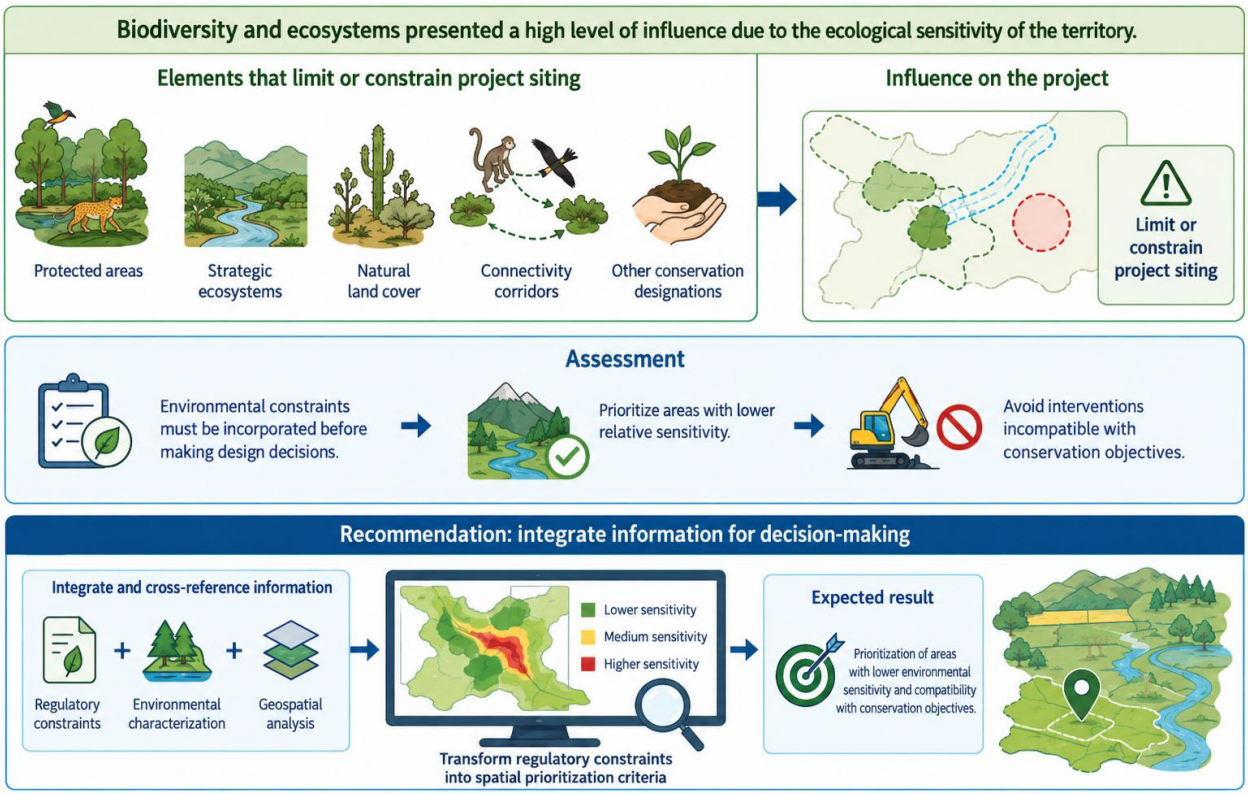
Source: Prepared by the authors based on Decrees 1079 of 2015 and 1076 of 2015 and Law 1523 of 2012. Óptima Consultores S.A.S. (2026).

1.7 Biodiversity and Ecosystems

Biodiversity and ecosystems presented a **high level of influence** due to the ecological sensitivity of the territory. Protected areas, strategic ecosystems, natural land cover, connectivity corridors, and other conservation designations may exclude or restrict intervention, depending on their legal framework, ecological importance, and spatial relationship with the proposed infrastructure.

The assessment established that these conditions should be incorporated before making design and siting decisions, prioritizing areas with relatively lower sensitivity and avoiding interventions that are legally incompatible or could compromise the identified conservation objectives. To this end, regulatory constraints were integrated with the environmental characterization and geospatial analysis in order to translate them into spatial criteria for the comparison and prioritization of alternatives.

Figure 2 Environmental criteria to guide project siting



Source: Prepared by the authors with the support of artificial intelligence tools, based on technical information provided by Óptima Consultores S.A.S. (2026).

1.8 Climate Change and Risk Management

Climate change and risk management are cross-cutting components in the structuring of H_2V/PtX projects due to their influence on the location, design, technology, operation, and continuity of facilities. In the assessment conducted, **climate change** presents a **Medium-High** level of constraint, while **risk management** is classified as **High**, given the territory's exposure to natural and technological hazards and the existing response capabilities.

Regarding climate change, the assessment should consider both the quantification and traceability of greenhouse gas (GHG) emissions and the project's adaptation to territorial conditions. For AkuaippaHy, it will be necessary to assess, among other factors, water stress, extreme temperatures, droughts, storms, and climate variability, as these may influence technology selection, the location of critical infrastructure, and operational continuity.

These factors should be incorporated from the alternative comparison and conceptual design stages. The joint assessment of hazard, exposure, and vulnerability will make it possible to identify configurations with relatively lower exposure and define prevention, response, and continuity measures. Table 7 presents the aspects requiring early attention.

Table 7 Summary of the Main Constraints Associated with Climate Change and Risk Management

Area	Analysis result	Implication for the project	Level of constraint
GHG mitigation and management	The project should consider the quantification, reduction, and traceability of its emissions, as well as their alignment with decarbonization objectives.	Influences technology definition, GHG quantification, and project sustainability criteria.	**Medium-High**
Climate adaptation and vulnerability	La Guajira is exposed to climate variability, water stress, extreme temperatures, and other climate-related events.	May constrain technology selection, the location of critical infrastructure, and resilience and operational continuity measures.	**High**
Natural hazards	The territory presents exposure to droughts, intense wind events, localized flooding, and other hazards associated with local conditions.	Requires the incorporation of hazard and vulnerability criteria into site selection and infrastructure design.	**High**
Technological hazards and industrial risks	The industrial scale and handling of energy and chemical inputs introduce technological risk scenarios.	Requires risk assessments, prevention and mitigation measures, and contingency plans.	**High**
Response capacity and operational continuity	The available information does not allow local response capacities to be established in sufficient detail for all emergency scenarios.	Institutional and operational capacities should be verified and, where necessary, supplemented with project-specific resources.	**High**

Source: Prepared by the authors based on Law 1523 of 2012 and the climate and risk assessment conducted as part of the study. Óptima Consultores S.A.S. (2026).

1.9 Environmental Management, Licensing, and Institutional Coordination

The involvement of the identified entities is not triggered uniformly across all alternatives and does not constitute a single permitting pathway. The applicable authorities and requirements will depend on the selected location, the components comprising the project, and the activities associated with renewable energy generation, H_2V/PtX production, water supply, storage, transportation, and port infrastructure.

For this reason, the management pathway should be defined for each alternative and infrastructure component, identifying the competent authorities, applicable permits or authorizations, and the aspects requiring further definition during the subsequent stages of project structuring. This review will make it possible to anticipate potential institutional requirements and identify differences among alternatives that may influence their development.

The involvement of these entities is not uniform across all alternatives and does not constitute a single permitting pathway. Their involvement will depend on the components ultimately comprising the project, the selected location, and the activities associated with renewable energy generation, H_2V/PtX production, water supply, storage, transportation, port infrastructure, and other complementary facilities. Early identification of institutional responsibilities makes it possible to anticipate the requirements applicable to each alternative, define the **corresponding management pathways**, and identify the aspects that will need to be further specified during the subsequent stages of project structuring.

1.10 Results and Implications for AkuaippaHy

The assessment shows that the location and design of AkuaippaHy do not depend on a single variable. The energy framework supports the development of H_2V/PtX; however, each alternative will need to address environmental, water-related, territorial, social, and institutional constraints that may overlap within the same area.

The comparison should jointly assess land-use compatibility, water supply and management, ecosystem sensitivity, waste and hazardous materials, risk management, and engagement with communities. The assessment provides a framework for organizing these considerations and identifying those requiring further analysis before a decision is made.

Favorable physical or energy conditions alone are not sufficient to determine the overall suitability of an alternative. Its selection should consider the environmental, territorial, social, institutional, and regulatory constraints that may influence its development.

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2 Geospatial Analysis and Cartographic Integration

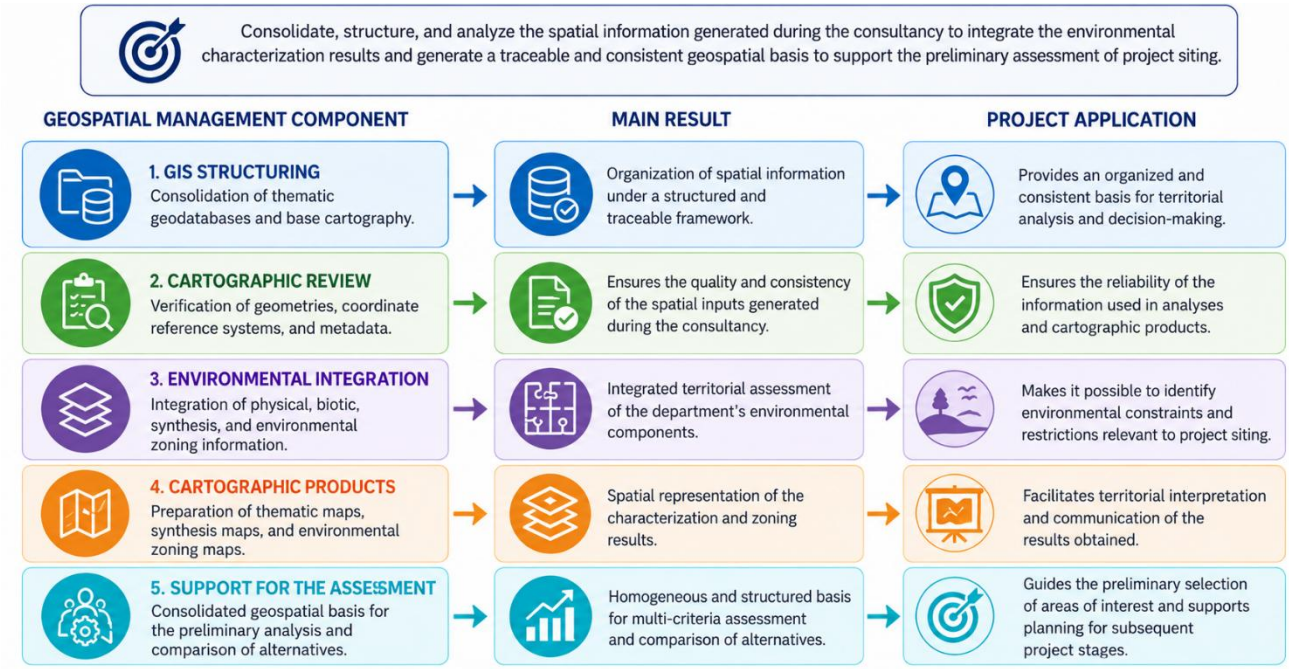
Based on the constraints identified in the assessment and the environmental characterization, the spatial information generated during the consultancy was consolidated and reviewed. The work included the organization of cartographic information, the review of geometries and coordinate reference systems, the consolidation of geodatabases, the preparation of thematic maps, and the spatial representation of the synthesis and environmental zoning results.

Information from the physical and biotic components was integrated, together with the sensitivity and zoning results, to provide a comprehensive territorial assessment and identify relevant environmental constraints and restrictions for project siting. The resulting products provide inputs for the comparative assessment of the alternatives and their subsequent integration with technical and logistical criteria and resource availability.

The geospatial assessment was conducted at a regional scale for the department of La Guajira. The information makes it possible to identify general spatial patterns and guide the preliminary selection of areas with relatively lower levels of constraint; however, it does not provide the level of detail required for property-level decisions, engineering designs, field delineations, or the direct preparation of an Environmental Impact Assessment (EIA).

This phase provides cartographic support for early-stage planning and a consistent basis for the territorial comparison of location alternatives, within the scale and limitations of the information used.

Figure 3 Management and integration of spatial information



Source: Prepared by the authors with the support of artificial intelligence tools, based on technical information provided by Óptima Consultores S.A.S. (2026).

2.1 Sources, Traceability, and Quality Control of Geospatial Information

The cartographic database was updated using a hierarchy of official sources, prioritizing administrative acts and data issued by the competent authorities, followed by national and regional information databases, environmental and territorial planning instruments, and, lastly, technical inputs derived from image interpretation and field verification. The selection process considered the authority of the issuing entity and the relevance of each source to the variable being analyzed.

The consolidated information incorporated official sources from entities such as IGAC, DANE, SGC, IDEAM, the Ministry of Environment and Sustainable Development (Minambiente), ANLA, Corpoguajira, UPME, ANI, Invías, DIMAR, ANM, ANH, and ICANH, depending on the component analyzed, as summarized in Table 8.

