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Investigating inland waterway transport through a sustainable development perspective: a case study of Magdalena River (Colombia)

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World Maritime University

INVESTIGATING INLAND WATERWAY TRANSPORT THROUGH A SUSTAINABLE DEVELOPMENT PERSPECTIVE: A CASE STUDY OF MAGDALENA RIVER (COLOMBIA)

by

NATALIA LORENA CALDERÓN RIVERA

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A dissertation submitted to the World Maritime University in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy in Maritime Affairs

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This thesis is dedicated to my parents, Nancy and Eugenio, and my brother, Juan Sebastian, whose constant love, support, and guidance have shaped the person I am today. To my husband, Carlos, thank you for standing by my side through every challenge and for your unbreakable belief in me.

Esta tesis está dedicada a mis padres, Nancy y Eugenio, y a mi hermano, Juan Sebastián, cuyo amor, apoyo y orientación constantes han forjado la persona que soy hoy. A mi esposo, Carlos, gracias por estar a mi lado en cada reto y por creer inquebrantablemente en mí.

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Abstract

The development of transport systems significantly influences economies, growth, and welfare of populations. However, these systems can have negative consequences, such as water and air pollution, traffic congestion, noise, and biodiversity loss. To address these challenges, it is essential to implement strategies that mitigate negative effects while improving the environmental, social, and economic conditions of the population. In this regard, inland water transport (IWT) is globally recognized as a more sustainable transport alternative due to its high cargo load capacities and comparatively lower environmental and social impacts. In Colombia, the Magdalena River—the country's most important river basin—traverses approximately 1600 km from the south (Paramo de las Papas) to the Caribbean Sea, where two important seaports, Cartagena and Barranquilla, are located. It primarily contributes to the transportation of bulk cargo, including hydrocarbons, using barge convoys pushed by pusher boats. Additionally, smaller vessels provide passenger and cargo services, which are vital for accessing health-care, education, and mobility services in remote regions. This research is intended to comprehensively investigate IWT using a sustainable development perspective, both globally and locally, with a focus on the Magdalena River in Colombia. The study employs a mixed-methods approach, incorporating a systematic literature review, interviews, and survey.

The study identifies the three key elements of the IWT system – inland river ports, waterways, and inland fleets – and examines their characteristics. Additionally, it determines global barriers to and potential solutions for sustainable IWT development, with a particular focus on evaluating those relevant to the Colombian context. The findings indicate significant barriers, including governance issues, policy implementation challenges, inadequate infrastructure, technological deficiencies, and a lack of trained personnel in public entities. Moreover, the study identifies potential solutions, highlighting strategic planning, stakeholder integration, infrastructure optimization, and data generation (such as hydrological conditions, weather forecasts, vessel traffic, availability and status of infrastructure, among others) to facilitate decision-making. Finally, the results underscore the low implementation levels of environmental, social, and economic plans for sustainable IWT development on the Magdalena River, indicating a need for comprehensive and strategic interventions.

Key words: barriers, inland waterway transport, Magdalena River, solutions, sustainable development.

Abbreviations

B&R	Belt and Road Initiative
CEPAL	Economic Commission for Latin America and the Caribbean
GHG	Greenhouse Gas
GP	Governance and policy
GWP	Global Water Partnership
HR	Human resources
IMO	International Maritime University
IT	Infrastructure and Technology
IWT	Inland waterway transport
LNG	Liquefied natural gas
MG	Management
OECD	Organisation for Economic Co-operation and Development
OP	Operations
PIANC	World Association for Waterborne Transport Infrastructure
PPP	Public private partnership
RIS	River Information Service
SA	South America
SDG	Sustainable Development Goal
UNECE	United Nations Economic Commission for Europe

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List of papers included in this dissertation

Paper 1 (Published):

Calderón-Rivera, N., Bartusevičienė, I., & Ballini, F. (2024). Sustainable development of inland waterways transport: a review. *Journal of Shipping and Trade*, *9*(1), 3. https://doi.org/10.1186/s41072-023-00162-9

Paper 2 (Published):

Calderón-Rivera, N., Bartusevičienė, I., & Ballini, F. (2024). Barriers and solutions for sustainable development of inland waterway transport: A literature review. *Transport Economics and Management* 2: 31-44. https://doi.org/10.1016/j.team.2024.01.001

Paper 3 (Under review):

Calderón-Rivera, N., Bartusevičienė, I., & Ballini, F. (Unpublished). Barriers and solutions for sustainable development of IWT in Colombia: The Magdalena River case.

Paper 4 (Under review):

Calderón-Rivera, N., Wilmsmeier, G., Bartusevičienė, I., & Ballini, F. (Unpublished). Analysing sustainable development of inland waterway transport in Colombia: The Magdalena River case.

1. Introduction

Transportation plays a fundamental role in the socio-economic development of countries, particularly in vital activities such as commuting, energy supply, goods allocation, tourism and supporting a range of other key activities (Rodrigue, 2020b). However, the traditional transportation industry relies heavily on fossil fuels, leading to numerous environmental and social drawbacks that have been documented since the expansion of road networks in the 1970s. These issues are predominantly associated with pollution, traffic congestion and overreliance on non-renewable resources, thus presenting numerous challenges for the industry. As a result, the industry must establish strategies to promote its sustainable development (Schiller et al., 2010). In this regard, and understanding the relevance of transportation for the development of society, in 1987 the World Commission on Environment and Development posed the concept of sustainable development as meeting the needs of the present without compromising the resources of future generations (Brundtland, 1987). This definition has been widely applied to transportation development and sustainable transport systems, proposing a balance between environmental, social and economic aspects (Rohács & Simongáti, 2007).

Various authors argue that sustainable transport must ensure the basic needs of individuals and society, in an efficient and affordable way, but limiting the generation of emissions and waste, and reducing the consumption of non-renewable resources (Rohács & Simongáti, 2007; Schiller et al., 2010). Nevertheless, the pursuit of sustainable transportation requires innovative solutions intended to enhance performance across various modes, alongside implementing measures to mitigate negative externalities (Rodrigue, 2020a). These externalities are mainly focused on air, water, land and noise pollution, greenhouse gas emission, congestion, accidents, excessive land use, and other factors (Demir et al., 2015; van Lier & Macharis, 2014). Notwithstanding these challenges, transportation is a prerequisite for development, demanding exploration of sustainable alternatives to mitigate these issues. Consequently, modal shifts from road to rail and inland waterway transport (IWT) have gained relevance as strategies for fostering sustainable transportation. Furthermore, governments and international institutions, such as the European Commission, have formulated policies (for example, the European Green Deal and the Sustainable and Smart Mobility Strategy) and plans (e.g., NAIADES, NAIADES II, and NAIADES III) to encourage and incentivize the transition to alternative modes of transport (Jonkeren et al., 2019; Mihic et al., 2011). Several countries in Europe, the United States, and China have particularly strengthened their IWT systems, recognizing the socioeconomic and environmental benefits associated with such investments (Williamsson et al., 2020; Miciuła & Wojtaszek, 2019; Notteboom, 2012; Institute for Water Resources, 2012).

Wang et al. (2020) identified the most representative inland waterways in the world – based on to their bearing capacity and socioeconomic index – with the basins of the Rhine, Volga, Yangtze, Pearl, and Amazon ranking at the top. While much of the literature on sustainable development of IWT focuses on European or Asian countries, other developing countries (such as India, Indonesia, Nigeria and Nepal) have documented the state of their waterways, along with the challenges and solutions for their development (Achmadi et al., 2018; Emmanuel et al., 2018; Rasul, 2015; Trivedi et al., 2021). Nevertheless, despite South America possessing significant hydrological resources and relevant basins such as the Amazon, Orinoco, Paraná, and Magdalena, scientific research on IWT in the region is scarce. Moreover, the development of IWT in South America has been constrained by limited budgetary investment, as it has not been prioritized in public spending. This is further intensified by weaknesses in institutional and regulatory frameworks (Jaimurzina & Wilmsmeier, 2017).

1.1. Rationale of the study and research objectives

The development of IWT in countries with navigable rivers and waterways is relevant due to the multiple advantages it offers over road transport, especially in countries such as Colombia, where the development of rail transport is lagging due to governments' prioritization of the development of road transport (Quintero & Salomón, 2023). Currently, roads serve as the primary mode of transportation for hinterland connectivity. However, heavy reliance on automobiles has been linked to a host of social, economic, and environmental challenges (Table 1). These include greenhouse gas emissions; dependence on oil; traffic-related issues such as noise, visual intrusion and congestion; rising social health costs due to accidents and sedentarism; pollution; isolation of neighbourhoods; and disparities in social and accessibility levels, among others (Schiller et al., 2010).

Table 1. Challenges related to dependence on automobiles.

Environmental problems	Economic problems	Social problems
• Oil vulnerability • Urban sprawl • Photochemical smog • Acid rain • High greenhouse gases – global warming • Greater storm water runoff problems • Traffic problems: noise, neighborhood severance, visual intrusion, physical danger • Decimated transit systems	• Congestion costs • High urban infrastructure costs for sewers, water mains, roads, etc. • Loss of productive rural land • Loss of urban land to pavement • Poor transit cost recovery • Economic and human costs of transportation accident trauma and death • High proportion of city wealth spent on passenger transportation • Public health costs from air and other pollution • Health costs from growing obesity due to sedentary auto lifestyles	• Loss of street life • Loss of community in neighborhoods • Loss of public safety • Isolation in remote suburbs with few amenities • Access problems for those without cars or access to cars and those with disabilities • Road rage • Anti-social behavior due to boredom in car-dependent suburbs • Enforced car ownership for lower- income households • Physical and mental health problems related to lack of physical activity in isolated suburbs

Note. Adapted from Schiller et al. (2010).

Given the drawbacks associated with road transportation, IWT has now emerged as a prominent and valuable mode of internal transport, gaining recognition globally for its potential to facilitate sustainable hinterland operations (Kotowska et al., 2018). Indeed, IWT offers numerous advantages, and is widely recognized as the most environmentally friendly mode of transport, primarily due to its low greenhouse gas (GHG) emissions (Jonkeren et al., 2019). In fact, greenhouse gas emissions measurements for IWT are estimated to be approximately 40 per cent lower than those of road transport (Hofbauer & Putz, 2020). Another important matter is that IWT consumes about 75 per cent less energy than road transport; while noise pollution and land use are lower than other hinterland transportation modes, and water transport emits five times less CO_2 per ton/km than road transport (Gołębiowski, 2016; Hofbauer & Putz, 2020; Mihic et al., 2011). Furthermore, IWT boasts a high carrying capacity per vessel unit, and is considered as one of the safest modes of transportation, characterized by low incidence of fatalities or injuries (Rohács & Simongáti, 2007). Additionally, from an economic perspective, IWT is the most cost-effective mode of transport, and it incurs fewer external costs than road transport (Gołębiowski, 2016; Maternová et al., 2022; Mihic et al., 2011).

Wang et al. (2020) presents the most significant inland waterways based on their bearing capacity and socioeconomic index, including the Mississippi, Rhine, Volga, Yangtze, Pearl, Amazon, Ganges, Rhone, and Congo. These waterways largely correspond to countries with the most extensive inland waterway networks (Table 2). Moreover, Table 2 indicates that of the 15 countries with the longest waterways in the world, 5 are situated in South America, with Colombia ranking sixth worldwide and second in the region. However, far too little attention has been paid in the literature to IWT in Latin America, despite the significant length of its navigable waterways.

Table 2. The 15 countries with the longest waterways in the world

Country	Navigable length (km)
China	110000
Russian Federation	102000
Brazil	**50000**
United States	41009
Indonesia	21579
Colombia	**18000**
Vietnam	17702
Democratic Republic of the Congo	15000
India	14500
Myanmar	12800
Argentina	**11000**
Papua New Guinea	11000
Plurinational State of Bolivia	**10000**
Peru	**8808**
Nigeria	8600

Note. Adapted from Konings & Weigmans (2019).

Given the aforementioned factors, and considering that road transport entails serious environmental, social, and economic implications, but at the same time recognizing that the development of robust transport systems is a priority for the well-being and development of societies, sustainable solutions are needed for hinterland transport, within which IWT is a key tool to reduce the externalities previously exposed. In Colombia, the Magdalena River has a strategic location as it runs through 25 per cent of the national territory, traversing 724 riverside municipalities that house 65 per cent of Colombia's population (Figure 1) (Restrepo et al., 2005; Silva, 2009). Historically, the Magdalena River was considered to be the main route for transporting cargo and passengers, and enabling the social and economic development of the interior of the country. However, with the rise of road transportation, the development and strengthening of the IWT has significantly declined. Hence, the aim of this research is to comprehensively investigate IWT transport from a sustainable development perspective. For this purpose, this research is divided into two phases. The first explores the concepts of IWT in general and describes it from a systems perspective (Ackoff et al., 1984; Ackoff & Gharajedaghi, 1996; Fieguth, 2021; Meadows, 2008). The second review and categorize the main barriers and potential solutions at global level, using a force field theory approach (Hayes, 2022; Lewin, 1947). The second phase uses the results of the first stage as a reference point to analyse the Colombian case focused on the Magdalena River, and propose a framework of potential solutions to overcome barriers to its sustainable development.

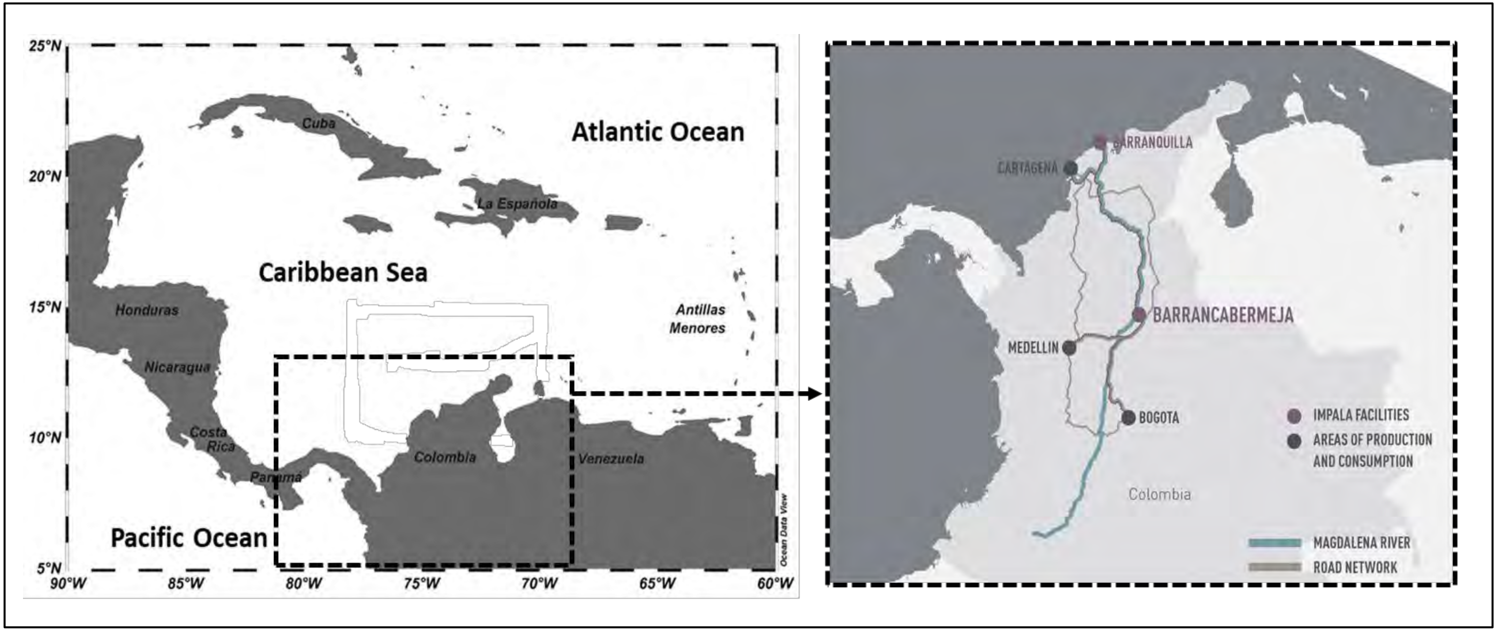

Figure 1. Geographical location of the Magdalena River
Note. Adapted from Calderón (2017) and Impala Terminals (2021).

To achieve the aim, three research objectives were formulated:

1. To explore the concept of sustainable development from an IWT perspective.
2. To identify and analyse the barriers and potential solutions to developing sustainable IWT from a general perspective.
3. To contextualize the barriers and potential solutions for developing sustainable IWT in the case of the Magdalena River.
4. To explore the current situation of sustainable development of IWT in the case of the Magdalena River.