Table 8 Summary of Priority Official Sources for the Control and Updating of the GIS Database

Information group	Main official sources	Application
Cartography and territory	IGAC, DANE, territorial authorities	Boundaries, populated centers, and territorial reference information
Physical environment	SGC, IDEAM, Corpoguajira	Geology, hazards, hydrology, climate, and water resources
Biodiversity and conservation	Minambiente, SIAC, PNN, Humboldt Institute, Corpoguajira	Ecosystems, protected areas, and connectivity
Social and territorial	DANE, ANT, Ministry of the Interior, territorial authorities	Settlements, ethnic territories, and territorial planning
Environmental licensing	ANLA, Corpoguajira	Licensed projects and environmental management zoning

Information group	Main official sources	Application
Infrastructure and sectors	UPME, ANI, Invías, DIMAR, ANM, ANH, ICANH	Energy, transportation, logistics, mining, hydrocarbons, and cultural heritage

Source: Prepared by the authors based on the official sources indicated in the table. Óptima Consultores S.A.S. (2026).

As part of the process, quality control and standardization were carried out, including the review of geometries, spatial extent, attributes, null values, areas, territorial coverage, and consistency among layers, legends, maps, and environmental characterization results. This quality control process made it possible to identify and address inconsistencies and strengthen the traceability and internal consistency of the geospatial information used in subsequent analyses.

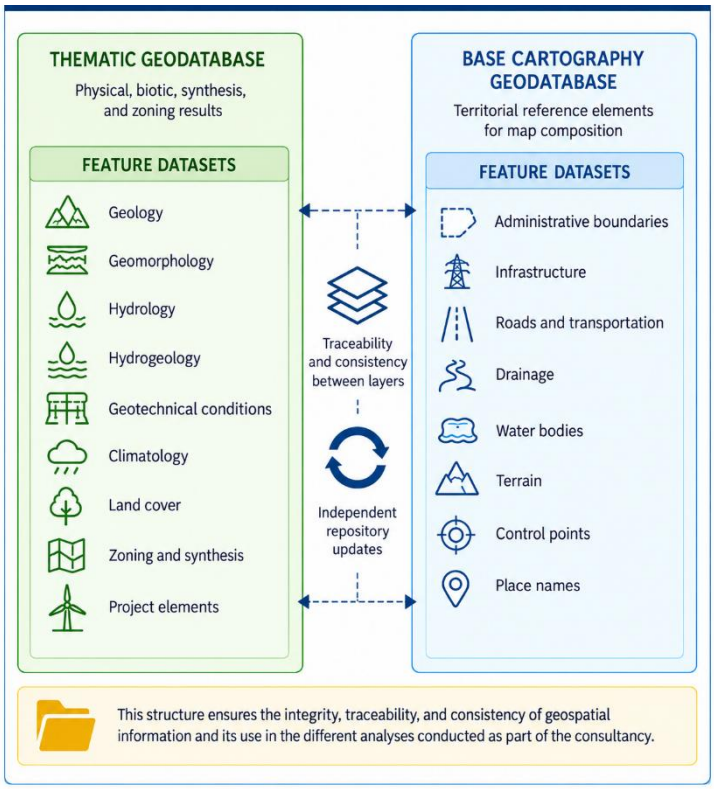
2.2 Structure of the Geographic Data Storage Model (MAG)

The Geographic Data Storage Model (MAG) was structured through two complementary geodatabases: a thematic geodatabase, which consolidates physical, biotic, synthesis, and zoning information; and a base cartography geodatabase, which contains the territorial reference elements used for map composition. This organization helps avoid duplication, facilitates independent updating, and maintains the traceability of the geospatial information.

The thematic geodatabase incorporates information on geology, geomorphology, hydrology, hydrogeology, geotechnical conditions, climatology, land cover, zoning, and project elements. In turn, the base cartography geodatabase contains administrative boundaries, infrastructure, roads, drainage networks, water bodies, terrain, control points, and place names. Together, these structures form the database used to manage spatial information and produce the cartographic outputs of the consultancy.

The MAG structure consolidates the geospatial inputs required for the preparation of thematic cartography and the management of the project's territorial information.

Figure 4 Structure of the Geographic Data Storage Model (MAG)



Source: Prepared by the authors with the support of artificial intelligence tools, based on technical information provided by Óptima Consultores S.A.S. (2026).

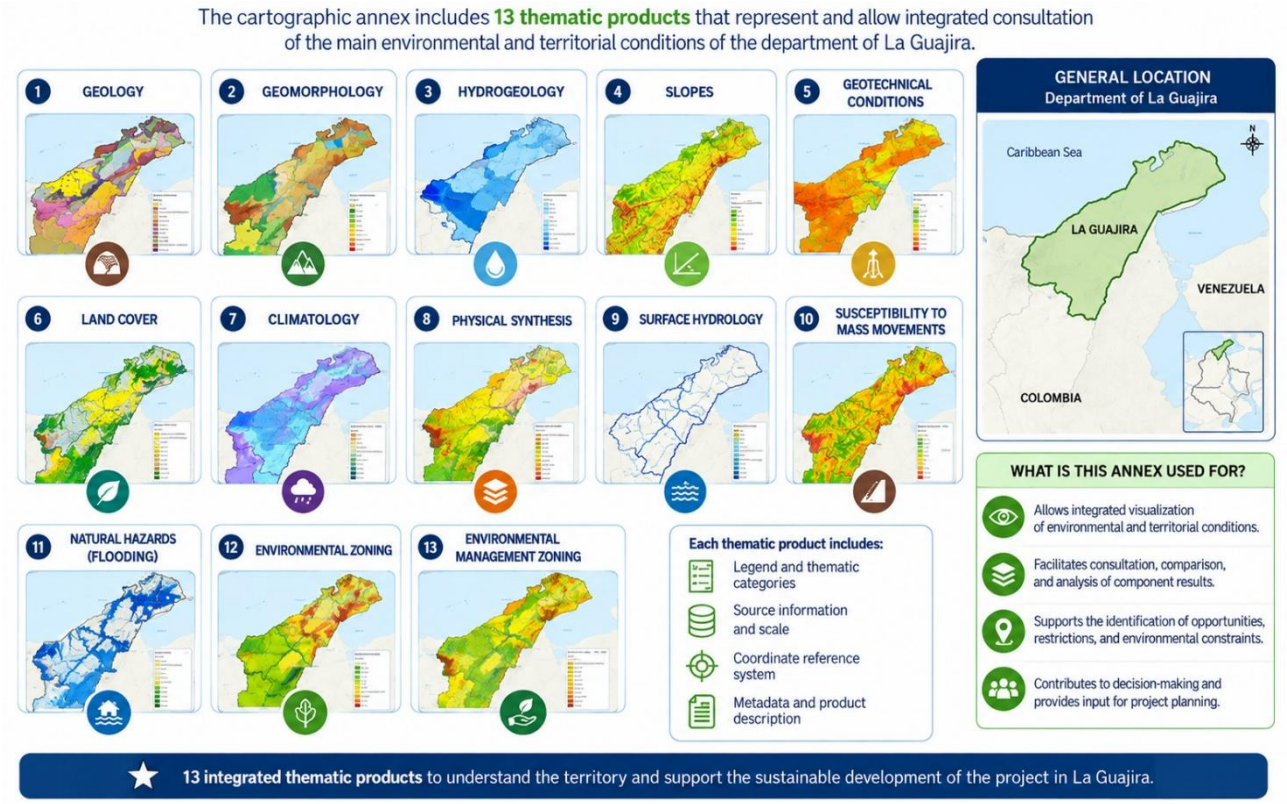
2.3 Preparation and Validation of Cartographic Products

The thematic maps were prepared based on the results of the physical and biotic characterization. For each component, the consistency among layers, attributes, thematic classification, scale, territorial coverage, and technical description was verified. Where necessary, visual cross-checks were conducted using satellite imagery and digital elevation models to assess the spatial consistency of the products.

The synthesis and zoning layers retained the categories, rules, and criteria previously defined, maintaining traceability between the environmental characterization and its geospatial products. This integration made it possible to consolidate a consistent spatial representation of the main environmental variables and facilitate their consultation, comparison, and territorial interpretation.

Prior to consolidation, the cartographic products were reviewed to verify consistency among attributes, legends, sources, and the technical results of the characterization, as well as their spatial continuity and readability.

Figure 5 Cartographic Products Prepared



Source: Prepared by the authors with the support of artificial intelligence tools, based on technical information provided by Óptima Consultores S.A.S. (2026).

The **cartographic integration rules** are presented in Table 9, which establish consistent criteria for incorporating physical, biotic, and territorial information into the project's geospatial database.

Table 9 Summary of Cartographic Integration Rules

Information group	Main products	Processing and quality control	Result
Physical environment	Geology, geomorphology, slopes, hydrogeology, and geotechnical conditions	Thematic harmonization and verification of scale, attributes, and spatial coverage	Integrated physical cartography
Biotic environment	Land cover, ecosystems, and protected areas	Layer integration and control of geometries and data currency	Consolidated biotic cartography
Territorial cartography	Boundaries, populated centers, roads, drainage networks, and infrastructure	Standardization and quality control of available inform ation	Standardized territorial database
Synthesis and zoning	Physical-biotic synthesis and preliminary sensitivity and constraint zoning	Preservation of established criteria and verification of consistency among layers, tables, and maps	Traceable products for territorial analysis

Source: Prepared by the authors based on the geospatial integration and quality control protocol developed for the study. Óptima Consultores S.A.S. (2026).

2.4 Contributions of Geospatial Analysis to Territorial Assessment

The integration of physical, biotic, and territorial information into a consistent geospatial database made it possible to consolidate an integrated view of the department of La Guajira and preliminarily identify patterns associated with the territory's geological, geomorphological, hydrogeological, climatic, and ecosystem conditions.

The products generated make it possible to identify environmental constraints, sensitivities, and conditioning factors, including exclusion areas, land-cover sensitivity, water resource-related conditions, potential compensation requirements, and physical and climate-related risk elements. These results provide inputs for the assessment of prioritized polygons and the evaluation of environmental criteria within the alternative comparison process.

2.5 Traceability Between Environmental Characterization and Geospatial Products

The final consolidation linked the environmental characterization results with the thematic layers, map documents, and cartographic products, maintaining consistency between the technical information and its spatial representation.

The thematic geodatabase integrates the results of the physical, biotic, climatic, hydrological, and environmental sensitivity components, while the base cartography geodatabase provides the territorial elements required for their representation and contextualization. Table 10 summarizes the relationship between the characterization results and the geospatial products generated.

Table 10 Summary of the Relationship Between Characterization Components and Geospatial Products

Component	Main result	Geospatial product
Land cover and biotic sensitivity	Distribution of land cover and sensitivity levels	Land-cover and sensitivity maps
Geology and geomorphology	Geological and geomorphological units and relative suitability conditions	Geological and geomorphological maps
Slopes and geotechnical conditions	Morphometric conditions, stability, and physical suitability	Slope maps and geotechnical zoning
Hydrogeology	Hydrogeological units and relative conditions associated with groundwater	Hydrogeological map
Climatology	Distribution of precipitation, temperature, and climate zones	Climate zoning map
Hydrology	Hydrographic units and drainage systems	Hydrological maps and products
Geospheric synthesis	Integration of physical conditions and relative suitability	Physical synthesis map
Territorial environmental sensitivity	Integration of exclusion and constraint criteria	Sensitivity map and preliminary constraint zoning

Source: Prepared by the authors based on the geospatial products developed for the study. Óptima Consultores S.A.S. (2026).

This structure maintains consistency among the environmental analyses, geographic information, and cartographic products, providing a common basis for territorial interpretation and the subsequent assessment of location alternatives.

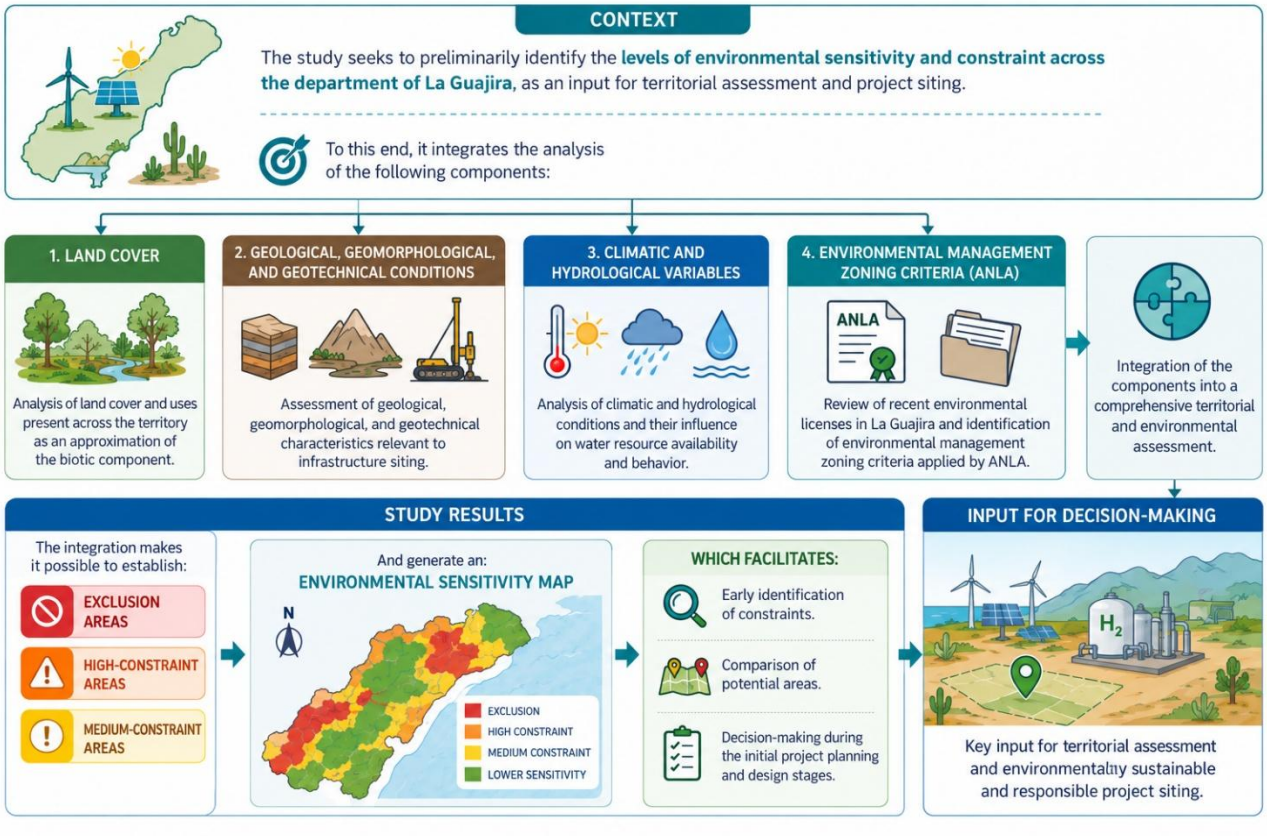
3 Environmental Characterization and Territorial Sensitivity of La Guajira

This section presents the environmental characterization used to interpret territorial conditions and preliminarily assess their sensitivity to the location of AkuaippaHy infrastructure. The characterization complements the regulatory assessment and is supported by the consolidated geospatial information to identify the territorial distribution of the main physical and biotic constraints.

The assessment integrated the analysis of land cover, geological, geomorphological, and geotechnical conditions, as well as climatic and hydrological variables. As a complementary reference, management zoning criteria contained in recent environmental licenses issued in the department were reviewed; their application to AkuaippaHy will depend on the territorial and technical relevance of each criterion.

The integration of these components made it possible to preliminarily classify the territory into **exclusion areas, high-constraint areas, and medium-constraint areas**, and to generate an environmental sensitivity map to support the early identification of constraints, the comparison of potential areas, and decision-making during the initial planning and design stages of the project.

Figure 6 Methodological approach for assessing the environmental sensitivity of the territory



Source: Prepared by the authors with the support of artificial intelligence tools, based on technical information provided by Óptima Consultores S.A.S. (2026).

3.1 Biotic Environment

The characterization of land cover was conducted using the CORINE Land Cover methodology adapted for Colombia (IDEAM, 2010), based on satellite imagery from the 2020–2024 period, GIS tools, and field verification. The analysis was

conducted at a scale of 1:25,000 and made it possible to assess the biotic sensitivity of the identified land-cover types. Table 11 summarizes the main groups and their relative sensitivity.

Table 11 Main Land-Cover Types and Their Biotic Sensitivity in the Study Area

Land-cover group	Representation / reference	Sensitivity	Environmental relevance
Natural and semi-natural land cover	Predominant	Medium – Very High	Aggregate category comprising land-cover types associated with biodiversity, ecological connectivity, water regulation, and ecosystem support functions.
Forest cover	Low open forests: 3.92%; Gallery and riparian forests: 3.96%	**Very High**	Strategic ecosystems for biodiversity, water regulation, and connectivity.
Grasslands	Significant proportion	Medium – High	Associated with ecological succession processes and biodiversity support.
Bare and degraded land	7.77%	**Low**	Areas with greater anthropogenic intervention and relatively lower ecological functionality.
Artificialized areas	1.54%	**Low**	Associated with urbanization, infrastructure, and territorial transformation.
Mining areas	0.76%	**Low**	Anthropogenic land cover reflecting land-use transformation and pressure.
Water bodies	0.92%	—	Low representation, but high importance for water regulation and associated ecosystems.

Source: Prepared by the authors based on land-cover interpretation and the CORINE Land Cover methodology adapted for Colombia (IDEAM, 2010). Óptima Consultores S.A.S. (2026).

The characterization identified a high representation of natural and ecologically significant ecosystems, together with areas subject to anthropogenic intervention and land-cover types with lower sensitivity. This information provides an input for establishing differentiated levels of environmental sensitivity and constraint and for guiding the territorial assessment and comparison of project location alternatives.

The environmental sensitivity classification of land cover, based on the *General Methodology for the Preparation and Submission of Environmental Studies*, indicates a territory with a significant presence of natural and semi-natural ecosystems. The **High sensitivity** category represents the largest proportion of the study area, covering **918,119.35 ha (44.65%)**, followed by **Medium sensitivity**, with **515,863.89 ha (25.09%)**, and **Very High sensitivity**, with **311,284.34 ha (15.14%)**. Combined, areas with high and very high sensitivity account for approximately **60% of the territory**, reflecting the ecological importance of natural and semi-natural land cover and its associated functions related to biodiversity, water regulation, habitat provision, and ecological connectivity.

Areas with **Medium sensitivity (25.09%)** mainly correspond to partially transformed land-cover types or areas undergoing intermediate successional processes, where ecosystem functions persist and opportunities exist for sustainable management and the strengthening of ecological connectivity. In contrast, **Low (13.59%)** and **Very Low (1.53%)** sensitivity categories are concentrated in areas with a higher degree of intervention, productive use, or artificial transformation, where relative ecological significance is lower.

Spatially, areas of **Very High sensitivity** are concentrated mainly in sectors associated with the Serranía de la Macuira in the northern part of the department and in the transition between ecosystems and moisture gradients of the Sierra Nevada de Santa Marta in the south. Areas of **High sensitivity** are widely distributed and include, among others, dense and open

shrublands and wooded grasslands characteristic of the arid and xerophytic conditions of La Guajira. The resulting distribution shows that biotic sensitivity is a relevant criterion for comparing potential location areas; however, the assigned categories do not, by themselves, establish an exclusion or determine environmental feasibility. Table 12 presents the general classification.

Table 12 Summary of the Environmental Sensitivity of Land Cover

Sensitivity	Main characteristics	Area (ha)	Area (%)
Very High	Strategic natural land cover with high ecological integrity and critical ecosystem functions.	311,284.34	15.14%
High	Natural or semi-natural ecosystems of ecological importance, with relevant environmental functions.	918,119.35	44.65%
Medium	Partially transformed land cover with moderate ecosystem functions and recovery capacity.	515,863.89	25.09%
Low	Disturbed or productive-use areas, with modified ecological functions and lower relative sensitivity according to the criteria applied.	279,375.52	13.59%
Very Low	Highly transformed or artificialized land cover with lower relative ecological significance.	31,545.43	1.53%
Total		**2,056,188.51**	**100%**

Source: Prepared by the authors based on the land-cover assessment conducted for the study, using IDEAM (2010) as a reference. Óptima Consultores S.A.S. (2026).

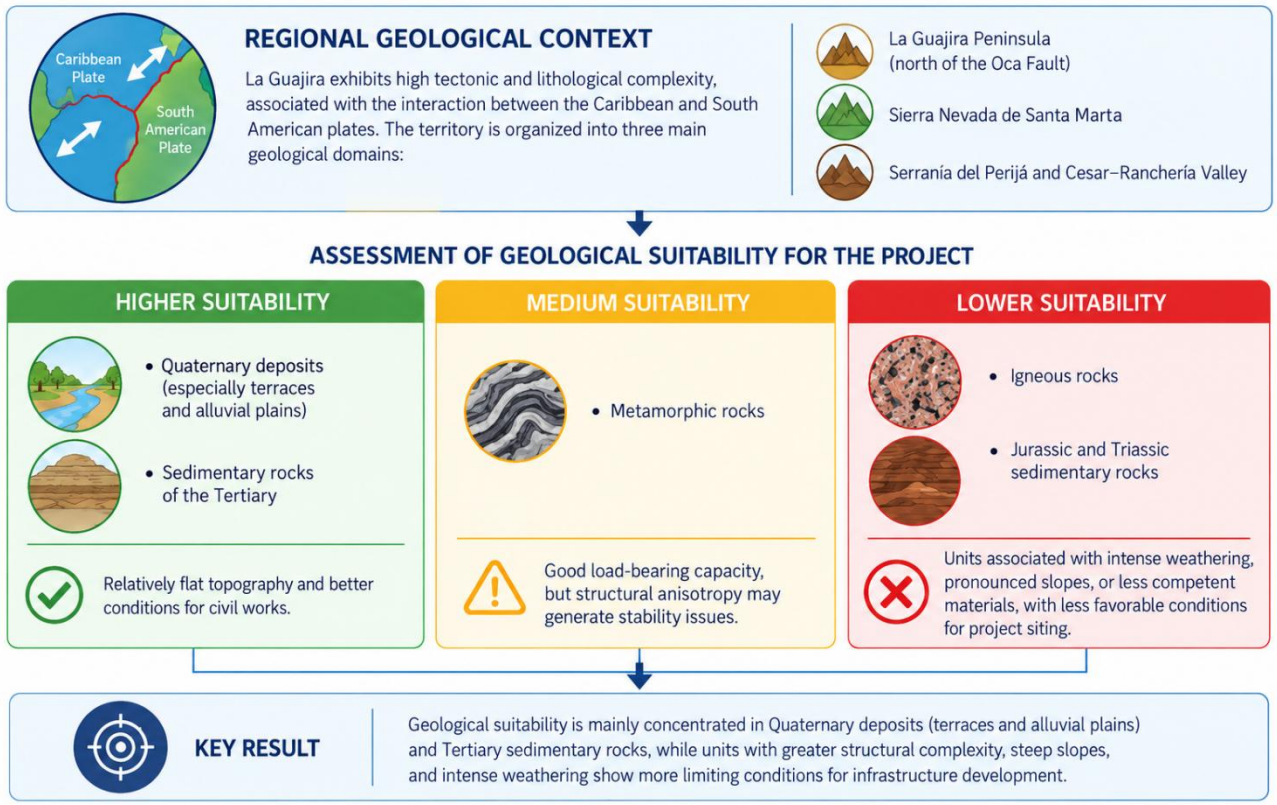
Overall, **84.88%** of the study area presents environmental sensitivity ranging from Medium to Very High, while only **15.12%** corresponds to areas with Low or Very Low sensitivity.

3.2 Physical Environment – Geospheric Components

The physical characterization integrated the geological, geomorphological, and hydrogeological components using cartography at a scale of 1:100,000, information from the Colombian Geological Survey (SGC), digital elevation models, and geospatial analysis. The results make it possible to identify territorial differences that are useful for a preliminary assessment; however, these conditions should be verified at the sites ultimately prioritized.

From a geological perspective, La Guajira exhibits high tectonic and lithological complexity, associated with the interaction of the Caribbean and South American plates and the presence of the La Guajira Peninsula, Sierra Nevada de Santa Marta, and Serranía del Perijá–Cesar-Ranchería Valley domains.

Figure 7 Preliminary geological favorability



Source: Prepared by the authors with the support of artificial intelligence tools, based on technical information provided by Óptima Consultores S.A.S. (2026)

The assessment identified relatively more favorable conditions in Quaternary deposits, particularly terraces and alluvial plains, and in Tertiary sedimentary rocks, according to the geological and topographic criteria applied. Metamorphic rocks present medium suitability, while igneous units and some Jurassic and Triassic sedimentary rocks present relatively lower suitability, mainly associated with slopes, weathering, and stability conditions. This regional classification should be verified through site-specific geological and geotechnical studies for the selected sites and project components.

The geomorphological component revealed a marked diversity of landscapes resulting from the interaction of tectonic, denudational, aeolian, marine-coastal, and alluvial processes. The morphometric analysis showed that low slopes (0–7%) predominate in alluvial and coastal plains, while steeper slopes are concentrated in mountainous systems, constituting a relevant factor in the preliminary assessment of terrain conditions.

The hydrogeological analysis organized the units according to their porosity and permeability conditions, based on the geological and hydrogeological inputs used in the study. Systems associated mainly with alluvial deposits, porous sedimentary formations, and fractured units in mountainous areas were identified.

Groundwater availability and dynamics vary across Alta, Media, and Baja Guajira. At this stage, hydrogeology was used as a criterion of relative potential and not as evidence of availability for project water supply. Any groundwater use must demonstrate quantity, quality, and sustainability through specific studies. Table 13 summarizes the identified units.