An overview of the research is provided in the Figure 2. System theory concepts are employed to describe the IWT system and its constituent elements (Objective 1). Additionally, principles of sustainable development are applied for understanding and defining sustainable IWT systems, as well as for applying these characteristics to the selected case study. Force field theory, derived from change management, is also integrated into the research to develop a conceptual framework, both for IWT worldwide (Objective 2) and specifically for the Magdalena River case, using empirical data (Objective 3). Furthermore, the study presents the current status of Magdalena River using sustainable development perspective (Objective 4). This conceptual framework was instrumental in building a knowledge base to identify potential solutions for overcoming the barriers to sustainable IWT development on the Magdalena River, Colombia.

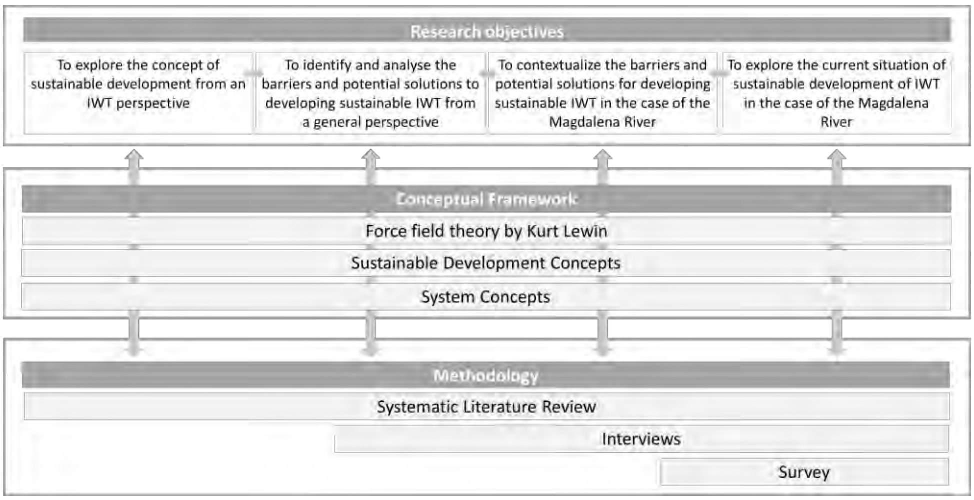

Figure 2. Overview of the research

The methodology of the research included a systematic literature review that helped to comprehend and develop the general understanding of the barriers and potential solutions towards the sustainable development of the IWT. However, to enrich the findings from the limited literature available on inland waterways and navigable rivers in South America, the interviews were conducted to provide insights of different local stakeholders on the current situation of the Magdalena River and to analyse the definitions of sustainable development in the context of developing countries. Finally, a survey was carried out to validate the results obtained, and to assess the current state of IWT on the Magdalena River (Figure 2).

This dissertation begins with a kappa, which provides a comprehensive explanation of the research, including the conceptual framework and methodology employed, followed by a summary of the results, discussion and conclusions. Additionally, it contains four academic papers that contribute to achieving the research aim and objectives. Paper 1 provides an overview of the IWT system, its drivers, and the characteristics of sustainable development as outlined in the literature. Paper 2 identifies, classifies and analyses the main barriers and solutions for IWT globally. Building on the general understanding of sustainable IWT developed through the literature review, Paper 3 employs empirical analysis to describe the primary barriers and potential solutions for the sustainable development of IWT in the case of the Magdalena River. Finally, Paper 4 proposes definitions for the elements of the IWT system, and presents assessment results of the implementation level of various characteristics of a sustainable IWT system.

1.2. Scope

The research adopts a mixed methods and transdisciplinary approach to understanding the concept and characteristics of sustainable development of IWT, along with identifying key barriers and potential solutions. Nevertheless – given the relatively scarce academic research of Latin American waterways, particularly in Colombia – the author seeks to explore barriers and potential solutions observed in other regions to provide a frame of reference for comprehending and evaluating the case study of the Magdalena River in Colombia, by triangulating systematic literature reviews, interviews and survey.

Furthermore, as the research is framed in the concept of sustainable development, environmental, social and economic issues are addressed in a transdisciplinary manner, including disciplines such as economics, sociology, political sciences, geography, anthropology, demography, technology, ecological economies (Becker et al., 1997; Kastenhofer et al., 2011). The above understanding that transdisciplinarity is significant and useful in addressing societal challenges, and is considered an appropriate approach when researchers must approach problems in a way that enables (1) understanding of the complexity of the problem, (2) consideration of various perspectives on the issue, (3) connecting theoretical and specific knowledge, and (4) generating descriptive, normative, and practical insights that advance collective welfare (Pohl, 2011). The above is aligned with the focus and methodology of the research, which seeks to propose a framework of potential solutions to overcome barriers to sustainable development of the IWT system in Colombia (the Magdalena River).

From a geographical perspective, Colombia encompasses numerous hydrographic basins, with notable rivers such as the Amazon, Orinoco, and Putumayo forming its borders. However, this study has narrowed its focus onto the Magdalena River, recognized as the country's primary and longest waterway. However, the author acknowledges that many of the analyses and findings proposed in this study can be extrapolated, not only to other rivers within Colombia but also to navigable rivers worldwide, particularly in developing countries where the advancement of IWT is not yet in an advanced stage.

2. Theoretical Foundations to Conceptualize (define) Sustainable Inland Waterway Transport

2.1. Theoretical approach

The utilization of theories in the social sciences is vital, as it provides a foundational framework for understanding social phenomena and interpreting collected data (Bryman, 2016). Grunwald (2015) outlined four key functions of theories in the scientific process and the advancement of science. First, theories enable the description and delineation of observed objects from a unified perspective. Second, they facilitate the abstraction of concrete singularities into general concepts, aiding the inductive understanding of commonalities and generalities within specific cases. Third, theories promote conceptual, logical, and methodological coherence, thereby facilitating the systematization of knowledge. Last, they enable the abstraction and integration of knowledge, enabling the interpretation of new starting points for innovative research.

In the context of inland waterway transport, systems theory, sustainable development concepts, and Force Field Theory work together to build a comprehensive framework for guiding the study of sustainable development of IWT systems from a general perspective and with the focus on the Magdalena River case.

First, systems theory concepts provide a holistic understanding of IWT as a system and give the basis to identify the elements and factors that constitute the IWT system, showing how economic, social, and environmental factors interact within the system and broader with other transport means and the logistics network. By applying systems concepts, stakeholders can anticipate unintended consequences, recognize interdependencies, and design more resilient and adaptive transport systems. Second, sustainable development concepts provide a foundational basis for action through principles of normativity, urgency, participation, and interdisciplinarity, which guide balanced approaches to economic, social, and environmental considerations, promoting equitable and responsible growth. Sustainable development concepts, also focuses on managing the trade-offs and synergies between economic growth (making IWT profitable and competitive), social inclusion (ensuring fair access to transport benefits), and environmental protection (minimizing the ecological damage and preservation of biodiversity). Lastly, force field theory offers a clear lens to analyse the forces that either push IWT towards sustainability or hold it back, also, it contributes to the contextualization and understanding of specific cases, such as the Magdalena River, by identifying the forces that drive or restrain change, enabling strategic reinforcement of positive drivers and proposed solutions, and reduction of barriers that create resistance to sustainability initiatives. For instance, policies supporting infrastructure improvement, greener technologies and modal shift act as driving forces, while financial costs, lack of business models, or infrastructure inertia serve as restraining forces.

Incorporating these theoretical foundations into the research provide a framework to establish a comprehensive and practical basis for analysing sustainability of IWT systems. Through this approach, the author not only outline the definition of sustainable IWT system, but also the drivers, barriers and actionable strategies to support its sustainable development, making the framework an indispensable tool for understanding and advancing the future of inland waterway transport. Thus, the framework serves as a tool for deepening the understanding of IWT systems, outline barriers and solutions in a general perspective using approaches from several waterways worldwide, and finally contextualizing it in the Magdalena River in Colombia. The theoretical approach described above will be elaborated on in the subsequent sections.

2.2. Theorizing sustainability

The terms “sustainability” and “sustainable development” have been used for the past three decades. However, some authors express doubts about considering sustainability as a conclusive theory, given its diverse structures and processes, suggesting that attempts to establish a rigid theory may be unsuccessful (Enders & Remig, 2014). Nevertheless, if such a theory were to be formulated, it should elucidate how, where, and when transformations toward sustainable development can occur (Enders & Remig, 2014). Moreover, it should also consider bifurcation points and windows of opportunity (Jahn, 2014), with the goal of achieving consensus between theoretical frameworks and practical applications (Grober, 2014).

In this context, Enders & Remig (2014) explain that, rather than being a uniform concept, sustainability serves as a guiding principle that must consider the social and cultural contexts of the region where it is being implemented. This aligns with the viewpoint described by Grunwald (2014), who emphasizes the need for a flexible model that encompasses not only the dynamics of sustainability-related issues but also considers factors such as spatial, temporal, social, cultural, and geographical diversity, among others. Furthermore, Grober (2014) suggests that sustainability is not an ultimate destination but rather an orientation for an uncertain future.

The discussions on rigorously defining sustainability or conceptualizing sustainability theory continue over more than two decades. For example, Enders & Remig (2014a) highlight the controversies surrounding the precise definition of its goal orientation and the methods for translating its objectives into action. The authors argue that sustainability encompasses more than just indicators for emission reduction; rather, "it is about a shared vision, political strategies, lifestyle changes and new social practices" (Enders & Remig, 2014a, p. 10), predominantly approached from a holistic perspective. Furthermore, the aspect of application of sustainability and its use in practice is not clear. However, accurately defining the concept of sustainability might facilitate the decision making processes for proper evaluations and political decisions (Grunwald et al., 2014).

On the other hand, according to Jahn (2014) comprehension of the characteristics of sustainability might be approached from three perspectives. First, sustainability refers to ensuring the continuity of processes rather than achieving an ultimate condition. Second, sustainability presents a unique set of complex integration challenges. Third, sustainability considers the needs that must be sustained for the process to continue, or the patterns and relationships that must be maintained amid changing conditions. The final aspect emphasizes a knowledge-oriented approach that enables the evaluation of objectives, their development, and the prevailing conditions. Furthermore, Jahn (2014) posits that the sustainability discourse has three levels. Firstly, the normative level encompasses what is considered desirable for contemporary society and what actions should or could be taken in the future, including considerations of inter and intra-regional justice. Secondly, the operative level involves the translation of knowledge into practical actions, prioritizing feasibility over desirability. Lastly, the descriptive level involves analysis of conditions and trends, determining which are sustainable and which are not.

However, Ekardt (2014) contends that a comprehensive definition of sustainability should involve six levels, as illustrated in Figure 3. These levels begin with (1) a precise definition of the term "sustainability" followed by including (2) a descriptive analysis of the current situation, (3) an understanding of external factors and motivations, (4) an examination of why sustainability is desirable and to what extent it is necessary from a regulatory standpoint, (5) consideration of conflicting interests, and (6) the involved institutions and the flexibility of decision-makers.

Moreover, Ekardt (2014) emphasizes the importance of addressing aspects of financing, governance, and frameworks that serve as points of reference.

Figure 3. Levels to define sustainability
Note. Adapted from Ekardt (2014).

On the other hand, Ziegler & Ott (2017) describes the key characteristics of sustainability science, which according to them should not be viewed as sustainability measurement indicators or tools. Instead, the characteristics should be utilized to comprehend the background and context in which practical problems are studied, including their values and principles, the temporary nature of their needs, the inclusion of non-scientist and the relationship between natural and social relationships (Table 3). Additionally, Parodi (2014) argues that sustainability discourse encompasses a diverse array of aspects, and has been applied and contextualized in various ways, including as a political strategy, a model for globalization, an economic paradigm, a corporate strategy, a cultural and social critique, a theory, and a scientific paradigm. Parodi (2014) further stresses the significance of understanding cultural aspects and perspectives, as differences exist in the forms of recognition and implementation. This includes the incorporation of art and education into sustainable development efforts, as well as lifestyles that promote sustainable consumption.

Table 3. Four features of sustainability science

Features	Description
Normativity	Values and principles
Urgency	Temporality of research and current events
Participation	Inclusion of non-scientist
Interdisciplinarity	Relationship between nature and society

Note. Adapted from Ziegler & Ott (2017).

Various authors have emphasized the relevance of including non-scientists as part of an extended peer review process, and propose some epistemological, political and ethical arguments for their inclusion in sustainability science, as shown in Table 4 (Ziegler & Ott, 2017).

Table 4. Arguments for non-scientific inclusion

Arguments		Inputs
Epistemological	Local knowledge	Relevant for problem formulation and applying contextual knowledge
	Bias	Helps to expose the limits of science and lack of practical knowledge (paradigmatic view).
	Self-criticism	Engenders criticism from outside perspective and challenging scientific claims
	Alertness	Novel challenges that usually does not fit in a theoretical outlook
	Conjectures	Openness to new conjectures through unexpected questions and observations
Political	Care and concern	Most affected are more concerned and likely to care the most about understanding and resolving practical problems
	Timing	Understanding of timing in practical problems and its urgency
	Power	Power of non-scientists to communicate and policy implementation
Ethical	Normativity	Scientists should not have authority in moral matters

Note. Adapted from Ziegler & Ott (2017).

In addition to non-scientific participation (Ziegler & Ott, 2017), interdisciplinary and transdisciplinary research are essential, as addressing the challenges of unsustainability necessitates solutions that comprehensively integrate interconnected social, economic, and environmental dimensions (Enders & Remig, 2014). Furthermore, Ziegler & Ott (2017) propose a linkage between the social and natural sciences, emphasizing sustainability as a transversal issue. This involves not only the inclusion of scientists but also interventions from non-scientists, along with timely considerations regarding the urgency of problems and ethical concerns related to transparency and regulations.

Finally, one of the primary constraints in transdisciplinary research on sustainable development is analysing strategies for maintaining developmental capacity within socio-ecological systems, especially in the face of challenging circumstances. At the same time, it is crucial to identify and foster alternative pathways that ensure the persistence of the ability to progress and remain adaptable in the future (Jahn, 2014). Moreover, Jahn (2014) describes four problem types of transdisciplinary research based on their knowledge and values consensus (Figure 4) and argues that complex problems such as sustainable development are situated in the fourth quadrant, "lack of system orientation and transformation knowledge", due to their weak value and knowledge consensus.

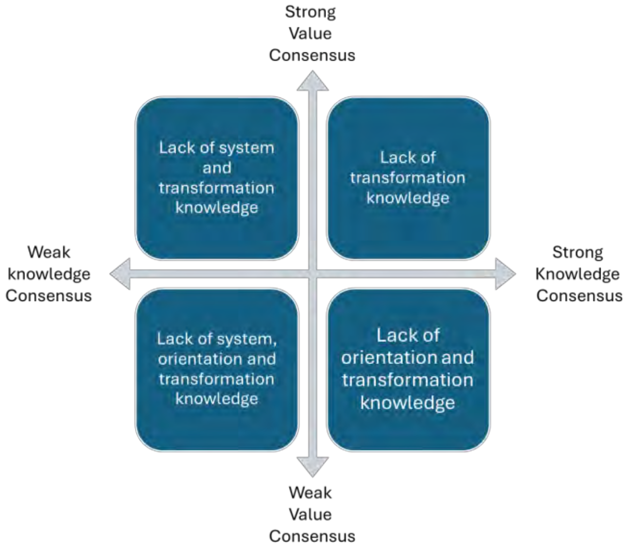

Figure 4. Basic understanding of transdisciplinary approach
Note. Adapted from Jahn (2014).

The analysis of sustainable development in the maritime transport sector has reached an advanced level compared to the research conducted for ITW. The maritime transport research mainly highlights advances in the implementation of strategies to mitigate environmental impacts, providing a comprehensive approach to sustainability, applying technological innovations and optimizing efficiency in ports and logistics chains (Song & Panayides, 2012). These strategies include the adaptation of the fleet for the use of alternative fuels and the integration of emission control technologies, such as liquefied natural gas (LNG), hydrogen, electrification, among others (Munim et al., 2023). The studies also highlight the transformation of ports into sustainable energy hubs as critical to reduce the sector's carbon footprint and to implement waste management and renewable energy technologies in these strategic environments (Bergqvist & Monios, 2018).

In addition, efforts to regulate internationally the negative impact of shipping on the environment have advanced significantly. For example, regulations on ballast water management and atmospheric emissions, together with the sustainability policies promoted by the International Maritime Organization (IMO), have been instrumental in setting global standards for ocean and environment protection. Although challenges remain, especially in developing countries, the establishment of an international regulatory framework has encouraged the adoption of sustainable practices and innovation in technologies that reduce pollution and conserve marine biodiversity (Braathen, 2011; David et al., 2015).

Sustainable development in maritime and inland waterway transport and the Sustainable Development Goals

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In 2015, the United Nations agreed on 17 Sustainable Development Goals (SDGs) with the aim to promote sustainable development in five critical areas: people, planet, prosperity, peace and partnership. Each goal possesses a specific set of targets designed to provide a consistent framework of rights and obligations of states under international law. In this regard, SDGs have gained relevance to transportation, and especially in some discussions about IWT, due to their significance for addressing various social, economic, and environmental challenges worldwide by 2030 (United Nations, 2015). In this context, the United Nations Economic Commission for Europe (2015) proposed a framework for conceptualizing transportation, by emphasizing key aspects–including safety, accessibility, affordability, and environmental sustainability–as outlined in the table below. It is important to note that these factors are not considered exclusive or exhaustive, but indicate the multifaceted nature of transportation (Table 5).

Table 5. Conceptualization of transportation using the SDGs

Goal and Target
SDG 3. Ensure healthy lives and promote well-being for all at all ages
3.6 By 2020, halve the number of global deaths and injuries from road traffic accidents
SDG 7. Ensure access to affordable, reliable, sustainable and modern energy for all
7.3 By 2030, double the global rate of improvement in energy efficiency
SDG 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
9.1 Develop quality, reliable, sustainable, and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all
9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries acting in accordance with their respective capabilities
9.a Facilitate sustainable and resilient infrastructure development in developing countries through enhanced financial, technological and technical support to African countries, least developed countries, landlocked developing countries and small island developing States
SDG 11. Make cities and human settlements inclusive, safe, resilient, and sustainable
11.2 By 2030, provide access to safe, affordable, accessible, and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons
11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage
SDG 13. Take urgent action to combat climate change and its impacts
13.2 Integrate climate change measures into national policies, strategies and planning
13.a Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly $100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible

Note. Adapted from United Nations Economic Commission for Europe (2015).

Although it is acknowledged that IWT can contribute to reducing some of the externalities generated by road transport, few publications specifically address the application of the SDGs to this mode of transport. For instance, Barros et al. (2022) selected some SDGs applicable to IWT, similar to those proposed in Table 5; however, SDGs 6 and 8 were included, as shown in Table 6.

Table 6. IWT issues according to environmental, social and economic dimensions and SDG goals

	Regional development	Traffic & safety	Port congestion	Vessel emissions	Extreme weather events	Urban waterways	Ship-induced wake	Port emissions	Multiple water uses	River morphology	Fauna disturbance	Stakeholder participation
	Economic			**Environmental**								**Social**
ustainable Development Goals												
.6 Road safety		X										
.9 Healthy air				X				X				
.5 Integrated water resource management									X			X
.6 Protect water ecosystems				X			X	X		X	X	X
.3 Energy efficiency				X								
.2 Economic productivity		X										
.3 Development-oriented policies	X											X
.1 Resilient infrastructure	X		X									X
1.2 Sustainable transport systems			X			X						
1.a Sustainable links between urban and rural areas						X						
1.6 Reduce per capital environmental impact						X						
3.1 Adaptation to climate-change hazards					X							
3.2 Climate change policy				X	X							

Note. Adapted from Barros et al. (2022).

The SDGs and their applicability to the Colombian case

Colombia possesses reports published by public institutions tracking progress towards certain achievement of SDGs nationwide. However, these documents lack a specific focus on IWT. Consequently, relying solely on the measurement of the SDGs would not provide sufficient insight into the complexities of sustainable development within the IWT sector, and this becomes even more complex when there is a lack of data in various aspects, as shown in Figure 5, where the spaces marked in grey indicate absence of information for the measurement of certain indicators.

Figure 5. Data gaps in the measurement of the SDGs in Colombia
Note. Adapted from National Planning Department (2024).

Given the above, this study will integrate the taxonomy associated with the SDG targets for IWT proposed by Barros et al. (2022) into the analysis. However, to provide a comprehensive framework for the assessment of IWT, additional aspects discussed by experts during interviews will also be incorporated and analysed. This inclusive approach will enable a deeper understanding and a clearer focus towards achieving the research objectives.

2.3. Change management theory

The concept of changes has been discussed by scientists (in academic literature) for several decades, but its more formal development began in the mid-20th century. Van De Ven & Poole (1995) observed a rich array of theories and concepts being deliberated among scholars regarding the dynamics of change within organizations, all with the shared objective of comprehending the processes or sequences of events that lead to change. To understand the change, a diverse range of theories and concepts from multiple disciplines were employed to comprehend the complexities of organizational change. This approach gave rise to a pluralistic theoretical landscape, and the emergence of isolated lines of research. In this sense, the authors put forward four main types of theories that explain changes in both social and biological entities: teleological, dialectical, life cycle, and evolutionary theories (Van De Ven & Poole, 1995).

The teleological model describes development as a cycle that ranges from the formulation of objectives, their implementation, evaluation and the modification of these objectives based on the learning acquired. On the other hand, the dialectical model arises when a series of theses and antitheses come into conflict, giving rise to a synthesis. Meanwhile, the life cycle model presents the process of change through a sequence of necessary steps, and the evolutionary model is defined as a competition for environmental resources that involves a sequence of variation, selection and retention of entities (Van De Ven & Poole, 1995). After analysing the four groups of theories, Hayes (2022) argue that these models have the involvement of a series of interconnected events, decisions, and actions in common, but they also differ in the degree of change, as well as in the essential steps and the level to which the direction of change is predetermined. Hayes (2022) also argues that life cycle and evolutionary theories are associated with change generated by a predetermined process that unfolds over time in a predetermined direction, whereas teleological and dialectical theories view change as a construct where goals and the steps to achieve them can be modified by the actors involved in the process.

In the case of teleological and dialectical theories, where individuals have certain freedoms to shape change trajectories, some challenges are identified. Changes in routines and movements towards attaining goals can be difficult to implement, often resulting in a reactive sequence or self-reinforcement loop. These challenges can be reduced through proactive event anticipation, threat comprehension, and resistance anticipation. In this case, stakeholder analysis is a valuable tool for understanding these challenges, while maintaining awareness to enable pivoting towards alternative actions across different courses of action (Hayes, 2022).

One of the ways to explain the change process in the organization is Lewin's three-stage model (Errida et al., 2021). This approach was taken into consideration to investigate the change generation process towards sustainable development of IWT. In this context, the barriers and potential solutions for sustainable development of IWT are viewed as driving and restraining forces within the model. The study seeks to examine these barriers and identify viable solutions to promote the sustainable development of IWT. In addition to Lewin’s approach, various models have been proposed in the literature to guide and implement change in organizations. Table 7 presents the main contributions from which various procedural and descriptive models have emerged. However, a holistic assessment needs to take place of the need for change, and various models should be used that address all the different factors and steps to follow (Errida et al., 2021; Mento et al., 2002).

Table 7. Change management model approaches

Lewin (1947) Three-stage model	Jick (1991) Tactical level model to guide the implementation of major organisational change	Kotter's (1995) Eight-step model for transforming organisations	Garvin (2000) The seven-step change acceleration process
1. Unfreeze 2. Change 3. Refreeze	1. Analyse the need for change 2. Create a shared vision 3. Separate from the past 4. Create a sense of urgency 5. Support a strong leader role 6. Line up political sponsorship 7. Establish an implementation plan 8. Develop enabling structures 9. Communicate and involve people 10. Reinforce and institutionalize change.	1. Establish a sense of urgency about the need to achieve change 2. Create a guiding coalition 3. Develop a vision and strategy 4. Communicate the change vision 5. Empower broad-based action 6. Generate short-term wins 7. Consolidate gains and produce more change 8. Anchor new approaches in the corporate culture.	1. Leader behaviour 2. Creating a shaded need 3. Shaping a vision 4. Mobilizing commitment 5. Making change last 6. Monitoring progress 7. Changing systems and structures

Note. Adapted from Errida et al., (2021) and Mento et al. (2002).

On the other hand, Hayes (2022) maintains that recognizing or anticipating the need for change is not enough to guarantee its implementation. Therefore, he proposes an intentional management of change supported by the perspective presented by Lewin in 1951, who describes the force field theory of change as the driving and restraining forces towards a desired change (Figure 6). The desired change refers to the movement of the forces from a quasi-stationary equilibrium to another, either increasing or decreasing forces towards the desired direction (Hayes, 2022; Lewin, 1947).

Figure 6. A force field
Note. Adapted from Hayes (2022, P18).

Based on the concepts presented by Lewin and the models developed from his contribution, Hayes (2022) proposes five key elements for the change management process, as shown in Figure 7. For the purposes of this research, the author seeks to utilize the force field model proposed by Lewin, and also the first two phases proposed by Hayes – recognition of the need for change and diagnosis of the needs for change – to formulate a vision of the future desired, which is in this case a sustainable state for IWT. This contribution will provide various decision makers and policy makers with a framework that allows them to understand the status quo and thus make informed decisions with a clear understanding of the desired state.

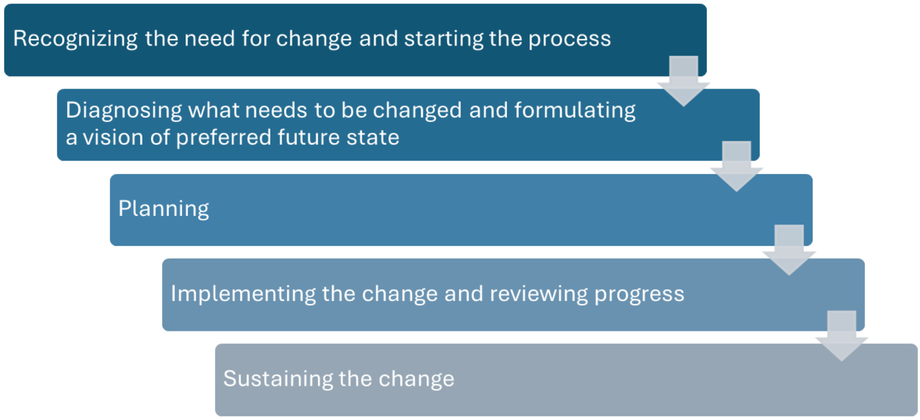


Figure 7. The change process
Note. Adapted from Hayes (2022).

The main ideas of Lewin's Force Field Theory were taken into consideration to investigate sustainable development of IWT. As presented in Figure 8 the change process consists of desired state, status quo, and driving and restraining forces. in this study, firstly, the "Desired State" outlines the characteristics projected for sustainable IWT. This is the ideal outcome or goal to strive for in the context of the Magdalena River Case. Secondly, the "Status Quo" provides an assessment of the current conditions concerning sustainable IWT development. It offers insight into the existing situation, serving as a baseline for understanding current barriers and potential solutions. Thirdly, the "Restraining Forces" are the barriers hindering sustainable IWT development, specifically challenges relevant to the Magdalena River Case. Lastly, the "Driving Forces" are the potential solutions towards sustainable development of IWT, particularly adapted to address the challenges faced in the Magdalena River region. Together, these elements provide a comprehensive framework for understanding and assessing sustainable development in the context of IWT.

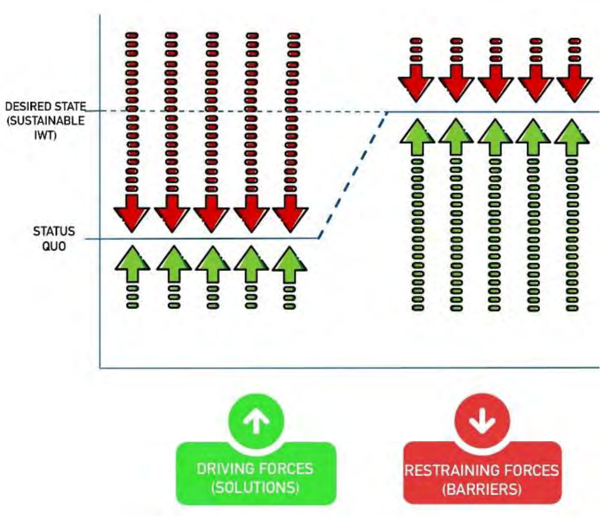


Figure 8. Force field theory applied to the research
Note. Adapted from Lewin (1947) and Hayes (2022).

For this purpose, a systematic review of the literature was initially carried out to understand the characteristics of, barriers to, and potential solutions for sustainable development of the IWT as presented in the academic literature. Subsequently, the author transferred that focus to the selected case study (Magdalena River) where interviews were carried out with experts from the stakeholder groups that are part of the IWT system. Following a qualitative approach for "exploring and understanding the meaning individuals or groups ascribe to a social or human problem" (Creswell, 2014, p.43), where the opinions of various experts were considered for initial construction of the force field diagram focused on the case of Magdalena River, followed by validation of the status quo through the development of a questionnaire.

2.4. IWT from a system perspective

This section introduces the concept of the system and its application in transportation, specifically focusing on IWT. It provides an explanation of IWT as a transport system, and elaborates on its main elements. Furthermore, relevant considerations regarding IWT in Colombia are addressed.

2.4.1. System and its elements

The definitions of systems found in the literature have been gathered from multiple disciplines, and there are several ways to classify systems (by discipline, size, location and functions, among others) although the choice is made depending on the purpose of use (Ackoff & Gharajedaghi, 1996). Jackson & Keys (1984) define a system as a group of at least two interrelated elements that are connected to each other in a direct or indirect way. From the author´s perspective this definition can be complemented by Ackoff & Gharajedaghi (1996), who defined a system as a "functioning whole that cannot be divided into independent parts". Moreover, systems are characterized according to how they interact with their surroundings; they can be open, closed, or isolated. In this regard, most human systems are open, given that societies are based on trade and the exchange of goods. Besides, every system possesses a boundary through which it interacts with the environment (Fieguth, 2021).

Ackoff (1994) identified and divided systems into three types: mechanic, organismic and social. Mechanic systems lack a purpose or parts; organismic systems occurs when the systems have at least one goal or purpose; and social systems are those that that are part of a larger system, have a purpose of their own and at least one of their essential parts also has a purpose. In this regard, institutions, organizations, and societies are considered social systems.

Another important notion proposed by Fieguth (2021) is the concept of *systems of systems* to refer to an interacting collection of systems that are not just a larger system. On the other hand, performance of the systems not only depends on the performance of the parts, but it also falls on the relationships between the elements of the system and its interactions. Therefore, the best way to interpret the problems and propose potential solutions to them is to obtain an interdisciplinary and inclusive perspective using different perspectives and points of view (Ackoff, 1994).

Given the above-mentioned points, the author defines IWT as a transportation system that possesses four main elements: first inland river ports, second fleets, third waterways, and finally ports (the explanation of the elements will be addressed in section four). In this respect, IWT can be considered more as a social system, as the system itself and its essential parts possess purposes. Furthermore, IWT acts as a system of systems as it belongs to the entire local transportation system which is a part of a global one. Moreover, IWT is considered an open system due to its interaction and exchange with the environment and other transportation systems: mainly road, maritime and rail transport.

2.4.2. Transport system

Transport plays a vital role in the global economy and fosters social interaction, making it one of the most important human activities worldwide (Rodrigue et al., 2013). Cascetta (2001) defined a transportation system as the "combination of elements and their interactions, which produce the demand for travel within a given area and the supply of transportation services to satisfy this demand". In addition to that, Rodrigue et al. (2013) suggest three essential concepts for transportation systems: *nodes, networks and demand*, in addition to three geographical considerations to support transport systems: *location, complementary and scale* (Figure 9).

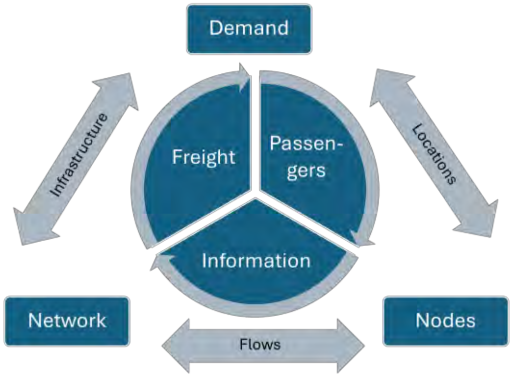


Figure 9. Transportation system
Note. Adapted from Rodrigue et al. (2013).