Table 13 Summary of Hydrogeological Units in the Study Area

Rating	Groundwater potential	Main units	Relevance for siting
1 – Very Low	Very low or none	Igneous and metamorphic rocks	Lower relative potential, subject to the fracturing and weathering conditions of the units.
2 – Low	Low	Units with limited hydrogeological capacity	Less favorable conditions for groundwater use.
4 – High	High	Sedimentary rocks, sandstones, and carbonate rocks	Relatively favorable conditions for aquifer occurrence, subject to hydrogeological verification.
5 – Very High	Very high	Quaternary sediments	Highest relative hydrogeological potential according to the classification applied, subject to verification of availability, quality, and sustainability.

Source: Prepared by the authors based on geological and hydrogeological mapping from the Colombian Geological Survey (SGC) (2016, 2023). Óptima Consultores S.A.S. (2026).

The geotechnical zoning integrated lithology, slope, morphodynamic processes, and geomorphological conditions, making it possible to identify areas with differentiated relative conditions for infrastructure siting. The results indicate greater preliminary suitability in alluvial areas and recent sedimentary units, while mountainous areas with steep slopes may require more extensive assessment, stabilization, and management measures. Table 14 summarizes the geospheric component and the relative physical suitability of the territory.

Table 14 Integrated Summary of the Geospheric Component

Level of physical suitability	Main territorial conditions	Implication for siting
Higher suitability	Alluvial plains, Quaternary terraces, and Tertiary sedimentary units	Preliminary favorable conditions according to the regional criteria applied, subject to assessment of hazards and local geotechnical conditions.
Intermediate suitability	Areas with intermediate geological, geomorphological, hydrogeological, or geotechnical conditions	Require detailed assessment and management measures.
Lower suitability	Structural mountainous areas, highly weathered igneous and metamorphic lithologies, and steep slopes	Greater physical constraints and potential stabilization requirements.

Source: Prepared by the authors based on the geological, geomorphological, hydrogeological, and geotechnical characterization conducted for the study. Óptima Consultores S.A.S. (2026).

3.3 Physical Environment – Climatological and Hydrological Components

- **Climate Characterization**

The climate characterization was developed based on historical records from IDEAM meteorological stations. The completeness and homogeneity of the records, outliers, and missing data were reviewed. The results describe a predominantly warm, arid to semi-arid climate with marked seasonality, influenced by the dynamics of the Intertropical Convergence Zone (ITCZ).

The precipitation regime is characterized by low cumulative rainfall and high temporal variability, with rainfall concentrated during the April–June and September–November periods. Spatially, the highest rainfall totals are concentrated in the western and southwestern parts of the department, mainly associated with the orographic influence of the Sierra Nevada de Santa Marta, while the northern, central, and northeastern sectors receive lower precipitation.

Thermal conditions across the department are relatively homogeneous and warm throughout the year, with slightly lower temperatures toward the west and southwest due to the influence of elevation. These conditions, combined with high potential evapotranspiration, result in recurrent climatic water deficits during dry periods.

Table 15 summarizes the regional behavior of the variables analyzed. Solar radiation duration presents mean annual values ranging from 6.5 to 8.4 hours per day, with the highest values recorded mainly at stations near the coast. These values provide a preliminary reference for the assessment of solar resources.

Table 15 Climate Variables

Variable	Regional behavior	Implication
Precipitation	Low, seasonal, and variable; highest rainfall totals in the western and southwestern areas	Influences the water balance and the relative availability of surface water resources
Temperature	Warm conditions throughout the year, with spatial variations associated with elevation	High evaporative demand
Evapotranspiration	High, approximately 1,500–1,800 mm/year	Recurrent water deficit
Solar radiation duration	High; approximately 6.5–8.4 h/day	Regional reference for the preliminary assessment of solar resources
Wind	Predominantly E–ENE, with mean speeds close to 5.8 m/s	Regional reference for the preliminary assessment of wind resources

Source: Prepared by the authors based on official historical series from IDEAM consulted through DHIME. Óptima Consultores S.A.S. (2026).

- **Water Balance and Winds**

The water balance indicates a recurrent water deficit because potential evapotranspiration exceeds precipitation during a significant portion of the year. Rainfall is concentrated during specific periods, generating temporary surpluses and rapid runoff responses, while during dry periods water storage decreases rapidly. The wind regime is predominantly E–ENE, associated with the trade winds, with mean speeds close to 5.8 m/s. This behavior provides a regional reference for the assessment of wind potential and influences atmospheric dispersion conditions.

The water balance shows a recurrent deficit because potential evapotranspiration exceeds precipitation during a significant portion of the year. Rainfall is concentrated during specific periods and generates temporary surpluses and rapid runoff responses; during dry periods, water storage decreases rapidly. **E–ENE winds predominate.**

- **Hydrology**

Regional hydrology is characterized by a predominantly intermittent and seasonal drainage network, mainly composed of streams and watercourses that carry flow during rainy periods. This condition is a response to the arid and semi-arid climate and the temporal concentration of precipitation.

The analysis included the main hydrographic units in the area identified by IDEAM, including the Uareteha, Mouasiro, Juluapua, and Taray streams, the Paraguachón River, and drainage systems flowing directly into the Caribbean, as well as morphometric parameters related to area, perimeter, drainage density, sinuosity, and drainage network configuration.

The results show low flow permanence, prolonged low-flow periods, and rapid responses to intense rainfall, conditions that may favor flash floods in intermittent channels. The surface water system includes temporary watercourses and storage bodies, some of which are influenced by marine conditions and exhibit brackish characteristics. Table 16 presents the identified hydrological characteristics.

Table 16 Hydrological Characteristics

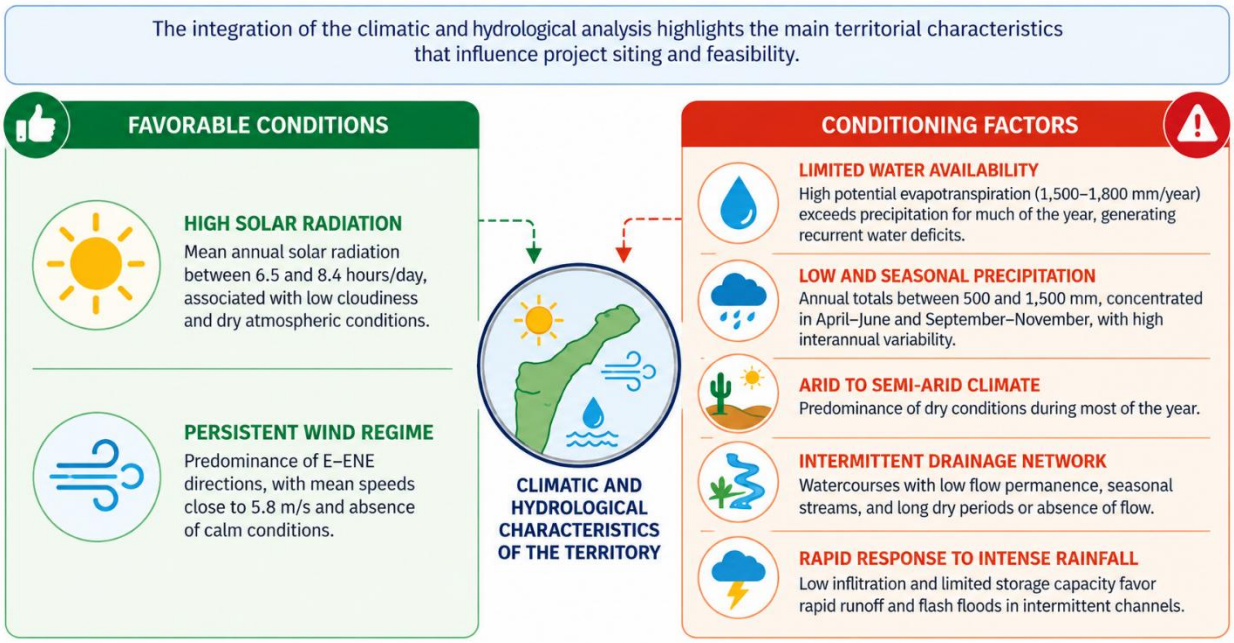
Aspect	Main result
Hydrological regime	Intermittent and seasonal
Drainage	Predominance of streams and direct coastal drainage systems
Response to rainfall	Rapid, with potential for flash floods
Dry periods	Long periods of low flow or absence of flow
Water bodies	Temporary lotic systems and dispersed lentic systems
Management	Several hydrographic units do not have an adopted POMCA

Source: Prepared by the authors based on hydrological information from IDEAM (2023) and the watershed planning instruments reviewed for the study. Óptima Consultores S.A.S. (2026).

- **Climate and Hydrological Synthesis**

The climate and hydrological characterization reveals a territory with regional conditions relevant to the use of solar and wind resources, but with structural limitations associated with water availability and regulation. Low and seasonal precipitation, high evapotranspiration, and the intermittent nature of the drainage network constitute relevant factors for the planning of water-intensive projects.

Figure 8 Synthesis of the environmental analysis of the territory



Source: Prepared by the authors with the support of artificial intelligence tools, based on technical information provided by Óptima Consultores S.A.S. (2026)

- **Integration of the Territorial Environmental Assessment**

The integration makes it possible to identify where relatively favorable conditions coincide and where the overlap of constraints increases siting complexity, as summarized in Table 17.

Table 17 Summary of the Environmental Assessment of the Territory

Component	Aspects assessed	Main result	Contribution to territorial assessment
Biotic environment	Land cover and environmental sensitivity	Natural and semi-natural land cover predominates; approximately 60% of the area presents high or very high sensitivity.	Identifies the main ecological constraints and areas of greater sensitivity.
Geospheric environment	Geology, geomorphology, slopes, geotechnical conditions, and hydrogeology	Greater relative physical suitability in Quaternary terraces and sedimentary units; greater limitations in mountainous and steep-slope areas.	Provides a preliminary differentiation of the physical conditions of the territory.
Climate and hydrology	Precipitation, temperature, solar radiation, winds, water balance, and drainage network	Regional conditions are favorable for solar and wind resources, but water availability is limited, precipitation is seasonal, and drainage networks are intermittent.	Identifies regional energy conditions and constraints associated with water resources.
Territorial integration	Overlay and joint analysis of the components	Identifies areas where favorable conditions and environmental, physical, and water-related constraints converge.	Guides the preliminary prioritization and comparison of location alternatives.

Source: Prepared by the authors based on the integration of the biotic, geospheric, climatic, and hydrological components of the study. Óptima Consultores S.A.S. (2026).

The integration of the components makes it possible to identify areas where lower biotic sensitivity, greater physical suitability, and relatively favorable water conditions coincide, as well as areas where the overlap of constraints increases the complexity of project siting.

3.4 Environmental Sensitivity of the Territory

The environmental sensitivity of the department of La Guajira was determined through a review of seven (7) projects recently licensed by ANLA, selected based on their spatial representativeness, license validity, and sectoral diversity. The projects analyzed comprised one hydrocarbon transportation project, two wind farms, and four electricity transmission lines. Their respective Environmental Management Zonings were reviewed based on the corresponding administrative acts.

The review identified **26 environmental sensitivity criteria**, classified into exclusion areas, intervention areas with high restrictions, and intervention areas with medium restrictions. These criteria were spatialized using a maximum-value approach, based on the management categories previously established by the environmental authority.

The zoning demonstrates a high level of environmental sensitivity across the department, with **more than 99% of the area classified as either exclusion or intervention with high restriction**. These categories are mainly associated with the presence of strategic ecosystems, protected areas, watercourse buffer areas, flood-prone areas, and areas exposed to natural hazards, which represent the main constraints for the siting of industrial infrastructure.

Table 18 presents the municipal differences identified. Dibulla and Riohacha have their entire territories classified within exclusion or high-restriction categories. In Dibulla, the highest proportion of exclusion areas is also concentrated due to the influence of the Sierra Nevada de Santa Marta. Manaure and Maicao have exclusion areas accounting for less than 25% of their territories, while some municipalities in the southern part of the department show a relatively greater share of areas with medium or low restrictions.

Table 18 Summary of Environmental Sensitivity Results by Territory

Area	Main result
Department of La Guajira	**>99%** of the territory classified as exclusion or high restriction
Dibulla	High proportion of exclusion areas; the entire municipality falls within exclusion or high-restriction categories
Riohacha	The entire municipality falls within exclusion or high-restriction categories
Manaure and Maicao	Lower proportion of exclusion areas, below 25%
Southern municipalities	Relatively greater share of areas with medium and low restrictions

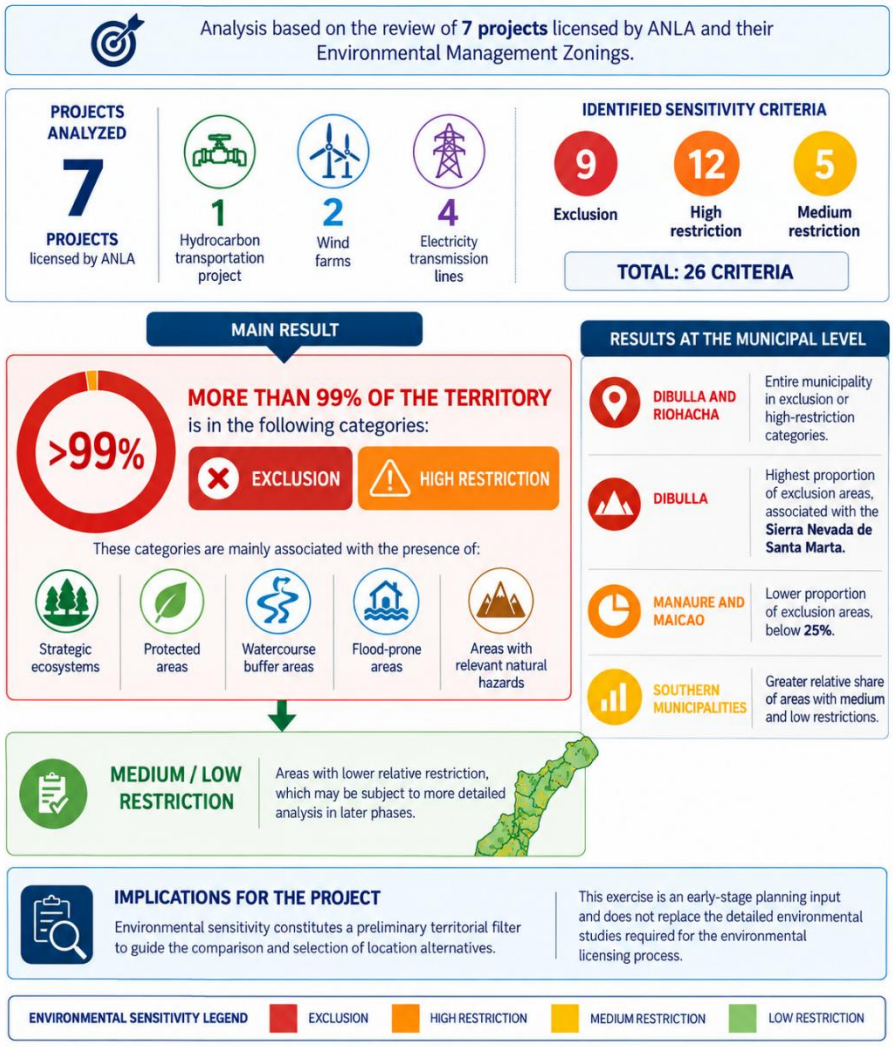
Source: Prepared by the authors based on the sensitivity zoning developed from the administrative acts of seven projects licensed by ANLA and the territorial inputs used in the study. Óptima Consultores S.A.S. (2026).

- **Project Implications**

The results show that the siting of H_2V/PtX infrastructure faces significant environmental constraints across a large part of the department. Areas with medium and low restrictions represent relatively more favorable sectors for continuing the alternative assessment, provided that appropriate management measures are incorporated and the applicable environmental and regulatory requirements are met.

The sensitivity map therefore constitutes an early-stage planning input for identifying areas with relatively lower levels of restriction and guiding the preliminary selection and comparison of potential areas. In subsequent stages, these results will need to be complemented and validated through primary data, fieldwork, and project-specific environmental studies.

Figure 9 Environmental sensitivity of the Guajira territory



Source: Prepared by the authors based on the integration of the biotic, geospheric, climatic, and hydrological components of the study. Óptima Consultores S.A.S. (2026).

3.5 Interpretation of Results and Implications for the AkuaippaHy Project

The environmental, physical, hydrological, and regulatory analyses developed for the department of La Guajira made it possible to establish an integrated territorial assessment of environmental sensitivity, aimed at identifying favorable and restrictive conditions for the development of the AkuaippaHy project.

The sensitivity map shows a high presence of areas with environmental sensitivity and restrictions, mainly associated with natural and strategic ecosystems, protected areas, watercourse buffer areas, areas exposed to natural hazards, and other environmentally important features. Nevertheless, the territory presents spatial differences, and sectors with medium and low restrictions can be identified, generally associated with areas where the landscape has undergone greater transformation or where established productive uses are present.

For the preliminary selection, sectors with lower levels of restriction should be prioritized, while exclusion areas and areas with high restrictions should be avoided. The map does not define the final location; rather, it narrows the scope of the analysis and should be considered together with water and energy availability, logistics connectivity, existing infrastructure, and socio-territorial conditions. Table 19 presents the conditions identified to support preliminary project siting decisions.

Table 19 Main Implications for Project Siting

Aspect	Result / condition identified	Implication for the project
Environmental sensitivity	High presence of exclusion areas and high-restriction areas	Differentiate legally applicable exclusion areas from restrictions and sensitivities that require further assessment.
Ecosystems and biodiversity	Presence of natural and strategic ecosystems	Minimize habitat fragmentation and impacts on ecosystems and their functions.
Water resources	Arid conditions, limited water availability, and potentially high project demand	Assess the availability, quality, and sustainability of water supply sources at an early stage.
Physical conditions	Areas with different geotechnical, geomorphological, and hazard conditions	Further assess stability, flooding, erosion, and construction conditions.
Socio-territorial conditions	Presence of communities and ethnic territories	Incorporate participation, territorial management, and applicable social requirements at an early stage.
Siting	Areas with medium and low restrictions represent areas of preliminary interest	Use these areas as a starting point for the comparison and detailed assessment of alternatives.

Source: Prepared by the authors based on the environmental characterization, sensitivity zoning, and territorial analysis conducted for the study. Óptima Consultores S.A.S. (2026).

The analysis guides the early selection of potential areas by identifying sectors with relatively lower restrictions. Its results constitute a regional planning tool and should be validated through primary data, fieldwork, component-specific assessments for each infrastructure element, and the environmental studies required for project definition and licensing.

Los análisis ambientales, físicos, hídricos y regulatorios desarrollados para el departamento de La Guajira permitieron construir una lectura territorial integrada de la sensibilidad ambiental, orientada a identificar condiciones favorables y restrictivas para el desarrollo del proyecto AkuaippaHy.

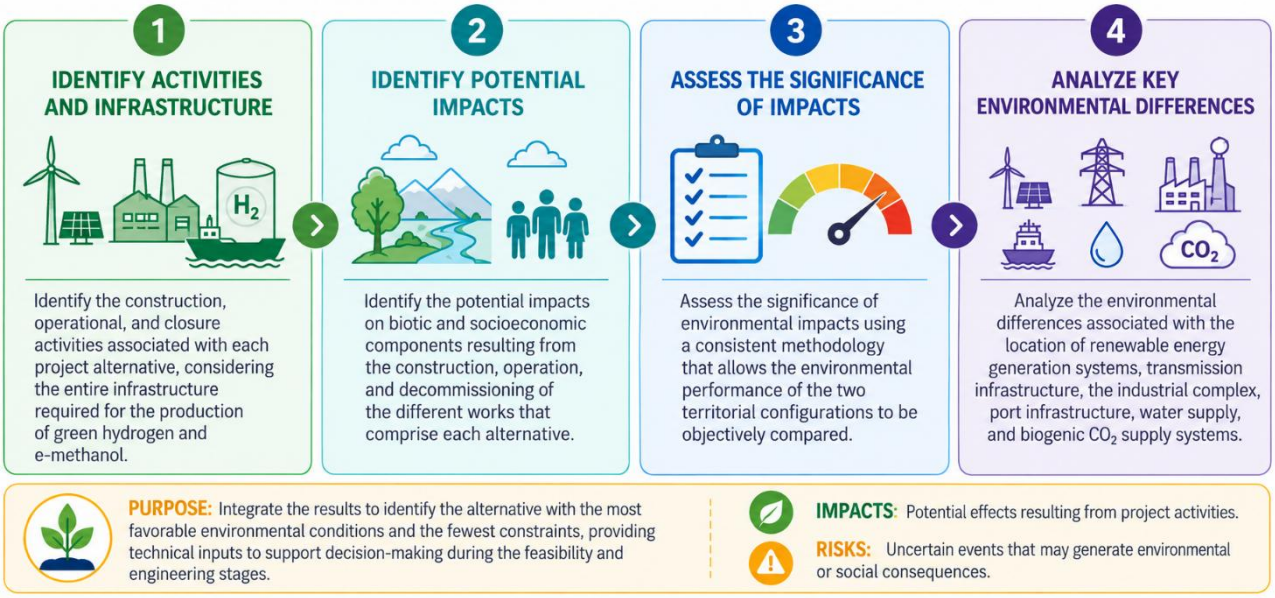
4 Environmental Comparative Assessment of Alternatives

The environmental assessment constitutes an input for comparing the location alternatives for the AkuaippaHy project, as it makes it possible to identify and assess the main impacts, risks, and constraints associated with each territorial configuration. The analysis complements the technical, logistical, and economic criteria considered to determine which alternative presents the most favorable relative conditions for progressing to feasibility and more detailed studies.

For the AkuaippaHy project, two territorial configurations were assessed, considering the full set of infrastructure required for its development, including renewable energy generation, electricity transmission, green hydrogen and e-methanol production, utilization of biogenic CO_2, port infrastructure, water supply, and auxiliary works.

A common methodology was applied to both alternatives, covering the pre-construction, construction, operation, and decommissioning stages. Environmental risks associated with events that could affect the natural or social environment were also reviewed. The results make it possible to identify differences in the nature and territorial distribution of potential impacts, as well as the components that require further assessment before selecting an alternative.

Figure 10 Objectives of the comparative environmental assessment



Source: Prepared by the authors based on the integration of the biotic, geospheric, climatic, and hydrological components of the study. Óptima Consultores S.A.S. (2026).

4.1 Environmental Assessment Methodology

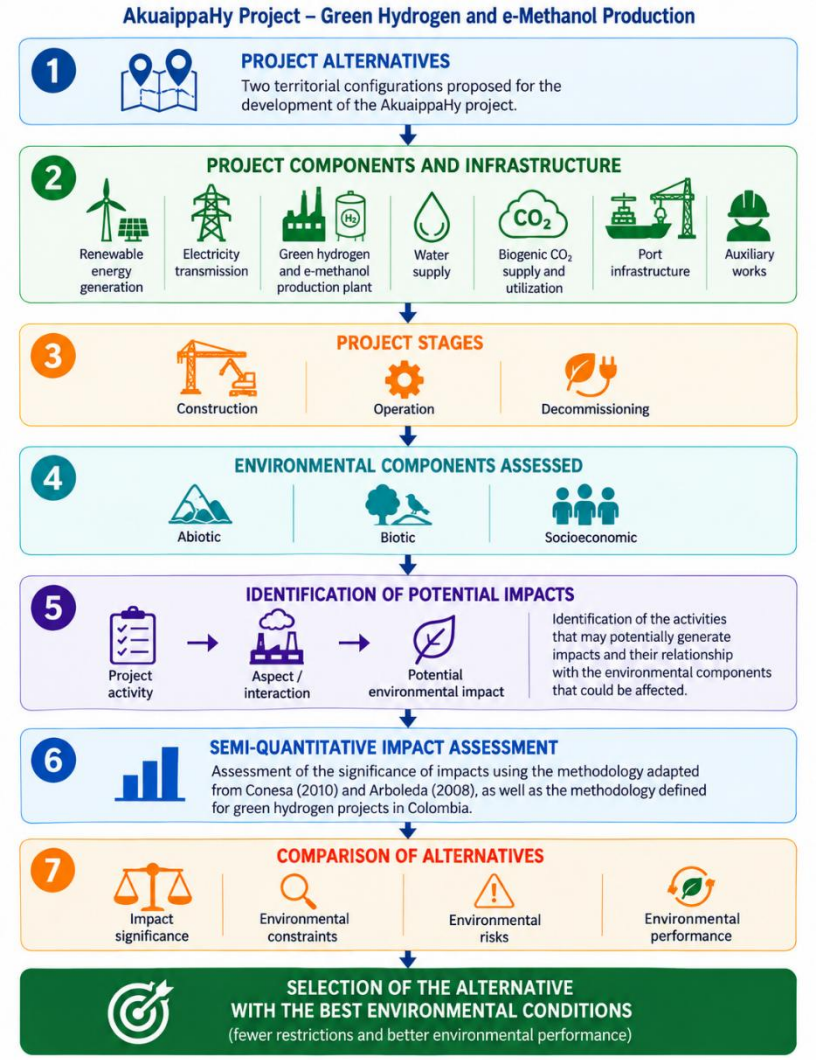
The comparative environmental assessment was developed using a conceptual engineering approach, with the purpose of identifying, assessing, and comparing the potential environmental impacts associated with the two territorial configuration alternatives for the AkuaippaHy project. This exercise does not constitute an Environmental Impact Assessment (EIA), but rather a preliminary assessment aimed at identifying differences in environmental performance and supporting the selection of the alternative to be further assessed during subsequent stages.

The analysis considered all components required for the development of the green hydrogen and e-methanol production complex, including renewable energy generation, electricity transmission, the industrial complex, water supply, biogenic CO_2 supply, port infrastructure, and auxiliary works. For each alternative, the pre-construction, construction, operation, and decommissioning stages were assessed, considering their potential effects on the abiotic, biotic, and socioeconomic environments.