Transport systems consist of geographical, social, and economic components. Given their complexity, particularly in systems engineering, the elements are often isolated, and the most relevant ones are selected to form the basis of analysis (Cascetta, 2001). Transportation systems are strongly interconnected with other systems (Cascetta, 2001), and rely mainly on transportation modes; geographers have categorized these modes according to the medium in which they operate (water, land and air). Each one possesses specific characteristics and conditions, and requires some adaptations to meet transportation demand (Rodrigue et al., 2013). Rodrigue (2020) lists six modal options (air, truck, rail, maritime, inland/coastal and pipeline) as the most relevant for freight transportation (Table 8).

Table 8. Advantages and disadvantages of freight transport modes

Transport means	Advantages	Disadvantages
Air	High speed Operational flexibility Suitable for "just-in-time" distribution	More fuel-intensive Low cargo capacity Environmental externalities
Land (truck)	Flexibility and convenience of route choice Relatively high speed Low cost of the vehicles Low cost of transportation	Determining factor of road congestion High maintenance requirements Environmental externalities High operational costs More fuel-intensive Low capacity
Land (rail)	High transport capacity Meets the needs of heavy industries Using containerized cargo economies of scale can be reached Less fuel-intensive	Less flexible than road transportation due to scheduled services Low speed
Land (pipeline)	Low operating costs	Designed for a specific purpose (mainly oil and gas) Inflexibility
Water (maritime)	High transport capacity for long distances Less fuel-intensive Development of economies of scale	Low speed High capital costs Regular itineraries (Maritime routes)
Water (inland)	High transport capacity Less fuel-intensive Low costs and high transport capacity Good environmental performance	Limited to tourism in some regions Depth limitations High cost of investment for infrastructure and maintenance

Note. Adapted from Konings & Weigmans (2019) and Rodrigue (2020).

Differences in geographical markets, transport markets and levels of services ensure the complementarity of the different means of transport. Nevertheless, because of modal competition in some geographical areas, cost, time, level of service and frequency are critical factors when selecting a mode of transport. Given the advantages, disadvantages, and technological evolution of each system, as well as the increase in industry requirements, intermodal transport is seen as a pertinent tool to generate complementarity between transport systems. However, despite the recommended modal equality, there is competition between the various modes, mostly influenced by public policies, regulations and infrastructure financing (Rodrigue, 2020c). Despite the abovementioned differences, the ability to develop river navigation is unique for some privileged regions with adequate hydric potential. For this reason – and given the social and environmental benefits of river transport—this research will focus on analysing the characteristics, drivers and potential solutions to overcome the existing barriers to sustainable development of IWT both at general level and in the case of the Magdalena River.

2.4.3. IWT as a transport system

Van Dorsser (2016) characterized inland waters as regions of water that do not fall under the classification of 'sea'. This classification encompasses water bodies such as rivers, canals, lakes, and certain estuarine waters. Inland waterway systems serve a variety of socioeconomic and environmental roles, with the primary ones being the provisioning of freshwater, mitigation of flood risks, and facilitation of IWT (van Dorsser, 2016; van Vuren et al., 2015). Moreover, waterways also play a crucial role in supporting significant economic sectors, like tourism, agriculture, and industrial activities (Konings & Weigmans, 2016).

Seven important characteristics of IWT systems were listed by van Dorsser (2016): (i) depth and draught on the waterways, (ii) length and beam of inland vessels, (iii) bridge heights along the waterway, (iv) operational regime of IWT infrastructure, (v) wave and wind conditions, (vi) strength of the currents, and (vii) river ice events. However, the characteristics and properties of IWT differ all over the world: these variations are based on the condition of the natural structure of the rivers, the extent to which infrastructure (such as canals, bridges and dams) has been installed, or other specific interventions such as canalizing and dredging, and interactions with road and rail transport systems (van Dorsser, 2016; Wang et al., 2003).

Three main elements of the inland waterway transport system were identified. First, the waterways themselves, as the means to develop inland waterway transportation; second, inland fleet or inland waterway vessels; and the third element, which is divided into two categories: inland river ports and seaports, as the nodes or links to develop IWT operations. The graph shows that the three elements (ports, fleet and waterway) work together to enable cargo flow, the presence of each of them is essential for the system to correctly function. Although the elements persist in all waterways, there are marked political, social, economic, and geographic differences in each basin, making it necessary to understand the characteristics of each basin, as well as the barriers and applicable strategies for its sustainable development.

Waterway

The definition of integrated river basin management results from the concept of integrated water resources management (Rijke et al., 2012), which is defined by the Global Water Parentship as “a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems” (GWP, 2000). Because of the complexity and diverse functions of water basins—related to agriculture, transportation, tourism and other sectors—it is necessary to take a multidisciplinary and management approach from an integrated perspective (Havinga, 2020).

Zhaldak (2021) recognizes that the concept of management is broad and should be approached in a holistic way, with the intervention of numerous sciences, including aspects such as operation, planning, organization, motivation, and control. In this regard, the challenges of national public management today are abundant and require the interaction of many public and private stakeholders. Additionally, issues such as climate change, land use planning, economic growth, social services and education, among others, require the agreement of subnational governments, municipalities, and governmental institutions to settle regulations that promote the country's economic and social growth (O'Toole & Meier, 2011).

In the 1980s, ecological values were incorporated and the concept of "integrated water management" surges, but only in 1995—when extreme water level conditions caused a massive evacuation of people and cattle—did politicians, public water administrations and water professionals became aware of the need to implement new ways of managing rivers (Rijke et al., 2012). For the purpose of guaranteeing waterway transit conditions, various strategies have been developed to control water volume during drought and flood periods, using gates to reach adequate water levels that guarantees the continued use of the waterways (Nouasse et al., 2016).

So far, there is no rule of international law that obliges states to allow inland waterway navigation to third parties. In the case of rivers that share their course with different countries, the adoption of international conventions and commissions are vital tools for management and development of waterways (Reichert, 2016). For inland waterway administration, several authors have different perspectives. In the Netherlands a mixed centralized-decentralized government approach has reinforced integrated water management (Rijke et al., 2012). Other studies on the nature of hydrographic basins, whether national or international, have been completed. For international rivers in Europe, various organizations—including the United Nations, the European Union, river commissions, non-governmental organizations, and national governments—have introduced numerous policies and frameworks to promote IWT. These efforts, through multiple mechanisms, emphasize IWT's economic, ecological, efficient, and reliable benefits, and support the strengthening of technical standards for waterways, vessels, and crews (Mihic et al., 2011; UNECE, 2011). Nevertheless, countries such as Bangladesh, Bhutan, China, India and Nepal—which are connected by the Ganges system—require cooperative efforts for regional development through a shared perspective (Rasul, 2015).

Furthermore, countries that do not have shared basins face other challenges. In the United States—where the most important waterways are the Mississippi, Ohio, Illinois, Missouri, Tennessee, and Arkansas basins—inland navigation is supported by 191 locks with 238 chambers, the main cargo is dry and liquid bulk, the fleet comprises 31238 barges and 2789 push boats, and the average tow depends on the characteristics of the waterways. There IWT is founded on a "fuel-taxed inland waterway system", and the legal establishment is based on public and private liability. The United States Army Corps of Engineers is responsible for the physical infrastructure of the waterway, and the United States Coast Guard for aids to the navigation, vessel inspection and certification, and safety and security, as well as crew licensing and certification. Vessel construction and training facilities are the responsibility of private companies (Institute for Water Resources, 2012).

Ports (inland river ports and sea ports)

Global changes in production systems and variations in consumption markets, along with the global increase of supply chains, cargo movement and port expansion enabled the development of inland transportation and have strengthened the relationship between inland and seaports (Notteboom & Rodrigue, 2005; Witte et al., 2014). Currently, research on governance and management of inland ports and their spatial and economic impact on adjacent regions has gained academic relevance, as terminals are no longer passive elements and face enormous challenges in terms of capacity, efficiency and reliability (Rodrigue & Notteboom, 2009; Witte et al., 2019). Hence, inland regions require efficient physical cargo movement and information flow to compete in international trade, which in turn involves adequate intermodal connectivity and the development of rail hubs and barge terminals (Notteboom & Rodrigue, 2005).

Unlike inland ports, seaports and supply chains have received high attention among scientific researchers. Moreover, various authors have argued that there is no common consensus on the definition of inland ports, their roles and functions, because of the convergence of numerous factors such as their multiple geographical settings, their different functions, and the diversity of actors involved (Rodrigue et al., 2010; Wiegmans et al., 2015; Witte et al., 2019). Another important aspect in the literature is the difference between European and United States definitions of inland ports. Wiegmans et al. (2015) argue that European inland ports are defined as ‘places along a waterway with facilities for loading and unloading ships’ while North American ports refer to ‘larger freight sites with mostly rail terminals (and sometimes water) including surrounding business properties and an own governance structure’.

One of the first studies of inland ports was made by Slack (1999), who suggests the creation of satellite terminals as a solution for hub congestion, where only certain activities of the main terminals could be carried out, such as transfer of cargo, assembly of freight, storage, control and distribution. Thereafter, Notteboom & Rodrigue (2005) argue three phases of port evolution: setting, expansion, and specialization; and they propose the concept of port regionalization, which includes contemporary challenges such as emergence of hub terminals and the impact of inland freight distribution systems and port development. In addition, the concept includes a broader perspective on the geographical scope and emphasizes the strengthening of the link between the hinterland and foreland.

Subsequently, among shippers and logistics providers there is an increasing tendency to use terminals as a cheaper means of storage, and the concept of ‘terminalization of supply chains’ was introduced to describe the role of inland terminals as regulators of freight flows (Rodrigue & Notteboom, 2009). In view of the above, three main criteria were used by Rodrigue et al. (2010) to build a definition of an inland port: containerization (including activities such as consolidation, deconsolidation, transloading and manufacturing), a dedicated link (with a high-capacity corridor) and massification (able to handle larger volumes at lower cost). Conversely, Wilmsmeier et al. (2011) identify two directional development models of inland ports, the first is the 'Inside-out' model, based on promotion and cooperation strategies by inland carriage companies or public bodies, and the second 'Outside-in', about the development performed by port authorities, port terminal operators or ocean carriers. These proposed models have been applied in studies carried out in various regions in Latin America, Europe, and the United States (Wilmsmeier et al., 2011; Wilmsmeier et al., 2015).

From a general perspective, Witte et al. (2019) through a systematic review of inland port studies, classify three stages of port research, the first is the early stage (1992–2005) where port dynamics change from port congestion to port regionalization. Subsequently, the diversification stage (2006–2011) is characterized by a broader scope of inland ports and the introduction of the regionalization concept, while in the last contextualization stage (2012–2017) the research focus expanded from regionalization in various geographical contexts, to the development of Outside-in and Inside-out approaches, and planning and governance challenges. From the author's point of view, these concepts help planners and policymakers to review past lessons when considering future planning, management, and governance of inland ports.

Inland ports play a central role not only in the social and economic development of local regions but also in freight transportation, as it ensures shipping between inland areas and seaports (Zheng et al., 2020). Therefore, port authorities are called to understand and propose solutions for inland transport challenges: primarily congestion, growing costs, handling capacity and the generation of additional traffic (Notteboom & Rodrigue, 2005). Therefore, massification of flows, regular barge or rail service and diversity in type of goods are relevant characteristics of inland port performance, and their development is considered a beneficial strategy in port governance (Wiegmans et al., 2015).

With regard to inland port functions, Notteboom & Rodrigue (2005) describe them as loading centres or cargo bundling, cargo consolidation or deconsolidation centres and logistics zones. This concept was expanded by Rodrigue et al. (2010), who propose a three-tier functions system, the first related to transportation and involving satellite terminal, load centre and transmodal centre; the second considering supply chain, including consolidation and deconsolidation, transloading, postponement and light transformations; and the third to the market area and the commercial and manufacturing sector.

The need to expand the terminals dates back approximately 50 years, and on this basis new facilities have been built in rural areas, although this has not been enough for the pressures that freight transportation demands (Slack, 1999). Currently, this remains one of the main issues faced by national and international policymakers at global level, due to congestion and lack of available land in European, American, and Asian port cities (Notteboom & Rodrigue, 2005; Notteboom, 2012). This idea has been further developed by various authors, who highlight conflicting land uses as a multidimensional challenge – not only in seaports but also in inland port cities – and emphasize a reactive attitude and absence of urgency to face these demands in some governments. For instance, in China companies are looking for locations to manufacture upstream, as they have higher land availability and cheaper labour costs, and are closer to raw materials (Notteboom, 2012; Witte et al., 2014).

On the other hand, promotion of sustainable transport policies for a modal shift from road to IWT has gained relevance in the European Union in recent decades and is currently becoming a global trend. Those measures seek reduced port dues for ships with lower emissions, incentives for ships using low-sulphur fuel, prohibition of vehicles with high emissions, and also the development of environmentally sustainable and energy-efficient ports (Di Vaio et al., 2018; Kotowska et al., 2018). In this respect, Kotowska et al., (2018) identify, analyse and classify internal and external measures taken by ports in Europe to promote inland waterways. This approach suggests that policies on improving inland waterway infrastructure, quality of inland connections and administrative support are classified as external measures, while internal measures focus on improving barge infrastructure and creating an adequate information and promotion policy. In fact, governance strategies have been analysed along the Rhine–Alpine Corridor, among which the following stands out: cooperation between inland and maritime ports, the search for cooperation with small ports at intraregional level and the institutionalization of formal regulations; all these have been introduced to strengthen the development of the transnational corridor (Witte et al., 2016).

Currently, global growth of freight transport and the emergence of Asian and Latin American markets, is having an impact on freight movements, port selection and routing (Witte et al., 2016). In fact, China's role in global supply chains has been growing in recent decades, and regions upstream along the main rivers have increased their focus on social and economic development that strengthen international trade (Notteboom, 2012). Notwithstanding this, to overcome the challenges that that this entails, since 2000 various policies have been implemented with the purpose of stimulating the economy in the country, particularly the 'Go west' policy which seeks to stimulate local economies in the west, emphasizing the Yangtze River as key infrastructure for the economic development of the region, the Belt and Road Initiative (B&R, which improved the infrastructure to connect central and western provinces with eastern developed regions), and finally port integration to improve the efficiency of inland ports (Zheng et al., 2020). Despite this, IWT development and inland ports in China continue facing challenges of modal competition with rail and road transport. While it is true that the Three Gorges Dam allows year-round navigation along the river from Shanghai to Chongqing, there is a risk associated with water levels and conditions for freight transportation (Notteboom, 2012).

Fleet

The river fleet is made up of a wide variety of vessels, which can vary in size from small boats with outboard motors to large convoys that can carry thousands of tons, depending on the geographic and socioeconomic characteristics of the region. The largest inland waterway fleets in the world are found on the Yangtze, Danube, and Mississippi Rivers. The fleet used for IWT is mainly composed of two types of vessels. Self-propelled vessels are robust, relatively easy to build and can be operated by small crews. On the other hand, a barge convoy requires a power unit (pusher boat) and at least one load unit (barge), which makes them less robust in adverse weather conditions, and their construction cost is higher, but at the same time they have a higher load capacity and flexibility of coupling and uncoupling of barges, which enables them to achieve economies of scale and reduce fuel consumption per ton transported (Hekkenberg & Liu, 2016). Transportation by waterways is characterized as slow, which is why they are mainly used to transport bulk cargo. However, other types of cargo have entered the market: for example, since 1980 container transport has increased, as well as other types associated with transporting palletized cargo, aircraft segments and vehicles, especially in Europe.

According to Hekkenberg & Liu (2016), currently innovation on the IWT fleet is mainly driven by cost reduction, improving environmental performance, accessing niche markets, complying with new regulations, and adaptation to climate change. However, vessels used for IWT usually belong to small companies with low investment potential, which inhibits development and implementation of technologies on board (Bernardini et al., 2018; El Gohary et al., 2014; Hekkenberg & Liu, 2016; Koralova, 2017; Perčić et al., 2021; Sihn et al., 2015).

Technological advancements and innovative practices in the fleet are among the pivotal factors driving sustainable development of IWT. These aspects primarily encompass modernization of the fleet (Mihic et al., 2011; Tuan, 2011), adoption of alternative fuels and propulsion systems (El Gohary et al., 2014; Perčić et al., 2021), enhancement of vessel design for heightened efficiency (Bernardini et al., 2018; Koralova, 2017; Sihn et al., 2015), integration of autonomous navigation (Chen et al., 2016), and incorporation or enhancement of information and communication applications intended to support crew members to make optimal speed choices for fuel economy and understanding waterway meteorological conditions (Niedzielski et al., 2021).