The assessment linked project activities to the environmental components that could potentially be affected. A semi-quantitative assessment was then applied, adapted from Conesa (2010) and Arboleda (2008) and adjusted to the criteria defined for this study. This approach made it possible to compare the two alternatives using a common assessment scale.

The comparison was aimed at identifying differential impacts, risks, and constraints, without replacing the baseline studies, impact assessments, and definition of management measures required during subsequent project stages.

Figure 11 Methodology of environmental assessment



Source: Prepared by the authors based on the integration of the biotic, geospheric, climatic, and hydrological components of the study. Óptima Consultores S.A.S. (2026).

4.2 Environmental Assessment of the Alternatives

The environmental assessment was conducted independently for the two alternatives of the AkuaippaHy project, followed by a comparison of their main environmental and social impacts, risks, and constraints. The analysis considered the construction, operation, and decommissioning stages, as well as the components associated with renewable energy generation, electricity transmission, green hydrogen and e-methanol production, water supply, biogenic CO_2 supply, port infrastructure, and auxiliary works.

Alternative 1 – Puerto Brisa presents advantages related to the availability of existing port and logistics infrastructure, the possibility of supplementing water supply through continental sources, and favorable connections to energy infrastructure and potential biogenic CO_2 sources. Its main constraint is the **Manaure–Puerto Brisa transmission corridor**, whose greater length increases territorial occupation and interactions with natural land cover, properties, communities, and ecosystems.

Alternative 2 – Puerto Bolívar presents as its main advantage a more concentrated configuration, with a shorter transmission infrastructure length and, consequently, lower territorial intervention associated with linear infrastructure. However, it has greater constraints in the marine-coastal environment due to its reliance on desalination, brine management, and interaction with port infrastructure. In addition, it has greater potential interaction with Wayuu communities and traditional land uses, as well as greater dependence on agreements with third parties for access to port and electrical infrastructure.

Figure 12 Main characteristics of evaluated alternatives



Source: Prepared by the authors based on the integration of the biotic, geospheric, climatic, and hydrological components of the study. Óptima Consultores S.A.S. (2026).

The main biotic, physical, socioeconomic, and risk conditions identified for the alternatives are compared in Table 20.

Table 20 Comparison of biotic, socioeconomic, and risk conditions

Aspect	Alternative 1 – Puerto Brisa	Alternative 2 – Puerto Bolívar
Biotic environment	Greater exposure associated with the extent of the transmission corridor, with potential transformation of land covers and habitat impacts.	Greater potential intervention on natural land covers, estimated at 672.18 ha (6.04%) within the assessed area.
Associated physical dynamics	Potential alterations to drainage, erosion, and sedimentation associated with terrestrial and linear infrastructure.	Potential alterations to drainage, erosion, and sedimentation associated with the required interventions.

Aspect	Alternative 1 – Puerto Brisa	Alternative 2 – Puerto Bolívar
Socioeconomic component	Main challenges related to land acquisition and management, easements, and engagement with communities along the transmission corridor.	Greater potential interaction with Wayuu communities, traditional land uses, and areas that may require determination of the applicability of prior consultation.
Common risks	Hazardous substances, spills, land occupation, and social engagement.	Hazardous substances, spills, land occupation, and social engagement.
Differential risks	Greater exposure associated with terrestrial intervention and linear infrastructure.	Greater exposure associated with seawater intake and desalination, brine management, social sensitivity, and dependence on third-party infrastructure.
Main challenge	Managing the territorial, environmental, and social effects associated with the transmission corridor.	Managing marine-coastal and social/ethnic interactions, together with the requirements associated with desalination.

Source: Prepared by the authors based on the comparative environmental assessment of the two alternatives. Óptima Consultores S.A.S. (2026).

The comparison shows different conditioning profiles: Puerto Brisa presents greater challenges associated with the terrestrial corridor and linear infrastructure, while Puerto Bolívar concentrates its challenges in the marine-coastal environment, social aspects, and coordination with third-party infrastructure.

Table 21 summarizes the environmental conditions shared by the two alternatives. The differences are mainly explained by their location, the length of the transmission infrastructure, and the interaction with the marine environment and the social component.

Table 21 Common environmental conditions of the alternatives

Environment / factor	Common condition in both alternatives	Common environmental implication
Energy resource	Availability of solar and wind renewable resources to supply energy to the project.	Supports green hydrogen production but requires consideration of the interaction between energy infrastructure and the territory.
Terrestrial physical environment	Presence of soils and terrain susceptible to intervention due to the implementation of the industrial complex and electrical infrastructure.	Construction works may generate earthworks, soil compaction, drainage modification, erosion, and permanent land occupation.
Water resource	Water supply for the industrial process.	Proper water resource management is required, including abstraction, treatment, consumption, and effluent management.
Marine-coastal environment	Interaction with the marine-coastal environment, mainly due to the port location and activities associated with water supply and port operations.	Potential alterations to water quality, aquatic ecosystems, and aquatic biota must be controlled.
Vegetation cover and habitats	Presence of natural and semi-natural land covers, including xerophytic ecosystems and habitats for flora and fauna.	Infrastructure development may result in vegetation removal, habitat transformation, and impacts on ecological connectivity.
Fauna	Potential presence of aerial and terrestrial fauna.	Construction activities and infrastructure operation may cause disturbance, displacement, and risks of interaction with fauna.

Environment / factor	Common condition in both alternatives	Common environmental implication
Transmission infrastructure	Electrical transmission infrastructure to connect renewable generation with the industrial complex.	Generates territorial intervention, establishment of easements, and potential effects on soil, vegetation cover, landscape, fauna, and communities.
Port infrastructure	Integration with existing port infrastructure for logistics and export activities.	Reduces the need to construct entirely new port infrastructure but generates interactions associated with traffic, logistics operations, noise, emissions, and potential contingencies.
Socioeconomic component	Presence of communities and territorial stakeholders.	Requires early social management, participation, land management, expectation management, and, where applicable, prior consultation processes.
Land use and occupation	Land occupation for industrial, energy, water-related, and logistics infrastructure.	May generate changes in land use, restrictions, conflicts over existing uses, and landscape modification.
Air quality and noise	Construction and operation stages generate potential atmospheric emissions, particulate matter, and noise.	Emissions and noise levels require management and monitoring, particularly during construction and logistics activities.

Source: Prepared by the authors based on the comparative environmental assessment of the two alternatives. Óptima Consultores S.A.S. (2026).

Table 22 summarizes the critical conditions of each alternative. For Puerto Brisa, the main challenge is the territorial management of linear infrastructure; for Puerto Bolívar, attention is focused on the marine environment, desalination, and the social component.

Table 22 Exclusions and critical conditions of the alternatives

	Puerto Brisa	Puerto Bolívar
Main territorial characteristic	Greater terrestrial extent due to the transmission line.	Greater concentration of infrastructure.
Environment with greatest interaction	Terrestrial.	Marine-coastal.
Main sensitivity	Flora, fauna, landscape, soil, and territory.	Seawater, aquatic biota, and the social component.
Main advantage	Infrastructure and relative water availability.	Short transmission line and proximity to the port.
Main challenge	Transmission corridor.	Desalination and social management.

Source: Prepared by the authors based on the comparative environmental assessment of the two alternatives. Óptima Consultores S.A.S. (2026).

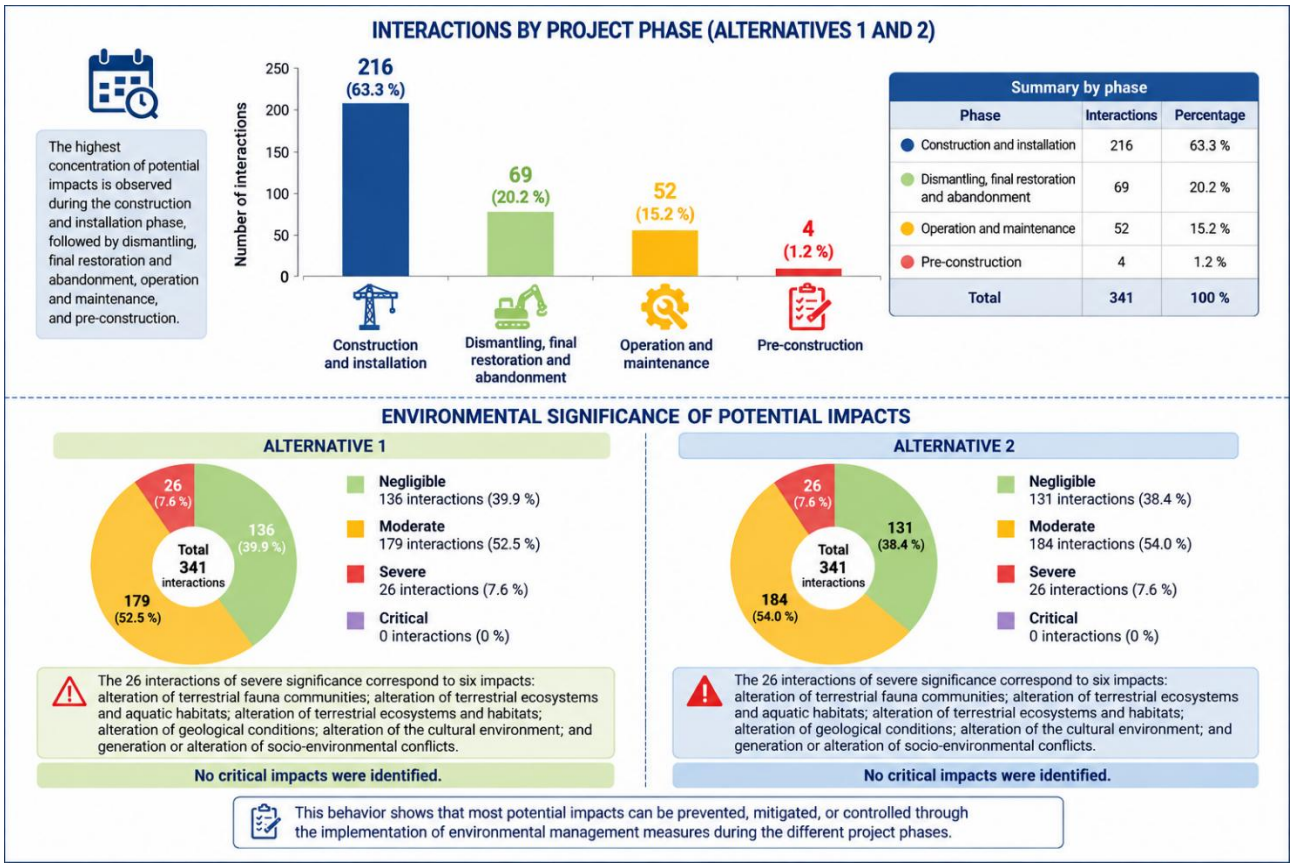
4.3 Assessment of Potential Environmental Impacts

The comparative environmental assessment made it possible to identify and evaluate the potential impacts associated with the two alternatives of the AkuaippaHy project, considering the pre-construction, construction, operation, and decommissioning stages, as well as the abiotic, biotic, and socioeconomic environments. The alternatives share the core technological configuration of the production process but differ in the location and layout of the associated infrastructure.

For each alternative, 408 interactions were identified between project activities and the abiotic, biotic, and socioeconomic components, of which 341 correspond to negative impacts and 67 to positive impacts. The analysis focuses on negative impacts due to the alterations or changes they cause to environmental elements.

Of the 341 interactions associated with negative impacts, 63.3% are concentrated in the construction and installation phase, while the remaining 125 interactions (36.7%) correspond to the dismantling, final restoration, and abandonment; operation and maintenance; and pre-construction phases. In terms of environmental significance, moderate and negligible ratings predominate. Additionally, 26 interactions with severe significance were identified (7.6%), and no impacts with critical significance were recorded.

Figure 13 Synthesis of potential impacts identified for each alternative



Source: Own elaboration with the support of artificial intelligence tools, based on technical information provided by Óptima Consultores S.A.S. (2026).

Note: The expression "environmentally viable" included in the illustration refers solely to the preliminary result of the comparison and does not constitute a declaration of environmental viability.

The severe impacts are mainly associated with impacts on fauna, ecosystems and terrestrial and aquatic habitats, geological conditions, the cultural environment, and socio-environmental conflicts.

In **Alternative 1 – Puerto Brisa**, the main constraints are concentrated in the terrestrial environment, particularly due to the construction and operation of the Manaure–Puerto Brisa transmission line, whose greater length increases territorial occupation and interaction with natural vegetation cover, properties, access routes, and communities. As a relative advantage, it exerts lower pressure on the marine environment and offers greater flexibility associated with port infrastructure.

In **Alternative 2 – Puerto Bolívar**, the shorter transmission line reduces intervention in the continental territory; however, impacts associated with the marine environment and the socioeconomic component become more relevant, particularly due

to seawater intake, desalination, brine management, and interaction with Wayuu communities and their traditional uses of the territory.