In summary, this section provides an overview of the elements of the IWT system, and their characteristics. However, due to the particularities of each basin, it is important to study in depth the geographic, socioeconomic, environmental and governance conditions of each basin, in order to propose potential solutions that meet the distinct needs of each waterway. Therefore, the following section provides an overview of the current situation in Colombia and the Magdalena River, and later papers 1 and 2 will explore its characteristics, barriers and potential solutions in depth.

2.4.4. Overview of IWT: the regional and Colombian context

In South America, IWT holds significant potential to address current challenges in logistic performance, connectivity with remote areas, sustainable development, import-export activities, and others. It can foster the development of new economic activities and redirect cargo flows that are currently transported via roads (Jaimurzina & Wilmsmeier, 2017). Mesquita-Moreira et al. (2008) assessed the reasons for and consequences of the high costs of international freight, and underscored the importance of implementing policies to reduce these costs in Latin America and the Caribbean. Furthermore, their analysis revealed significant challenges posed by internal logistic chain costs, and the scarcity of data and studies focused on transport in the region. Moreover, Mesquita-Moreira et al. (2013) suggest that one of the most significant disadvantages faced by the region is the high cost of domestic trade for exports. Indeed, several countries such as Chile, Peru, Colombia, Mexico, and Brazil must transport their goods from central or southern regions to ports, covering distances ranging from 466 to 1800 miles, with elevations reaching up to 7400 feet.

Regional studies suggest that the potential of waterways must be complemented by national capacity to implement policies and regulatory frameworks. These frameworks should be based on relevant and reliable technical knowledge, and require coordinated efforts from both public and private entities. These efforts should not only focus on inland waterways and ports but also address other aspects such as the river fleet, crew requirements, traffic rules and regulations, pollution prevention, and logistics methods for transportation and storage systems, among others (Jaimurzina & Wilmsmeier, 2017). In Colombia, this deficiency has been identified in the “Fluvial Master Plan”, which outlines potential solutions for improvement but has not yet yielded significant results (Ministerio de Transporte, 2015).

Colombia holds a privileged geographical position due to its strategic location, bordered by the Caribbean Sea to the north and the Pacific Ocean to the west, the only such country in South America. Moreover, Colombia ranks sixth globally by largest extension of waterways, providing ample opportunity for the development of IWT through a robust river system. Among Colombia's rivers, Magdalena is characterized as having the greatest potential for IWT development, thanks to its bifurcation, enabling cargo movement from the centre of the country to two of Colombia's most important seaports (Barranquilla and Cartagena). Barranquilla, situated at the mouth of the Magdalena River, is the country's fourth most important port in terms of cargo volume, and is the largest inland seaport in Colombia. Moreover, it serves as a multimodal port city, offering both maritime and IWT services. Moreover, Barranquilla is considered the most important multipurpose port in the Caribbean, complemented by Cartagena and Santa Marta, which specialize in container transport and dry bulk, respectively (Otero, 2011).

One of the main drawbacks of hinterland transportation in Colombia is that most exportations proceed from Cundinamarca, Antioquia and Valle del Cauca, regions in the centre of the country. In some cases, ports are placed at a range of 1300 kilometres which generates an increase in the costs of the freight. For instance, metal products for export must be shipped from Villavicencio in the centre of the country to Cartagena the main port city: the route takes around 18 hours and covers a distance of 1,100 kilometres (Mesquita-Moreira et al., 2013). Moreover, Colombian exportation administrative costs are around 3.6 times higher than the average of Organisation for Economic Co-operation and Development (OECD) countries, and times for exportations are 8.6 times above the average. These facts explain why road transportation plays a major role in the supply chain despite high prices related to fuel and tolls (with percentages of 43 per cent and 21 per cent respectively) and the need to resume more affordable and sustainable alternatives, such as river navigation (Nope-Zambrano, 2020).

In recent years, there has been increasing interest in IWT in Colombia: it has been described as a fundamental basis to connect production areas with global markets, due to its competitive advantages compared to other means of transport, mainly road (Ramirez et al., 2019). Colombia possesses four important river basins: Orinoco, Amazonas, Atrato and Magdalena. In Colombia, fluvial activities are regulated by various national public entities and institutions operating under different ministries. For the Magdalena River – the research subject – alone, the government established a specific corporation due to its strategic location and interaction with the main seaports in the Caribbean coast.

Magdalena River is the most important fluvial system in Colombia, its basin occupies 24 per cent of Colombia's area, and it is the longest river (1,612 km), with the highest drainage area (257,400 km^2) and unfortunately one of the highest sediment transport rates in the world (Higgins et al., 2016). The last of these has caused serious issues for the navigation along the river. The IWT along Magdalena river dates from 1824, when the first steamboat ship, called "Fidelidad", arrived (Silva, 2009). Since 1848, export and import traffic became pertinent for steam navigation, with leather, tobacco, and coffee the most important products. After this, in the early twentieth century, due to the low draft level, the lack of government concern and the railway construction, inland navigation suffered a breakdown (Márquez, 2016). In the middle of the twentieth century, the surge of diesel engines, the acquisition of tugs and barges, and the creation of new regulations enabled an important change in the cargo transportation. Subsequently, in the mid-1980s, the three largest river transport companies merged, establishing themselves as leaders in the inland trade, while smaller companies remained active in the market. This fleet has specialized in liquid bulk, fertilizers, grains and coal (Silva, 2009).

The river was for centuries the main communication route between the interior of the country and the Caribbean Sea. It has been characterized by challenging natural conditions, such as the formation of sandbanks, pronounced seasonal variability affecting canal depth, and strong torrents that can cause flooding, among others. These characteristics have worsened due to human interventions, especially deforestation and ecosystem alteration (Márquez, 2016). During the seventeenth century, a navigation channel called “Canal del Dique” was constructed: a 113 km waterway connecting Magdalena River with Cartagena Bay. Its importance lies in the fact that a vast majority of petroleum products are transported from the interior of the country to Cartagena port (Aguilera-Díaz, 2006). Currently, Cartagena is the most important port in the country, and it is considered the fourth most important port in Latin America (CEPAL, 2018).

Historically, for Colombia, Magdalena River was the main communication route between the interior of the country and the Caribbean (Márquez, 2016) and it has been a symbol of development, growth and progress in the country (García, 2011). Its basin occupies 25 per cent of Colombia and is home to 724 riverside municipalities that account for 65 per cent of the country’s population (Figure 10) (Restrepo et al., 2005; Silva, 2009). Furthermore, the river is the basin of diverse ecosystem services within Colombia’s economy, most of which are associated with agriculture, livestock, electricity generation, regulation of ecosystems and river transport, the main subject of this research (Vilardy, 2015). In recent decades, the Government of Colombia has made important investments in the river corridor, including infrastructure projects, physical components and action plans; nevertheless, these are not enough to improve IWT and strengthen international trade based on exploitation of the river (Zamudio et al., 2019). In this context, developing physical structures is needed to enable efficient transportation of goods from the country outwards and vice versa, to satisfy intermodal and multimodal trade necessities through efficient use of Magdalena waterways (Otero, 2011).

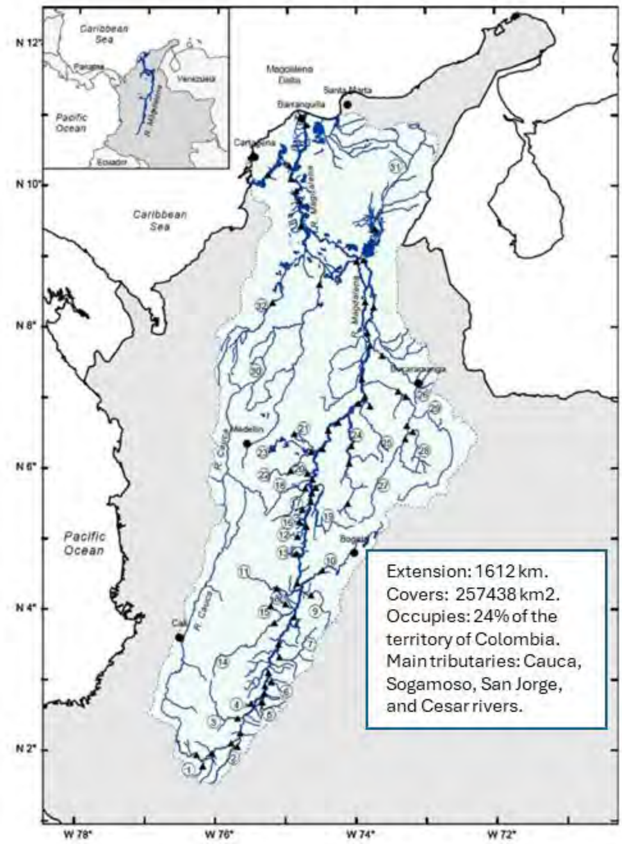


Figure 10. Magdalena River basin
Note. Adapted from Restrepo et al. (2006).

Although academic research in the study area is scarce, preliminary work on IWT recognizes the government's role in creating some public policies; however these have not been sufficient and research needs to be updated, adapted and commissioned regarding the current problems of IWT (Ramirez et al., 2019). Another significant concern is the lack of investment in river infrastructure. Despite the government's considerable economic expenditure, the development of IWT requires well-structured projects that ensure safe and uninterrupted navigation 24 hours a day (Zamudio et al., 2019). Furthermore, Chávez (2020) highlights the need to generate a legislative synergy in which institutional limits are established, since this generates scarce control of the river activities. In this context, the author describes the principal institutions that have direct or indirect influence in IWT management in the country in Table 9.

With regard to the regulatory framework, from the social, economic, legal and environmental perspective, various authors have exposed inappropriate inter-institutional coordination, lack of comprehensive management of administration of the basin, and the need for public and private actors to commit and contribute to strengthening these strategies (Chávez, 2020; Mogollon, 2015; Walschburger et al., 2015). These issues are clearly reflected in Table 9, where functions and responsibilities in different subjects of IWT fall on different governmental institutions, creating some concerns related to lack of cohesion and interinstitutional limits in their functions.

Table 9. Concerns about functions and responsibilities of private and public stakeholders involved in IWT

Functions and responsibilities	Institution	Concern
Regulations and criteria of navigation and transport	Ministry of Transport	Each institution issues its own rules
	National Planning Department (DNP)	
	Río Grande de La Magdalena Regional Autonomous Corporation (CORMAGDALENA)	
	National Infrastructure Agency (ANI)	
Hydraulic works	National Institute of Roads (INVIAS)	Each institution carries out hydraulic works for their own needs
	Ministry of Mines and Energy	
	Public and private companies	
Fluvial risks	Riverside municipalities	There is no unified doctrine, technical standards are not applied to prevent and address river disasters and fluvial casualties
	Disaster Risk Management Unit	
	Ministry of the Environment	
Control of river and maritime-river traffic	National Infrastructure Agency (ANI)	Each institution applies the criteria and standards it deems appropriate
	Maritime Authority DIMAR	
	National Institute of Roads (INVIAS)	
	Río Grande de La Magdalena Regional Autonomous Corporation (CORMAGDALENA)	
Fluvial safety	Fluvial inspections	There is no comprehensive security plan
	Police	
	Navy	
Fluvial pollution control	Ministry of Transport	This control is carried out using the criteria of each institution
	Ministry of the Environment	
	Shipping companies and shipowners	

Note. Author´s elaboration based on data from “Fluvial Master Plan 2015”.

Some authors highlights the relevance of transferring scientific knowledge to decision makers, and argue that proposed projects lack comprehensive vision for the basin, in this sense the construction and maintenance works that promote the IWT require a scientific transdisciplinary analysis and strengthened authorities that see the Magdalena River not only as a “Hydraulic Canal” but also as an interactive system in which biological, geological, social and legal studies are required (Restrepo, 2015).

In terms of inland transportation costs in Colombia, data analysed by Mesquita-Moreira (2013) reveal the existence of a "coastal effect" as economic activity is deconcentrated from the centre to other coastal regions. Moreover, exportation patterns are directly related to shipping distances from ports, airports, and borders. Mesquita-Moreira (2013) suggests that domestic transport costs could be an important obstacle to international trade. In addition to this, through an econometric study he measured the effect of domestic costs on regional exports, and presented a series of counterfactual simulations to assess the extent to which export performance would change with improved road infrastructure. Thus, they corroborate the positive effects of investing in new roadways, due to the weak road network lying far below the Latin American average, and propose fluvial transportation as an alternative route for trading goods and making serious investments for this to become a viable alternative for the country. Nevertheless, it is extremely important to build strategies based on historical and technical information of the region; according to Márquez (2016) lack of knowledge of correct management of natural resources and environmental and natural terms can lead us to commit the same errors as in the past in attempts to develop inland navigation in Colombia's major river.

Even though the development of the IWT provides an alternative shipping route, in Colombia navigable rivers have suffered sedimentation, lack of investment and internal conflicts, causing problems in navigation focused on unnavigability in certain areas, difficulties navigating at night, lack of signage and buoys, absence of port infrastructure and low levels of knowledge of the river level (Cepeda, 2013). On the other hand, limited public investment to improve maritime channel access and river channels—even when oil, coal and mineral industry and exportation have been growing—mean the cost of shipping goods in Colombia has been increasing, due to the poor transportation infrastructure and the lack of multimodal transportation options (De Pietro, 2013).

Given the factors above, this study provides thorough examination of the current conditions of the Magdalena River, from a multidisciplinary perspective that incorporates insights from diverse stakeholders. Through this inclusive approach, the research proposes viable solutions for overcoming the barriers to sustainable development in IWT.

2.5. Stakeholder management theory

In 1984, Edward Freeman was among the first scholars to articulate stakeholder theory, proposing a new conceptual framework that reflected the evolving business environment of the 1980s. Prior to this, organizational perspectives largely centred on an owner-manager-employee model focused on meeting the needs of suppliers and customers. Freeman's framework broadened this view, emphasizing the importance of considering the interests of a wider range of stakeholders to address the complexities of modern business (Freeman, 1984). Moreover, the implementation of new technologies and specialized production processes, associated with the creation of urban production areas, significantly changed the dynamics of business, making room for a more complex model from a managerial view. The changes experienced by managers during the 1980s stemmed from an internal change (such as owners, customers, suppliers and employees) who followed the former business model, and other external changes due to the rise of new groups which include governments, competitors, costumer advocates, environmentalist, special interest groups and media.

Academic interest in stakeholder theory and its concepts have increased in recent years, and it is also becoming more important among policy makers, governmental and non-governmental organizations, businesses, among others (Friedman & Miles, 2006). Wicks et al. (2010) claims that stakeholder theory is a "powerful source for thinking about how people come together to cooperate and create value in a wide array of settings". Moreover, Friedman & Miles (2006) suggests that the most common way to classify stakeholders is in the following five groups: shareholders, customers, suppliers and distributors, employees and local communities, although many other types of individuals and groups have also been considered as stakeholders (e.g., government, regulators, policy makers, business partners, academics, among others). On the other hand, Wicks et al. (2010) suggests a reciprocal relationship between stakeholder theory and public policy, mainly due to the focus, values, and the concern for providing results and adding mutual value. Moreover, Wicks et al. (2010) highlight the relevance of the theory in public private partnerships since it is used as a framework to decide important matters such as the definition of project success, the structure and inputs, and the strategy to maintain peaceful relationships among the participants. In addition, stakeholder theory is considering a tool identify stakeholders and choose standards for decision-making.

The author acknowledges the relevance of stakeholder management approaches in enhancing the development and sustainability of IWT, recognizing that this sector requires the active involvement of diverse stakeholders, including government authorities, local communities, environmental groups, transport companies, academia, cargo owners, among others. Effective stakeholder management in IWT can facilitate the balancing of stakeholder interests, strengthen community engagement, build collaborative partnerships, and support long-term sustainability. Moreover, it can contribute to improved quality of life, technological advancement, and infrastructure development. Understanding the interactions among various stakeholders is essential for sustainable IWT development. However, given the complexities of the IWT system and the time and resource limitations of this research, a comprehensive stakeholder analysis is identified as a priority for future work. Building upon the findings of this document, subsequent research could provide a more in-depth analysis of the drivers, barriers, and potential solutions, with both general insights and specific focus on the Magdalena River case.

3. Methodology

3.1. Research design

This section depicts the methodological approach following the research onion strategy proposed by Saunders et al. (2006) as presented in Figure 12. The philosophical view used for this study is described as interpretivist, due to the author seeking to understand a social phenomenon using the examination and interpretation of it from the responses of the participants involved in the study (Bryman, 2016). The ontological assumption which refers to conjectures about nature and reality applied to interpretivism is considered complex, and contemplates various meanings, interpretations, and realities; likewise, it is socially constructed through culture, language, processes, experiences, and practices. Additionally, from an epistemological viewpoint, which includes the assumptions about what is considered acceptable, legitimate, and valid about knowledge and the way of communicating it, this research will focus on narratives, perceptions and interpretations, along with new understandings, and multiplicity of opinions (Saunders et al., 2012). Moreover, Creswell (2014) argues that interpretivism allows the researcher to obtain a broad and complex vision instead of focusing on specific ideas or categories, enabling the meaning of a specific situation to be built, as it is in the case of this research, which seeks to understand the definition of sustainable development of the IWT, and the elements and factors that constitute it, as well as the role of stakeholders involved in the case of Colombia, in order to finally provide a framework of barriers and potential solutions for its sustainable development.

The author has applied both inductive and deductive approaches in the various stages of the research to investigate the sustainable development concepts in the context of IWT (Figure 11), starting with a focus on individual meaning, in order to understand the complexity of the circumstances experienced in IWT focused on the Magdalena River in Colombia, followed by a deductive approach where the author identifies a tool for assessing or observing the attitudes or behaviours of the participants in the research study (Creswell, 2014).

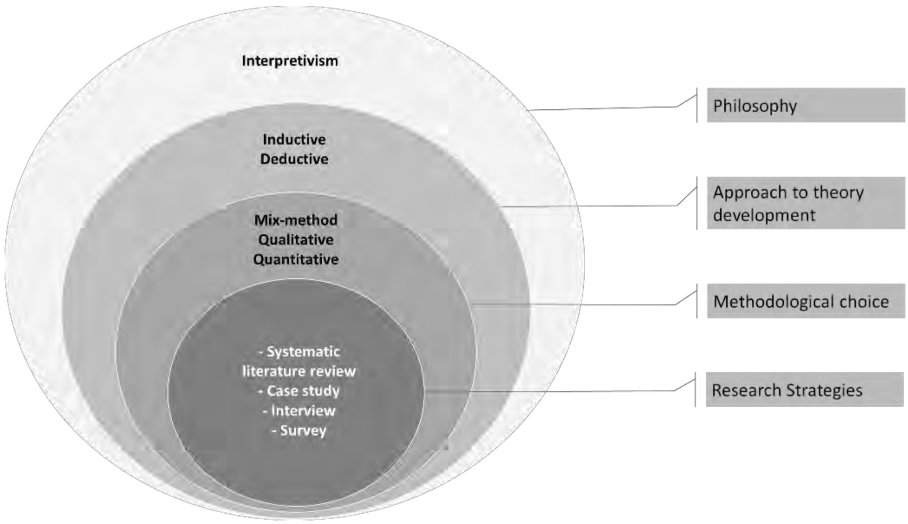


Figure 11. Research design
Note. Adapted from Saunders et al. (2006).

Furthermore, to achieve the research objectives, the author used a mixed methods approach that seeks to explore and understand a social problem (sustainable development of IWT) by analysing the specific characteristics of IWT in general and in a particular case in Colombia (Magdalena River), questioning individuals and groups of individuals (Creswell, 2014). Finally, the research strategies, and the techniques and procedures for data collection and analysis, were framed on the systematic literature review to understand the general approach of IWT globally, followed by a case study, interviews and a survey, as explained in the following sections.

3.2. Validity and reliability

Given that in qualitative studies the application of external and internal validity and reliability becomes complex, some authors have proposed alternative criteria to overcome this. For qualitative research, Gibbs (2007), as cited in Creswell (2014), describes validity as the pursuit of accuracy in research results through the application of specific procedures. He further argues that reliability refers to the consistency of a given approach when applied by different researchers and across various studies. On one hand some authors propose two broad criteria to ensure validity and reliability in qualitative research, trustworthiness and authenticity; each of which has its own criteria (Guba & Lincoln, 1994; Guba, 1985, as cited in Bryman, 2016) (Table 10).

Table 10. Criteria to ensure validity and reliability in qualitative research

Criterion		Description	Application in the research
Trustworthiness	Credibility	Some techniques—such as respondent validation or triangulation—are applicable. Credibility aligns with internal validity in quantitative research, as both focus on ensuring the findings accurately represent the reality being studied.	To understand the concept of sustainable development of the IWT and the main barriers to and potential solutions for its implementation, the author carried out a systematic literature review. Later, the information for the Magdalena River case was validated through interviews with the most relevant stakeholders in Colombia. On the other hand, the proposed definitions obtained in the literature review and interviews were validated using a questionnaire completed by experts in Colombia and worldwide.
	Transferability	Oriented to contextual uniqueness and significance, allowing a thick description that can act as a database for future transferability, assimilating to external validity.	The author proposed a framework of barriers and potential solutions for the sustainable development of IWT which serves as the basis for the analysis of case study (Magdalena River). However, given the unique characteristics of each waterway, the results obtained for Colombia are not generalizable to other cases, but serve as a basis for future research in developing IWT systems.
	Dependability	Complete records and phases in the research process should be adopted. In addition, peers should act as auditors during the research process, being considered parallel to reliability.	The methodology used in this research is described in detail in this chapter, where a description and justification of each method is made.
	Confirmability	Is parallel to objectivity, due to the complexity on social sciences, confirmability should be included in the objectives of the auditing process discussed above	The inclusion of scientists and non-scientists in this research allows us to cover the complexity of the social sciences, since this particular issue includes social, environmental, and economic problems.
Authenticity	Fairness	Fair representation of the diverse points of view of the members	20 stakeholders from various private and public institutions were interviewed to understand the variety of perspectives about sustainable development of IWT in Colombia. Moreover, the relationship between the barriers and potential solutions for sustainable development of IWT found in the literature and those obtained by the empirical research were discussed.
	Ontological authenticity	Members understand better the social setting	
	Educative authenticity	Members appreciate others´ perspectives	
	Catalytic authenticity	Engage members in action for change	
	Tactical authenticity	Empower members to take necessary steps	

Note. Adapted from Creswell (2014).

On the other hand, Yardley (2000) established three criteria to assure quality in qualitative research. The first one is “sensibility to the context”, which takes account of the background of the theory and awareness of relevant literature and previous empirical research. The second set of features is "commitment, rigour, transparency and coherence": this criterion is associated with prolonged engagement with the topic, skills in the use of data collection methods, including a detailed process and rules for collecting and coding the data, and desirable triangulation of data collection. The last characteristic is "impact and importance", under which the theoretical and practical impact of the study in the socio-cultural or socio-political context become relevant.

During this research, a triangulation was conducted of the definition of sustainable development, and the barriers and potential solutions applied to the IWT. Initially, a systematic literature review enabled the researcher to understand the main barriers and potential solutions proposed by several authors applied to various waterways around the world, both in developed and developing countries. Subsequently, this information was validated through interviews that allowed the development of a framework of barriers and potential solutions, focused on sustainable development of IWT for Colombia. Finally, a survey was conducted to measure the distance between the desired state (sustainable IWT) and the current state of IWT in the Magdalena River.

3.3. Research methods

This section outlines the mixed-methods approach used to investigate the sustainable development of IWT, considering both a global perspective and the specific case of the Magdalena River in Colombia. First, a systematic literature review establishes a foundational understanding of IWT systems worldwide. Through an analysis of current literature, it identifies the core elements and factors that contribute to a sustainable IWT system, as well as common barriers and proposed solutions globally. This comprehensive review provides a framework for contextualizing the Magdalena River's unique characteristics within a broader perspective. To build on these insights, interviews with key stakeholders—including public and private sector and the academia—offer perspectives on the specific barriers and opportunities for sustainable development along the Magdalena River, highlighting its essential role in transporting goods and passengers, supporting access to health care, education, and other critical services. Complementing this qualitative data, a survey distributed to a wider group of stakeholders validates the definition of sustainable IWT and quantifies perceptions regarding the river's current status and potential development pathways. Together, these methods create a broader understanding of the Magdalena River's potential for sustainable IWT, shaping recommendations to address infrastructure needs, governance challenges, and stakeholder collaboration to improve social, economic, and environmental outcomes.

3.3.1. Systematic literature review

The use of literature review as a research method has become increasingly prominent in social sciences and has become a key tool for understanding various fields of knowledge (Davis et al., 2014), due to its ability to assess and comprehend collective knowledge and theoretical development in particular areas of research when it remains fragmented and interdisciplinary (Snyder, 2019). Moreover, it makes it possible to "comprehensively locate and synthesize research that bears on a particular question, using organized, transparent, and replicable procedures at each step in the process" (Littell et al., 2008).

Some authors have classified literature review from different perspectives, Grant & Booth (2009) presented a descriptive insight of 14 types of review, mainly applied in health sciences, and stated the need for international agreed set of review types to obtain a clear understanding of the requirements and resources needed to meet specifications and avoid overlapping methodologies. Xiao & Watson (2019) categorized literature review by its purpose in four main groups: descriptive, testing, extending and critical reviews, with five, four, six and one subcategories, respectively; in addition, the authors argue that these types can be combined in a single review, using a hybrid form of these methods. Moreover, Snyder (2019) recognized three broader approaches to conducting a literature review using qualitative, quantitative and mixed methods, beginning with the systematic literature review, followed by the semi-systematic review, and in the end the integrative review. For each approach, the author describes the potential of its uses, and the process of conducting and assessing the quality of each.

During the initial phase of the research, after analysing the various types of literature review, it was determined that the most appropriate method to reach the first objective is the systematic literature review, as it is the most neutral, precise, and rigorous approach and covers all relevant data (Jesson et al., 2011). Furthermore, a systematic literature review is a useful method to assess the state of knowledge on a particular topic, in a systematic, transparent and reproducible way, and allows the identification, summarization and critical evaluation of the relevant research results, as well as the identification or determining whether an effect is constant across studies (Davis et al., 2014; Snyder, 2019). Palmatier et al. (2018) suggest standards focused on: sufficient past research, including and excluding criteria to literature collection and analysis, and capacity to offer significant insights to generate an adequate contribution. Moreover, Littell et al. (2008) recommended special attention to inadequate sampling, data collection methods and coding discrepancies, in order to have a good quality assessment and ensure validity and reliability.

To conduct a systematic literature review the author followed the process suggested by Snyder (2019), comprising four phases, starting with the design and conduct of the research followed by the analysis and the report. During the first stage, two systematic literature reviews were designed, as described in Table 11, to reach research objective 1, and Table 12 to reach research objective 2. For each case the research questions were formulated and the strategy for selecting literature involving inclusion and exclusion criteria was established. To select the relevant literature, the authors established key words, limiting the search to key words included in titles, abstracts and key words using "Scopus", "Google Scholar" and "EBSCO" as the databases for paper selection.

Table 11. Stages followed in the systematic literature review (Objective 1)

Research questions a. How is sustainable development addressed and applied in inland waterways transport systems? b. How can an inland waterways transport system be defined and what elements and factors constitute it? c. What are the drivers of sustainable development of inland waterway transport?	
Identification of key words "inland waterway" AND sustainab* (The use of asterisk allows the selection of publications that contain the words "sustainable" "sustainability")	
Inclusion Criteria Academic journals – reports – book chapters Full access to text Research covering sustainable development of IWT	**Exclusion criteria** Articles not directly focused on inland waterway transport Repetitive studies found in different databases
Stages for filtering data Stage one: Eliminating duplicates Stage two: Applying inclusion and exclusion criteria on title, abstract, and key words Stage three: Applying inclusion and exclusion criteria on full text Stage four: If necessary, including articles using a snowballing technique	
Paper identification Scopus: 424 Google Scholar: 354 EBSCO: 221 Total: 999	**Paper selection** After the title, abstract, and keywords review Papers excluded after applying inclusion and exclusion criteria: 923 Selected papers: 76
Paper selection After full-text review Papers excluded after applying inclusion and exclusion criteria: 33 Papers selected using snowballing: 8	
Selected literature: 51 papers	

In the following phase a pilot test was applied to revise the quantity of information, the three stages of data selection took place, starting with duplicate elimination, applying inclusion and exclusion criteria and use of snowballing technique. Finally, after applying the stages for filtering data the final number of papers were identified and analysed to provide answers to the proposed research questions.

Table 12. Stages followed in the systematic literature review (Objective 2)

<table>
<tr><td colspan="2">Research questions
a. What are the barriers to the sustainable development of inland waterways transport systems?
b. What are the solutions to overcome the barriers to the sustainable development of inland waterways transport systems?</td></tr>
<tr><td colspan="2">Identification of keywords
("inland waterway") AND (sustainab*) AND (measure* OR action* OR polic* OR solution OR driver* OR barrier* OR obstacle* OR issue*)</td></tr>
<tr><td>Inclusion Criteria
Academic journals – reports – book chapters
Full access to text</td><td>Exclusion criteria
Articles that do not cover barriers to and solutions for IWT development
Repetitive studies found in the various databases</td></tr>
<tr><td colspan="2">Stages for filtering data
Stage one: Eliminating duplicates
Stage two: Applying inclusion and exclusion criteria
Stage two: Applying snowballing technique</td></tr>
<tr><td>Paper identification
Scopus: 115
Google Scholar: 529
EBSCO: 46
Total: 690</td><td>Paper selection
Papers excluded after applying inclusion and exclusion criteria: 627
Selected papers: 63
Selected papers using snowballing: 16</td></tr>
<tr><td colspan="2">Selected literature: 79 papers</td></tr>
</table>

The findings from the literature review served as a frame of reference for analysing the characteristics of sustainable development in IWT. They also contributed to identifying potential solutions aimed at overcoming the existing barriers along the Magdalena River, which will be further explained by the development of a case study as outlined in the following section.

3.3.2. Case of Magdalena River

There are various positions regarding use of case studies as a research method; for this research, the author adopts the definition proposed by Thomas (2011) which argues that "The case study is not a method in itself. Rather it is a focus, and the focus is on one thing, looked in depth and from many angles… So, you have the focus for the case, and you choose the methods to help you inquire into the subject." Following this perspective, this research will approach the case study as an object of inquiry, aiming to gain a deep understanding of the specific characteristics of the Magdalena River case, and though it, offer insights into its relevance, uniqueness, or typicality of the selected case.

On the other hand, Yin (2018) posits three conditions to distinguish the suitability of applying a case study. First, the research question should be focused on "how" and "why", as these are focused on making an operational follow-up over time and not on understanding frequencies or incidence. Second, the research may not require control over behavioural events, and if it does other methods such as experiments can be conducted. Finally, the research should focus on contemporary events and rely on two main sources of information, direct observation of the events and interviews with persons who may be involved in the events (Table 13).

Table 13. Considerations to conduct case study research

Case \ Conditions	Research question	Requires control over behavioural events?	Focuses on contemporary events?
Sustainable development of IWT in the Magdalena River	How?	No	Yes

The purpose of including the case study concepts is both exploratory and explanatory: to gather facts, and understand potential explanations, potential solutions and their applicability. The case study follows an interpretative approach, with the aim of understanding in depth the setting of the subject, or in this case the elements and factors of IWT system in the Magdalena River (Thomas, 2011). Moreover, the design follows the classification proposed by Yin (2018), framed in an embedded single case with multiple thematic areas as shown in Figure 12.

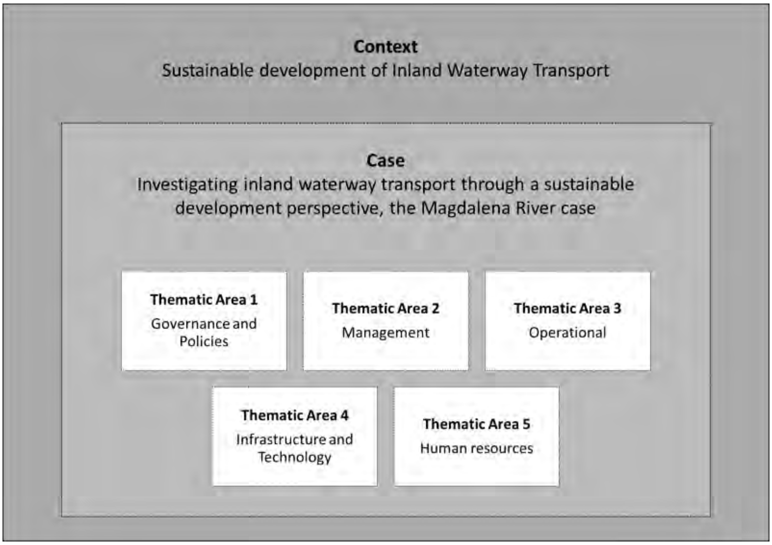


Figure 12. Magdalena River case

The results of the systematic literature review are considered the context of the case study, which uses the elements, factors and features identified and classified for IWT systems in general. Subsequently, these elements are analysed for the Magdalena River in order to define the concept of sustainable development of IWT as applicable in the selected case, as well as the main barriers and potential solutions in each of the five thematic areas.