The fact that the two alternatives have the same number of interactions does not mean that their effects are equivalent. The affected receptors, extent, location, and opportunities for prevention and management differ. The assessment makes it possible to differentiate the environmental and territorial profiles of the alternatives. The selection should jointly consider the environmental, technical, logistical, water-related, and socio-territorial results and subject the prioritized alternative to more detailed studies.

The shorter transmission line associated with **Alternative 2** reduces the extent of linear interventions compared with **Alternative 1**; however, this condition does not eliminate the terrestrial impacts associated with the direct footprint of the other project components. In contrast, **Alternative 1** presents as its main challenge the development of a transmission corridor between the renewable energy generation areas located in Manaure and the industrial complex located in Puerto Brisas. This configuration involves a greater length of linear infrastructure and, consequently, greater potential interaction with the environmental and social components of the territory, making it the main differentiating element compared with the alternative located in Puerto Bolívar. Nevertheless, since this is infrastructure whose location, design, and management can be directly managed by the developer, this aspect is considered technically manageable through appropriate planning and optimization of the corridor, accompanied by timely land management and early engagement with the communities present in the area of influence.

Table 23 presents a summary of the environmental comparison of the alternatives evaluated.

Table 23 Summary of the environmental comparison of the alternatives evaluated

Criterion	Alternative 1 – Puerto Brisa	Alternative 2 – Puerto Bolívar	Assessment
Electrical connection	Dedicated Manaure–Puerto Brisa transmission line, with a reference separation of ~75 km and greater territorial occupation.	Connection line of approximately 13–15 km between generation and the industrial complex.	Favors A2
Abiotic environment	Greater terrestrial intervention due to linear infrastructure; lower pressure on the marine environment.	Lower terrestrial intervention; greater dependence on seawater intake and brine management.	No significant difference
Biotic environment	Greater interaction with vegetation cover, flora, fauna, and terrestrial connectivity.	Lower terrestrial impact; greater relevance of marine-coastal ecosystems and aquatic biota.	No significant difference
Socioeconomic environment	Greater land occupation and engagement associated with the transmission line.	Lower territorial occupation, but greater sensitivity due to interaction with indigenous communities.	No significant difference
Port infrastructure	Existing multipurpose infrastructure, subject to verification of the required modifications and access conditions.	Existing specialized infrastructure, subject to access agreements and the required modifications.	Favors A1
Industrial process and renewable generation	Same technological configuration; includes new solar and wind farms connected through a dedicated grid.	Same technological configuration; includes new concentrated solar and wind farms connected through a short line.	No significant differences
Environmental viability	No definitive exclusion was identified; management of the linear infrastructure must be demonstrated.	No definitive exclusion was identified; management of the marine and social components must be demonstrated.	Further studies required

Source: Own elaboration based on the comparative environmental assessment of the two alternatives. Óptima Consultores S.A.S. (2026).

Table 24 summarizes the main environmental and social risks. In Puerto Brisa, risks associated with terrestrial intervention predominate; in Puerto Bolívar, the marine-coastal environment and the social component become more significant.

Table 24 Main environmental and social risks associated with the alternatives

Risk	Puerto Brisa	Puerto Bolívar
Territorial intervention	High	Moderate
Vegetation cover/habitats	High	High
Marine environment	Moderate	High
Social conflict	High	High
Third-party infrastructure	Low-moderate	High
Desalination/brine	Low	High
Cumulative impacts	High	High

Source: Own elaboration based on the preliminary identification of risks for the two alternatives. Óptima Consultores S.A.S. (2026).

Table 25 brings together the verifications that must be resolved before selecting an alternative. For Puerto Brisa, the environmental, land tenure, and social viability of the transmission corridor must be demonstrated; for Puerto Bolívar, the viability of the water-marine system, third-party infrastructure, and ethnic management must be demonstrated.

Table 25 Consolidation of assumptions, limitations, information gaps, and pending verifications

Alternative	Should be avoided	Must be demonstrated / verified
Puerto Brisa	Sensitive ecosystems, cultural sites, and sectors incompatible with the corridor.	Environmental, land tenure, and social viability of the transmission line.
Puerto Bolívar	Sensitive ecosystems, marine-coastal areas, and Wayuu cultural sites.	Viability of seawater intake/desalination, brine management, third-party infrastructure, and ethnic management.

Source: Own elaboration based on the assumptions, information gaps, and verifications identified in the assessment. Óptima Consultores S.A.S. (2026).

5 Conclusions

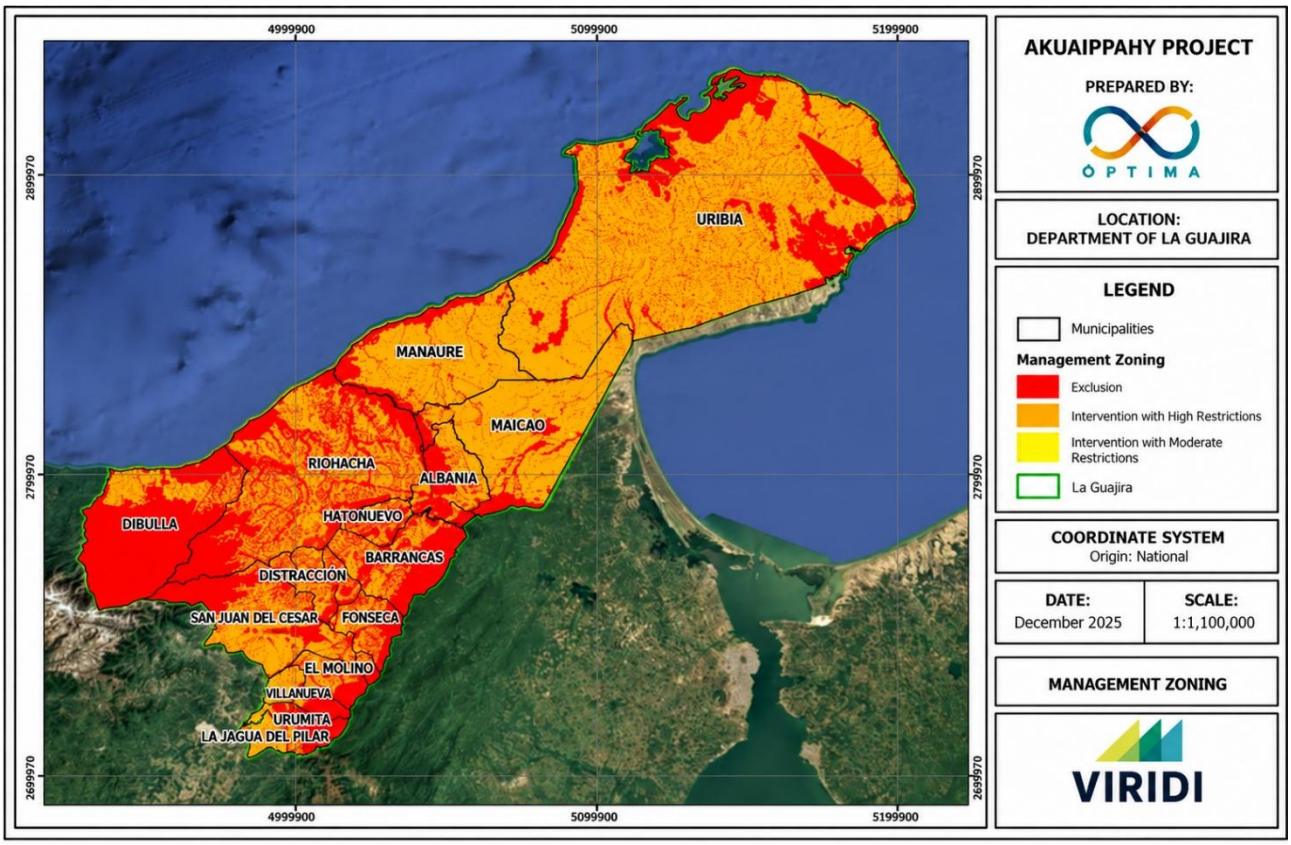
5.1 Territorial Constraints and Sensitivity

AkuaippaHy is subject to regulatory, environmental, territorial, institutional, and social factors. The overlap of environmental, sectoral, and land-use planning instruments may influence the project's location, configuration, and permitting pathway, as well as the timeframe and risks associated with its development.

Within this context, the main constraints are concentrated in the environmental, water-related, territorial, and socioeconomic components, mainly associated with the environmental sensitivity of the territory, the availability of water resources, and the presence of ethnic communities. These factors should be considered from the early stages of planning, particularly in defining location alternatives and technological configurations, as well as in identifying environmental licensing and social management requirements.

Figure 14 presents the environmental sensitivity map of the department of La Guajira. The results indicate that more than 99% of the territory falls within categories of environmental exclusion or high environmental restriction, representing a significant limitation for project interventions.

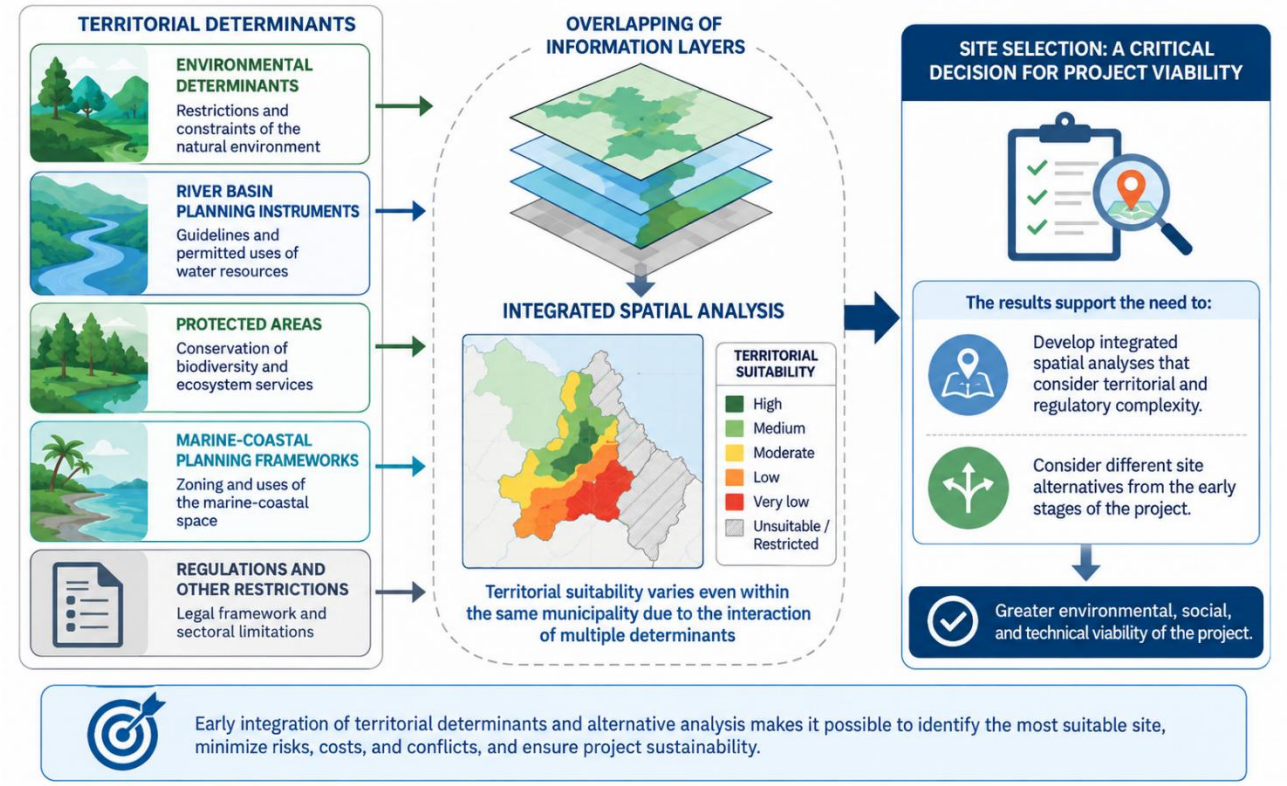
Figure 14 Environmental Sensitivity Map of the Department of La Guajira



Source: Óptima Consultores S.A.S. (2026).

Therefore, site selection constitutes a critical decision for the project's viability, given that territorial suitability varies even within the same municipality as a result of the overlapping of environmental determinants, river basin planning instruments, protected areas, and marine-coastal planning frameworks. In this regard, the results obtained support the need to develop integrated spatial analyses and to consider different location alternatives from the early stages of project development.

Figure 15 Importance of Site Selection



Source: Own elaboration with the support of artificial intelligence tools, based on technical information provided by Óptima Consultores S.A.S. (2026).

Additionally, institutional and regulatory management requires an anticipatory approach and coordination among sectoral entities, environmental authorities, and territorial authorities. The early definition of the project scope and the competent environmental authority is essential to guide the permitting and environmental licensing pathway, avoid rework, and reduce potential delays associated with administrative procedures.

Finally, disaster risk management is identified as a cross-cutting component with a significant impact on the development of H_2V/PtX projects in La Guajira. In subsequent stages, it will be necessary to further characterize natural and technological hazards, assess risk scenarios under extreme climatic conditions, evaluate local response capacities, and incorporate climate change projections, while also strengthening coordination with the National Disaster Risk Management System.

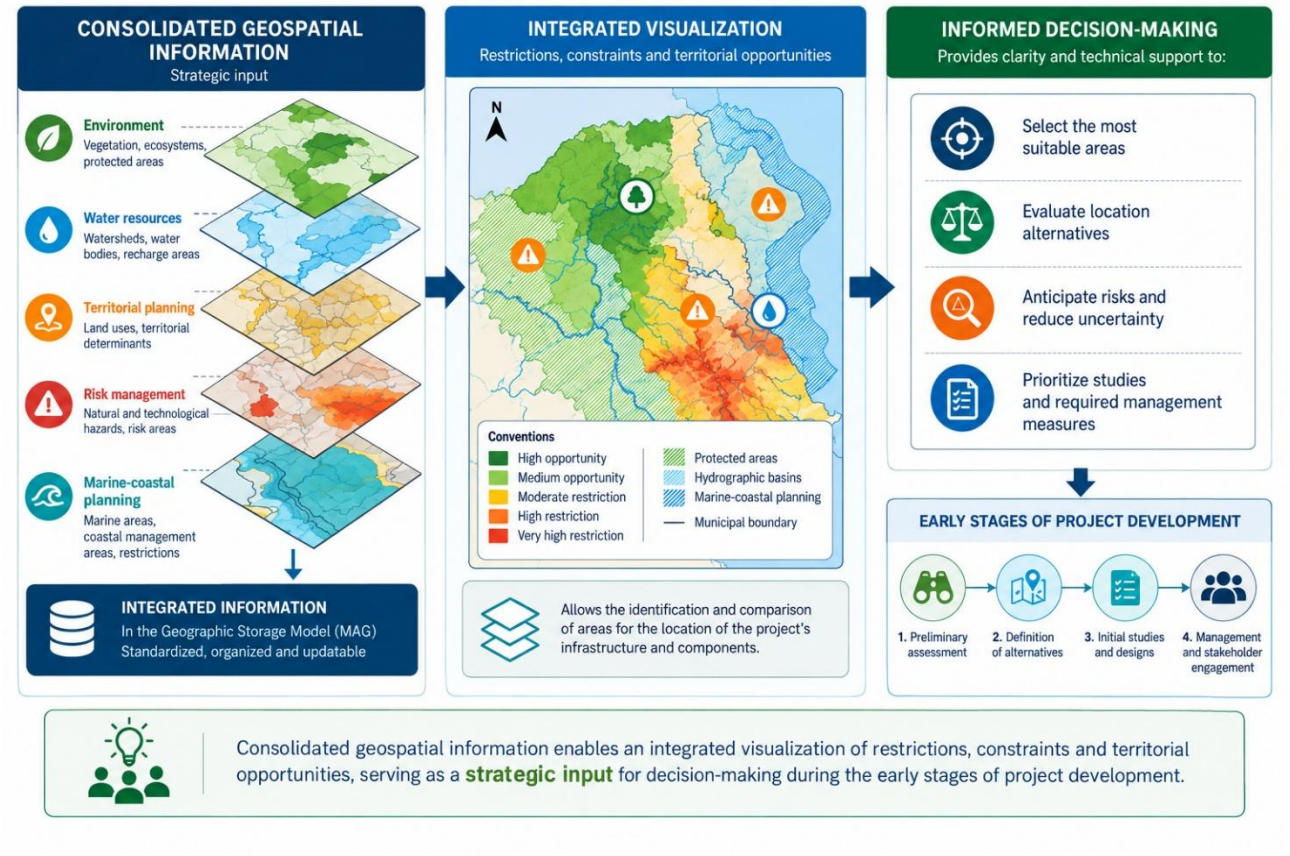
5.2 Geospatial Analysis and Site Selection Guidance

The geospatial analysis brought together physical, biotic, territorial, and zoning information within a single database. The Geographic Storage Model (MAG), thematic cartography, and synthesis layers enable the project's inputs to be consulted and updated and allow site areas to be compared using common criteria.

This information made it possible to identify areas with different levels of relative restriction. The zoning provides guidance for the multicriteria assessment of prioritized polygons and allows, from an early stage, the identification of areas where favorable conditions and restrictions that require further study overlap.

The result is a regional planning tool, not a site selection decision or a substitute for environmental studies. Areas with fewer restrictions should be validated using primary data, fieldwork, and specific analyses, particularly in hydrogeology, biodiversity, and social characterization.

Figure 16 Strategic Input for Decision-Making



Source: Own elaboration with the support of artificial intelligence tools, based on technical information provided by Óptima Consultores S.A.S. (2026).

5.3 Comparative Assessment of Alternatives

The assessment of the alternatives was based on a conceptual analysis and was developed with the purpose of identifying and comparing the environmental, territorial, technical, and social conditions associated with the two configurations proposed for the AkuaippaHy project. In this context, the assessment does not constitute an Environmental Impact Assessment (EIA), but rather a comparative analysis aimed at identifying the main differences between the alternatives and determining those aspects that may favor or constrain their development, as an input for selecting the alternatives with the most favorable conditions to advance to the subsequent stages of the project.

The comparative environmental assessment shows that the two alternatives analyzed present equivalent technological configurations, as they share the configuration associated with the production of green hydrogen (H_2V) and e-methanol, as well as the development of renewable energy generation and port infrastructure. The main differences identified between the alternatives do not arise from the production process, but rather from the territorial, environmental, and social conditions associated with the spatial configuration of each alternative.

The methodology for the assessment of the alternatives was based on identifying the components that comprise each conceptual alternative and the activities required during the construction, operation, and decommissioning stages. Based on this information, the potential interactions of each alternative with the abiotic, biotic, and socioeconomic components were analyzed, as well as with the elements associated with connection infrastructure, renewable energy generation, the industrial process, and port infrastructure.

To carry out the Environmental Management Zoning, guidelines approved and/or established by the National Environmental Licensing Authority (ANLA) for the department of La Guajira were used as a basis. Seven (7) licensed projects were analyzed, comprising one (1) hydrocarbon transportation project, two (2) electricity generation projects based on non-conventional energy sources (wind farms), and four (4) electricity transmission projects (transmission lines).

Alternative 1 – Puerto Brisa presents greater interaction with the terrestrial environment, mainly as a result of the electrical transmission infrastructure required to connect the renewable energy generation areas with the industrial complex. The greater length of the infrastructure routes implies more extensive territorial occupation and greater potential interaction with vegetation cover, land use, landscape, ecological connectivity, and social stakeholders located along the corridor. However, this alternative presents lower relative pressure on the marine environment and fewer challenges associated with the components resulting from seawater intake and brine management.

Alternative 2 – Puerto Bolívar significantly reduces the intervention associated with linear infrastructure due to the shorter conceptual connection between the generation area and the industrial complex. This configuration reduces interaction with the terrestrial environment, particularly with natural land cover, land use, and ecological connectivity elements. However, constraints associated with the marine environment and the social component become more relevant, particularly those related to seawater intake, brine management, and interaction with Indigenous communities, such as the Wayuu, present within the area of influence.

Table 26 provides a summary of the comparison of the criteria for the alternatives.

Table 26 Summary of Comparison of Alternatives

Criterion	Alternative 1 – Puerto Brisa	Alternative 2 – Puerto Bolívar
Main pressure	Terrestrial environment	Marine and social environment
Linear infrastructure	Greater	Lower
Land cover/land use	Greater interaction	Lower interaction
Marine environment	Lower relative pressure	Greater importance
Social component	Fewer preliminary challenges	Greater sensitivity due to Indigenous communities
Port infrastructure	Greater preliminary flexibility	Requires agreements and modifications

Source: Own elaboration based on the comparative assessment of the alternatives. Óptima Consultores S.A.S. (2026).

Regarding port infrastructure, Alternative 1 considers the use of Puerto Brisa, a multipurpose facility that would require modifications for the storage and export of e-methanol. Alternative 2 considers Puerto Bolívar, whose use will depend on access agreements and project-specific modifications. Based on the information available, Puerto Brisa presents a preliminary advantage due to its greater operational flexibility; this condition should be confirmed in the next stage.

At the level of analysis reached, no condition was identified that would allow either alternative to be definitively ruled out. This does not constitute a declaration of environmental viability. Puerto Brisa will need to demonstrate adequate management of the linear infrastructure and its terrestrial interactions. Puerto Bolívar will need to demonstrate adequate management of the marine and social components, including water intake, brine, and relations with Indigenous communities.

The comparison also does not establish an absolute environmental superiority. Puerto Bolívar reduces linear infrastructure and terrestrial intervention, while Puerto Brisa presents lower relative marine pressure and, preliminarily, fewer social

constraints. The final selection should weigh these factors together with the technical, territorial, social, environmental, and implementation criteria.

Based on the results obtained, an integrated comparison of the alternatives was conducted, considering both the differences in their interaction with environmental components and the conditions associated with the infrastructure required for their development. To facilitate interpretation of the results, a comparative traffic-light assessment was used, as shown in Table 27, identifying the criteria that favor one alternative, those for which no significant differences are identified, and those aspects requiring particular consideration during the subsequent stages of design and planning.

Alternative 2 is favored by the shorter connection length, while Alternative 1 presents an advantage in terms of port infrastructure. For the remaining criteria, it is indicated that there are no significant differences or that both alternatives are viable.

Table 27 Comparative Traffic-Light Assessment of the Alternatives

Criterion	A1 – Puerto Brisa	A2 – Puerto Bolívar	Comparative Result
Connection infrastructure	Dedicated line ~75 km; greater territorial interaction.	Connection line ~13–15 km.	**Favors A2**
Abiotic environment	Greater terrestrial intervention, lower marine pressure.	Lower terrestrial intervention, greater marine interaction.	**No alternative favored**
Biotic environment	Greater interaction with terrestrial ecosystems.	Lower terrestrial interaction, greater relevance of the marine-coastal environment.	**No alternative favored**
Socioeconomic environment	Greater land occupation and territorial interaction.	Lower occupation, greater sensitivity due to engagement with Indigenous communities.	**No alternative favored**
Port infrastructure	Multipurpose port with potential for modification.	Port specialized in coal, requiring agreements and modifications.	**Favors A1**
Industrial process	Equivalent technological configuration.	Equivalent technological configuration.	**No differences**
Renewable energy generation	Solar at Puerto Brisa 1 and wind at Manaure, with dedicated connection.	Solar and wind concentrated at Puerto Bolívar, with a short connection.	**No differences**
Environmental viability	Viable, subject to the management of linear infrastructure.	Viable, subject to marine and social management.	**Favors Both Alternatives**

Source: Own elaboration based on the comparative assessment of the alternatives. Óptima Consultores S.A.S. (2026).

5.4 Considerations for Subsequent Stages

Based on the results of the comparative assessment of alternatives, the following aspects have been identified for further analysis during the subsequent stages of the project:

- Water resource availability and management: Further analyze water demand estimates, potential supply sources, their availability, and alternatives for efficient use, reuse, and management. For Alternative 2, particular attention should be paid to seawater intake and brine management.

- Connection infrastructure and territorial occupation: Define the alignment and final length of the connection lines, as well as the required easements, crossings, affected land covers, sensitive ecosystems, land occupation, and potential interactions with communities. This aspect is particularly relevant for Alternative 1 due to the greater connection length between Manaure and Puerto Brisas.
- Ecosystems and biodiversity: Further characterize natural and semi-natural land covers, flora, fauna, and ecological connectivity in the areas potentially subject to intervention. For Alternative 1, interaction with terrestrial ecosystems is more relevant, whereas for Alternative 2, further analysis should also focus on aquatic biota and marine-coastal ecosystems.
- Socioeconomic and territorial conditions: Define land occupation, territorial dynamics, the presence of Indigenous communities and peoples, and potential requirements for participation, stakeholder engagement, and social management associated with each alternative.
- Port infrastructure: Further assess the capacity, operating conditions, modification requirements, and feasibility of the port facilities for the storage and export of e-methanol. For Alternative 2, it will additionally be necessary to further assess access conditions, required agreements, and the specific modifications associated with the use of Puerto Bolívar.
- Land-use planning compatibility: Verify the compatibility of the proposed areas with land-use planning instruments, environmental determinants, areas of special environmental importance, and other applicable restrictions.
- Permits and regulatory requirements: Identify and define the permits, authorizations, procedures, and other regulatory requirements that may constrain the development of the components of each alternative.
- Disaster risk management should remain a cross-cutting component throughout the subsequent phases of the project. It is considered necessary to further develop the quantitative characterization of natural and technological hazards, assess risk scenarios under extreme climatic conditions, identify local response capacities and potential gaps, and strengthen institutional coordination with the National Disaster Risk Management System. The incorporation of climate change projections will improve the assessment of future conditions that may affect the technical, social, and environmental viability of H_2V/PtX projects.
- The results of the territorial and environmental assessment should be integrated with the progressive definition of the project footprint, technical corridors, water-related interfaces, and exclusion zones, seeking to ensure that the final configuration reduces territorial and environmental conflicts and facilitates the management of the required permits.

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