3.3.3. Interviews

Interviewing is one of the most used methods used in qualitative research. However, is a time-consuming method that implies interviewing, transcription and analysis of the information, and is not always suitable for all researchers (Bryman, 2016). Various types of interviews have been reported in the literature from the qualitative and quantitative point of view (Bryman, 2016; Patton, 2002). Bryman (2016) argues that qualitative interviews can be divided into two groups: the unstructured interview, which is quite broad and addresses a wide range of topics; and the semi-structured interview, which while similar to the previous one, possesses a list of questions focused on specific topics and has the flexibility to ask other questions according to the answers obtained by the interviewees to emphasize topics of interest. As this study seeks to analyse the ideas and perspectives of stakeholders, to understand the interactions between them and the main barriers and potential solutions to overcoming them for the sustainable development of IWT in Colombia, semi-structured interviews are the most suitable to achieve the proposed objective, following a pragmatic approach due to the action-oriented inquiry process (Bryman, 2016; Patton, 2002).

Before applying the proposed methodology, the researcher considered the ethical aspects involved. In research, ethics refers to the standards of behaviour that guide the conduct of the scholar with respect to the rights of the individuals involved in the research. In order to overcome some ethical dilemmas, codes of conduct have been established which contain lists of ethical principles and standards to guide the researcher's conduct: these standards are usually guided by the codes of ethics established by the university through "research ethics committees" which comprise experienced researchers from different backgrounds and genders who act impartially and independently and review all research involving human participation and personal data (Saunders et al., 2012). For the interviews conducted in this research, in 2023 the WMU research ethics committee approved the proposed questions to conduct semi-structured interviews with experts in IWT in Colombia. Likewise, the participants filled out a consent form guaranteeing the anonymity of their answers, and were asked to accept their participation by filling out this document.

On the other hand, given the objective of the research and its qualitative nature, where the interviews are not intended to generalize to the population, non-probabilistic sampling was conducted until data saturation was reached, as conducting other interviews would provide little or no information suggesting aspects of interest to meet the research objective. In addition, a purposive sample was conducted with a heterogeneous variation sampling approach to select participants who were experts in different public private entities and academia, thus allowing the researcher to document perspectives on the sustainable development of IWT from different stakeholders (Saunders et al., 2012). Additionally, some participants were selected using snowball sampling, given the difficulties in identifying members of the various organizations in Colombia who had experience and expertise in the case study topic.

During the preparation process for the semi-structured interview, the researcher followed the guidelines proposed by Bryman (2016). In this phase the topics and flow of questions were organized and examined, the interview questions were checked to ensure they answered the research objectives and questions, and the language was reviewed to ensure that it was understandable for the interviewees, and they provided the information needed to understand the context of the answers delivered (position in company, time in office and functions performed). The interview was divided into four main sections: (i) information about the participants' experience and background; (ii) defining sustainable development of IWT from the Magdalena River perspective; (iii) general analysis of opinions regarding IWT in the Magdalena River; and (iv) respondents' understanding of barriers to and potential solutions for the sustainable development of IWT in the Magdalena River. The questions are presented in the Appendix 1.

The interviews were mainly conducted in the second half of 2023; the respondents comprised representatives of academia and the public and private sectors at managerial levels. All interviews were conducted in Spanish, as this is the mother tongue of both the researcher and the interviewees. The data analysis followed the seven steps proposed by Creswell (2014) (Figure 13). Moreover, the research interpretation adhered to the characteristics of content analysis. Firstly, objectivity was maintained by ensuring transparency in the process of assigning categories and applying specific rules to mitigate any potential bias from the analyst. Additionally, the analysis was conducted systematically, ensuring consistent application of the prescribed rules throughout the process. To further reinforce this approach, quantitative analysis was employed to ensure the application of neutral rules in defining categories (Bryman, 2016).

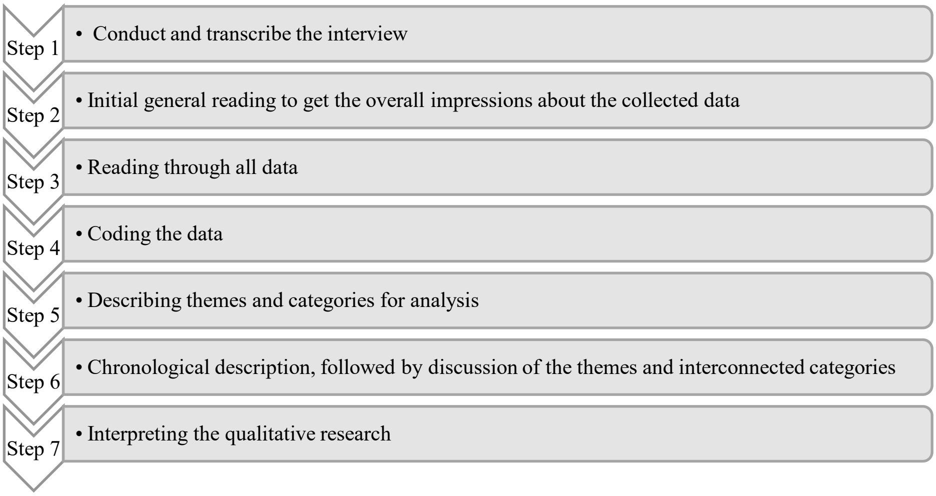


Figure 13. ***Data analysis process***
Note. Adapted from Creswell (2014).

The research used content analysis as a tool to analyse the data obtained from the interviews (Bryman, 2016). This is one of the most common approaches to analyse qualitative data, standing out for being a deductive approach compared to other methods that are inductive, for example grounded theory. Content analysis systematically and objectively seeks to identify specific characteristics, either as classes or categories embedded within the data. In this sense, with the aim of carrying out an objective process, the author must create some selection criteria established before starting the analysis (Bryman, 2016; Gray, 2009). In this regard, the researcher used two procedures suggested by Gray (2009) to identify classes and categories. First, common classes were used to identify those fragments that corresponded to barriers and potential solutions, and subsequently the data were categorized into the five factors previously identified in the literature: governance and policy, management, operations, infrastructure and technology, and human resources (Paper 2). Second, special classes were used to describe the barriers and potential solutions for each factor, which enabled identification and categorization of the main potential solutions to overcome the barriers to sustainable development of IWT. The coding of the interviews was carried out using NVivo, which made it possible to identify the frequency in which certain criteria were repeated, generating a ranking that could serve as a roadmap for decision makers and policy makers in Colombia.

3.3.4 Survey

Surveying is a tool for quantitatively assessing tendencies and opinions in a population by examining a sample of data (Creswell, 2014). De Vaus (2013) highlights the structured nature of surveys, characterized by a systematic organization of data into variable case grids, enabling comprehensive analysis and interpretation of results. In this regard, during the last stage of this study, the researcher seeks to understand and measure the perceptions of experts, focusing on sustainable development of the IWT and its characteristics in a systematic way (Trochim et al., 2016). While there are various tools to collect data – such as structured interviews and observation, among others – this study considers the development of questionnaires to be the most appropriate tool because they are structured, allow information to be collected directly to feed the data grid, and can be completed by the respondents independently (self-administered) (De Vaus, 2013).

Questionnaires can be administered in several ways, such as through certified mail or through group-administered questionnaires, where all participants are present and asked to provide their responses. However, today, because of the accessibility of internet services, electronic surveys have become more important. Its advantages include its relatively low cost, wide geographic coverage, and convenience for respondents, who can complete them according to their own availability. However, alongside surveys sent by certified mail, electronic surveys can also have disadvantages, such as low response rates and not being the most suitable means of obtaining detailed responses (Trochim et al., 2016).

Survey design should begin with deep understanding of the research's purpose and the issues to be explored through the questionnaire. It is essential to consider the type of analysis that will follow the data collection process. Additionally, it is beneficial to determine whether any existing questionnaires could be partially incorporated into the current survey (Trochim et al., 2016), although this was not applicable in the present study. Moreover, Trochim et al. (2016) suggests three considerations when writing a question. First, it is essential to determine the content, scope, and purpose of the question, ensuring it aligns with the research objectives. Second, selecting the appropriate response format is crucial for collecting information from respondents efficiently. Finally, crafting the wording of the question thoughtfully is vital to ensure the specific issue or topic of interest is addressed, clarity optimized and data collection accurate.

Following the ethical considerations suggested by Saunders et al. (2012), which were set out in the previous section, questions formulated in the questionnaire were approved by the ethics committee in 2024. Considering that the questionnaire was developed entirely online using the QuestionPro program, a section was included to explain to the participants the codes of ethics of the research and the subsequent use of the information, which would be confidential and used by the researchers in this document as well as in other academic publications. In this regard, participants were asked to confirm their voluntary wish to participate in the survey, or their right not to continue with it. On the other hand, given the limitations of time, money and access, non-probability sampling was conducted as the probability of each case being selected from the total population is unknown, which makes it impossible to make statistical inferences regarding the characteristics of the population. Additionally, purposive heterogeneous sampling was carried out to obtain responses not only from IWT experts in Colombia but also from all available waterways or navigable rivers worldwide, with the aim of validating the definitions of sustainable development of IWT and reviewing implementation of the characteristics, both in Colombia and in other regions, to be able to make some comparisons between them. Additionally, some participants were selected using snowball sampling, given the difficulties identifying experts both in Colombia and globally (Saunders et al., 2012).

The questionnaire employed various question types to gather comprehensive data. It included filter or contingency questions, with binary responses (Yes or No), which directed respondents to subsequent sub-questions based on their initial responses. Participants were also asked to rank the significance of information related to IWT services using ordinal responses. Additionally, questions were structured using interval-level response formats to evaluate the perceived distances between the current and desired states. Careful attention was given to the wording of questions to minimize misunderstandings and researcher bias. Moreover, question phrasing was revised to ensure clarity, neutrality and the avoidance of ambiguous terminology (Trochim et al., 2016). The questionnaire was divided into five sections, starting with a validation of the definitions and ranking of the characteristics, followed by four segments that covered transversal, environmental, social and economic aspects associated with the sustainable development of ITW. Finally, the questionnaire was validated by two academics with expertise in IWT on waterways and navigable rivers in Latin America and Europe. The survey questionnaire is presented in Appendix 2.

The analysis and presentation of the survey results was conducted using descriptive statistics. The survey collected nominal data to understand the geographic location, the element in which the participant has the most experience, and some other data in which they could express their opinion or report their knowledge on specific topics (such as new technologies implemented). Additionally, ordinal data were collected to rank some items related to the characteristics of sustainable IWT. The results show the degree of implementation of the characteristics of sustainable development of IWT in the Magdalena River and validate the proposed definitions not only in the Magdalena River but using the opinion of experts in other waterways or navigable rivers in the world (Paper 4 presents the results).

4. Results

This section presents the findings of the research, exploring the application of the concept of sustainable development in the context of IWT, and provides a description of the results as reflected in the papers (Figure 14). The study examines the fundamental elements and factors constituting the IWT system, and identifies the key drivers influencing its development. Additionally, an examination of the primary barriers to sustainable IWT development, along with proposed potential solutions, is provided. Moreover, a distinction is made between general challenges and those specific to the Magdalena River, offering insights tailored to the selected case. Finally, an evaluation of the current state of the Magdalena River and the desired sustainable state is presented, to facilitate the prioritization of potential solutions towards achieving a more sustainable IWT system in the selected case.

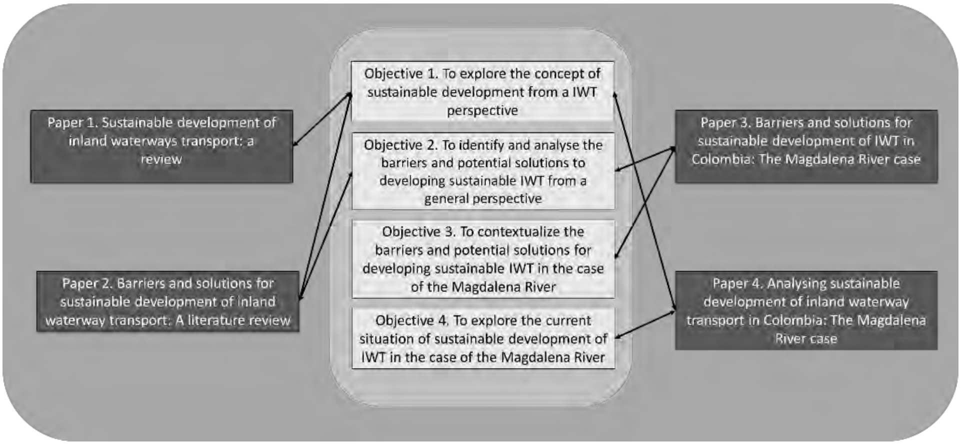


Figure 14*. Data analysis process*

4.1. Objective 1. To explore the concept of sustainable development from a IWT perspective.

4.1.1. IWT from a system perspective

The IWT system can be viewed predominantly as a social system, given its inherent purposes and functional elements. Additionally, IWT functions as a system within a larger network, as it is integrated into the broader transportation system. Furthermore, IWT can be characterized as an open system due to its ongoing interaction and exchange with the environment and other transportation modes, notably road, maritime and rail transport (Fieguth, 2021). The system concepts were used in the research to identify the elements, interconnection, and the function or purpose of IWT. Some other aspects—such as behaviours, interdependence, boundaries, environment and so on, intended to explore and identify the potential solutions to overcome barriers towards the sustainable development of IWT—could be discussed, although they are not the main focus of the research.

Meadows (2008) argues that a "system must consist of three kinds of things: elements, interconnections, and a function or purpose". In this context, this research delineates the following characteristics of IWT in accordance with this definition:

- *Elements*: Physical entities such as ports, waterways, and fleets (Figure 16).
- *Interconnections*: Various aspects identified in the systematic literature review, including governance and policies, management, operations, infrastructure and technology development, and human resources (Table 14).
- *Function/purpose*: The main function can be considered to be transportation services for people and cargo. However, from a sustainable development perspective, other social, environmental, and economic aspects should be considered.

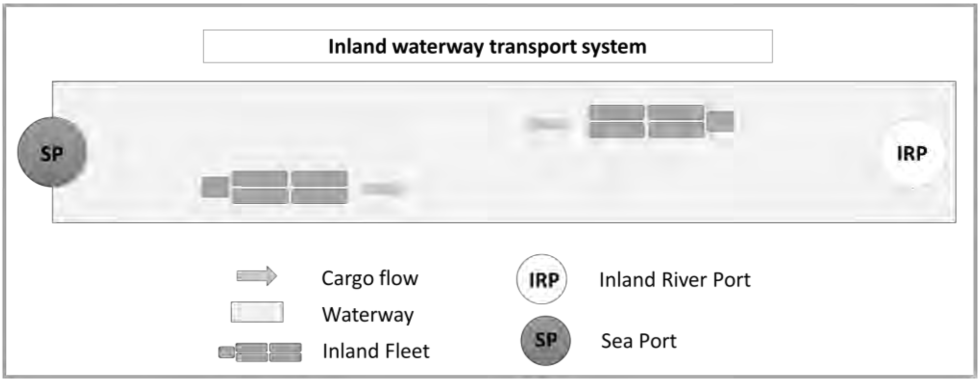


Figure 15. Physical elements of Inland waterway transport system
Note. Extracted from Paper 1.

Table 14 presents various classifications identified in the literature, alongside the classifications proposed by the author, utilized to outline the primary barriers and potential solutions for the sustainable development of IWT. Additionally, the table distinguishes between categories linked with the fleet, ports and waterways. To streamline comprehension and organization, this study introduces five categories that integrate previous categorizations. Governance and policy (GP) encompass aspects pertaining to the governance systems applicable to IWT, and policies adopted by governments or organizations contributing to decision-making processes.

These policies serve as guidelines for achieving specific objectives promoting sustainable development of IWT, taking into account environmental protection and socio-economic development of waterways. To distinguish between management (MG) and operations (OP), we adopt the definition proposed by Tako and Robinson (2012), which emphasizes the temporal nature and frequency of actions. Actions requiring two to five years for implementation fall under management-oriented strategies, whereas those rapidly implemented on a day-to-day basis or within a few months are categorized as operational aspects. Infrastructure and technology (IT) considerations are consolidated to address deficiencies in infrastructure and identify applicable solutions for waterways, ports, and fleets, encompassing innovation and technological advancement. Finally, the human resources (HR) factor covers all aspects related to personnel performing functions—either onboard crews or tasks associated with IWT in ports.

Table 14. Classification of factors for sustainable development of IWT

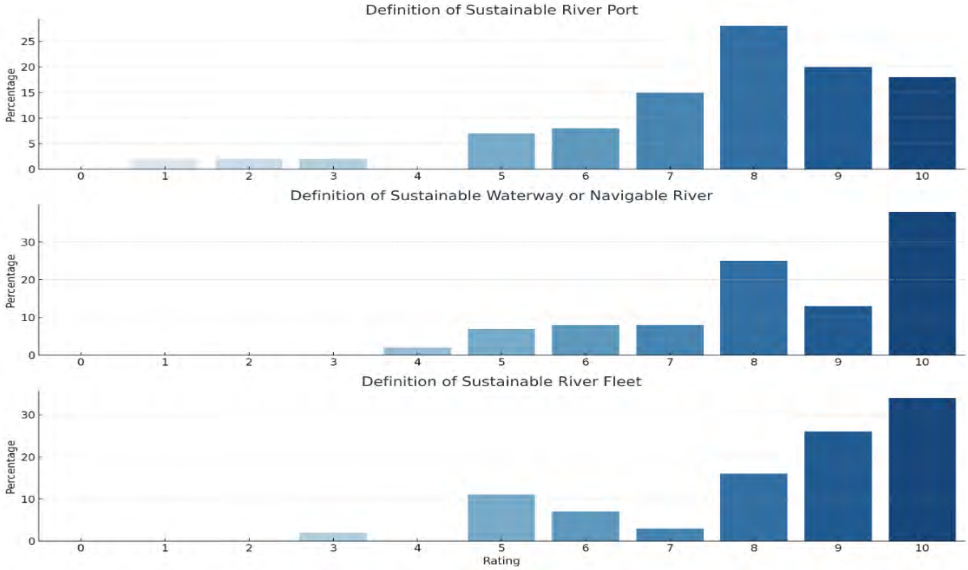
Classification based in literature		Classification by the author					Element of IWT		
Classification	Author	GP	MG	OP	IT	HR	Port	Waterway	Fleet
Technical	(Trivedi et al., 2021)				X			X	
Infrastructural	(Trivedi et al., 2021)				X		X	X	X
Regulatory	(Trivedi et al., 2021)	X					X	X	X
Geopolitical	(Trivedi et al., 2021)	X					X	X	X
Financial	(Trivedi et al., 2021)	X	X	X	X	X	X	X	X
Development works	(Barros et al., 2022)				X			X	
Operations	(Barros et al., 2022)			X				X	
Ports	(Barros et al., 2022)		X	X	X		X		
Governance	(Barros et al., 2022)	X						X	
Works	(Barros et al., 2022)	X						X	
Operations	(Barros et al., 2022)			X				X	X
Governance	(Barros et al., 2022)	X					X	X	X
Manpower	(Maternová et al., 2022)					X			X
Management	(Maternová et al., 2022)		X						X
Materials	(Maternová et al., 2022)			X	X				X
Machines	(Maternová et al., 2022)				X				X
Methods	(Maternová et al., 2022)		X						X
Mother nature	(Maternová et al., 2022)		X					X	X
Inland waterways infrastructure	(Kotowska et al., 2018)		X					X	
Quality of hinterland connections	(Kotowska et al., 2018)		X		X		X		
Administrative	(Kotowska et al., 2018)		X				X	X	
Quality of barge services	(Kotowska et al., 2018)		X	X	X		X		X
Information and promotion	(Kotowska et al., 2018)			X				X	X
Innovations	(Kotowska et al., 2018)				X				X
Regulatory	(Rogerson et al., 2019)	X					X	X	X
Financial	(Rogerson et al., 2019)		X	X	X		X	X	
Service quality	(Rogerson et al., 2019)			X			X		X
Market characteristics	(Rogerson et al., 2019)			X	X			X	X
Infrastructure management activities	(Nguyen & Nguyen, 2020)				X		X	X	X
Regulatory activities	(Nguyen & Nguyen, 2020)	X					X	X	X
General activities (support)	(Nguyen & Nguyen, 2020)	X	X	X	X	X	X	X	X

Note. Extracted from Paper 1.

4.1.2. Defining sustainable development of IWT

After outlining the elements making up the IWT system, various definitions relating to the sustainable development of IWT were examined. This exploration commenced with the definition put forth in 1987 by the World Commission on Environment and Development, which defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). Two additional definitions were proposed by Wang et al. (2020) and Barros et al. (2022). However, these definitions lack comprehensive coverage of the three sustainability components. The former primarily focuses on meeting navigation needs, while the latter is centred on increasing freight transportation, thereby excluding passenger transport, which constitutes a significant segment in developing countries such as Colombia.

Based on the data gathered from interviews and literature sources, the author formulated the characteristics of sustainable IWT, as well as the three elements of an IWT system (Paper 4). First, a **sustainable river port** is defined as "infrastructure on the edge of a body of water that facilitates the safe transfer of passengers or cargo, on which zero or low emissions technologies operate and possess social responsibility and environmental protection standards". Second, a **sustainable waterway** is a "body of water that is naturally navigable or intervened, that possesses a navigation classification system (PIANC, 2020) and environmental and social regulatory frameworks implemented". Third, a **sustainable river fleet** is "a set of vessels that comply with national or international safety and social protection regulations and standards, generate zero or low emissions, and the stakeholders jointly seek the optimization and resilience of the services". Those definitions were validated through the survey. The analysis of the data for this section was based on the opinions of 63 IWT experts from the private sector, the public sector and academia, with experience in navigable rivers such as the Amazon, Danube, Magdalena, Mississippi, Paraguay-Paraná-De la Plata, Rhine, among others, as shown in Figure 16.



	River port	*Waterway*	*Fleet*
Mean	8,77	9,38	9,35
Standard Dev	1,93	1,66	1,80

Figure 16. Level of agreement with the proposed definitions

Moreover, the characteristics of sustainable IWT (accessible; acts within the national, regional or international value chain; autonomous; available; efficient; generates zero or low emissions; inclusive; improves the quality of life of the population; allows access to basic services; protects available natural resources; resilient; and safe) were prioritized through the opinions of the surveyed experts. The ranking was obtained by calculating the total frequency sum and weighted average, and for both cases the result shows the same order (Figure 17).

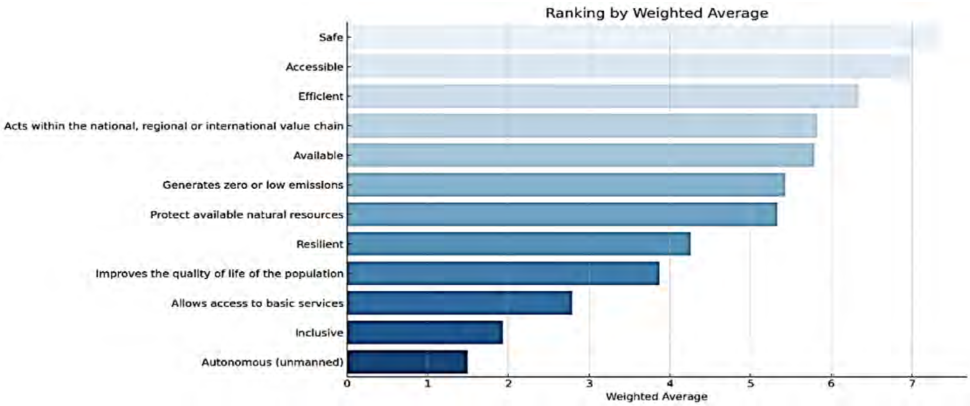


Figure 17. Ranking of sustainable IWT characteristics

4.1.3. Drivers for sustainable development of IWT

The sustainable development of IWT is driven by various factors including environmental, economic, and social dimensions. IWT is recognized as a crucial strategy for sustainable hinterland transportation, offering significant benefits in meeting demand and enhancing economic and environmental performance (Oulfarsi, 2016). However, while modal shift and intramodality have been prioritized in some regions like Europe, North America, and Asia, they remain less emphasized in African, and South American waterways (Gonzalez Aregall et al., 2018).

Environmental drivers play a significant role in forcing the development of IWT. Compared to other modes of transport, IWT demonstrates superior environmental performance, particularly in terms of lower energy consumption and reduced emissions (Rohács & Simongáti, 2007). Greenhouse gas emissions from IWT are significantly lower than those from road transport (Hofbauer & Putz, 2020), making it a more environmentally friendly option. Moreover, IWT consumes less fuel per ton-kilometre than trucks and emits lower levels of noise pollution (Gołębiowski, 2016). Despite its slower transportation speed, IWT offers advantages in energy efficiency and environmental impact reduction, making it an attractive option for certain types of cargo (Barros et al., 2022).

Economic drivers also play a crucial role in promoting the development of IWT. The cost-effectiveness of IWT compared to road transport has been well-documented, with significant cost savings and reduced external costs (Cempírek & Čejka, 2017). Moreover, IWT supports various economic activities such as tourism, hydroelectric production, and new trades, contributing to regional development and economic growth (Woś et al., 2022). Investment in IWT infrastructure has been shown to yield long-term economic benefits, although the return on investment may take some time due to geographical and political factors (Rohács & Simongáti, 2007).

Social drivers highlight the role of IWT in supporting rural development and providing access to basic services for remote areas (Awal, 2007). In many regions, IWT serves as a safer and more reliable means of transportation than road transport (Koralova, 2017). Additionally, IWT can alleviate road congestion, reduce accidents, and enhance accessibility to global markets, contributing to the overall well-being of communities (Knapčíková & Kaščák, 2019).

4.2. Objective 2. To identify and analyse the barriers and potential solutions to developing sustainable IWT from a general perspective

The barriers and potential solutions identified in the systematic literature review (Paper 2) were sorted based on the core elements of the IWT system: ports (Table 15), fleet (Table 16), and waterway (Table 17). Subsequently, they were categorized into the five suggested factors: governance and policies, management, operations, infrastructure and technology, and human resources. Additionally, the author incorporates the location of each item to facilitate understanding and facilitate the discussion of variations in reported items across different locations worldwide.

4.2.1. Ports

The barriers hindering the sustainable development of IWT are complex, often stemming from the limited attention given to inland river ports compared to seaports, despite their pivotal role in the transport chain. There is a need to create expanded intermodal terminals to address issues like road and port congestion, storage capacity limitations, and physical space constraints (Vilarinho et al., 2019). Encouraging a modal shift from roads to waterways is crucial to bolstering IWT and competing effectively with other modes of transport. However, regulations and policies promoting environmental sustainability in port operations are primarily focused on seaports, neglecting incentives and support for inland river ports and their integration with major seaports (Gonzalez Aregall et al., 2018).

The uneven development of waterways and supporting infrastructure globally exacerbates the challenges faced by the IWT industry. Disparities in infrastructure growth, availability of technical equipment, and cooperation among ports contribute to operational inefficiencies and increased costs (Miloslavskaya & Plotnikova, 2018). Factors such as added costs for transshipments, unreliable barge handling practices, and deficient infrastructure further diminish the attractiveness of IWT compared to alternative modes of transport. Moreover, longstanding issues like insufficient investment in maintenance and construction of inland river ports, coupled with shortages of skilled labour, exacerbate the challenges confronting the industry (Jaimurzina & Wilmsmeier, 2016; Koralova, 2017; Rogerson et al., 2019; Trivedi et al., 2021; Vilarinho et al., 2019).

To overcome these barriers, various solutions have been proposed. Countries with developed IWT systems emphasize policy formulation for IWT promotion and infrastructure maintenance, leveraging specialized institutions with unified development strategies (Jiang et al., 2018). Stakeholder cooperation and interinstitutional collaboration are key strategies for enhancing hinterland connections between inland and seaports (Hu et al., 2019; Kotowska et al., 2018). Additionally, coordination strategies between vessels and terminals can help alleviate operational bottlenecks, while digitization and automation initiatives can enhance operational efficiency and reduce transshipment costs (Kotowska et al., 2018; Mihic et al., 2011; Wiercx et al., 2019; Zhu et al., 2021). Finally, incorporating multimodal chains and applying models or systems that allow stakeholders to interact are other proposed solutions to enhance IWT efficiency and mitigate congestion issues (Ypsilantis & Zuidwijk, 2019; Oganesian et al., 2021).

Table 15. Barriers and potential solutions for the ports

Factors	Barrier	Location / References
Governance and policies	Lack of incentives for inland river ports	Non-classified (Gonzalez Aregall et al., 2018)
	Uneven development along the river	Danube (Miloslavskaya & Plotnikova, 2018)
Management	Relationship with ports, facilitating cooperation.	Sweden (Rogerson et al., 2019)
	Variation in working hours of ports and costumes	Danube (Pfoser et al., 2018)
	Wide range of languages of riparian countries	Danube (Pfoser et al., 2018)
Operational	High transshipment costs	Europe (Krause et al., 2022)
	Dependence on large terminals	Europe (Krause et al., 2022)
	Unreliability of barge handling in seaports	Rotterdam - Antwerp (Oganesian et al., 2021)
	Long waiting times at ports	Non classified (Li et al., 2018)
Infrastructure and technology	Lack of infrastructure and inland waterways ports	Europe (Blonk, 1994) India (Trivedi et al., 2021)
	Lack of cranes for containers in inland river ports	Sweden (Rogerson et al., 2019)
	Lack of intermodal terminals	Non-classified (Vilarinho et al., 2019)
	Lack of investment in inland river ports	SA (Jaimurzina & Wilmsmeier, 2016)
Human resources	Scarce Skilled labour force	Non-classified (Vilarinho et al., 2019)
	Reduction of port staff	Bulgaria (Koralova, 2017)
	Shortage of skilled labour staff ashore	Romania – Hungary (Pfoser et al., 2018)
Factors	**Potential solutions**	**Location / References**
Governance and policies	Policies to develop and rehabilitate terminal facilities	Nigeria (Sumaila, 2013)
Management	Interinstitutional and stakeholders' cooperation to improve hinterland connections	Europe (Kotowska et al., 2018) Non-classified (Hu et al., 2019)
	Improved administrative procedures and border clearance between inland and seaports	Europe (Kotowska et al., 2018)
	Sharing information through port community systems	Norway (Rodseth et al., 2020)
	Working hand in hand with seaport authorities	Europe (Kotowska et al., 2018)
Operational	Connectivity - optimization of transport routes	Non-classified (Zhu et al., 2021)
	Implementation of information technology systems	Europe (Kotowska et al., 2018) Danube (Mihic et al., 2011) Non-classified (Ambra et al., 2019)
	Optimizing handling activities at inland waterway terminals (such as stacking strategies)	Non-classified (Wiercx et al., 2019)
	Coordination strategies between vessels and terminals	Non-classified (Li et al., 2018)
Infrastructure and technology	Terminal automation	Europe (Krause et al., 2022)
	Construction of intermodal terminals and expansion of ports in other places with connections (hubs)	Non-classified (Vilarinho et al., 2019)
	Construction or modernization of barge terminals and their infrastructure	Europe (Kotowska et al., 2018)
	Creation of multimodal facilities	Rotterdam - Antwerp (Oganesian et al., 2021)

4.2.2. Fleet

In transportation, the duration of travel plays a decisive role in mode selection. However, IWT is often associated with slower speeds than other modes, making it suitable for transporting large quantities of cargo and oversized loads (Krause et al., 2022; Maternová et al., 2022; Meißner & Klein, 2019). However, various factors compound this situation, such as extended wait times at seaports for cargo loading or unloading due to the lower priority given to inland vessels, reliance on meteorological conditions, and inadequacies in navigation infrastructure (Li et al., 2018; Maternová et al., 2022; Vilarinho et al., 2019). Moreover, IWT is susceptible to weather variations, directly affecting vessel navigability and water level fluctuations, leading to operational disruptions and increased costs (Barros Cavalcante et al., 2020; Roso et al., 2020).

The urgency to modernize the river fleet and integrate new technologies for enhanced energy efficiency and sustainable development of IWT is increasingly evident (Koralova, 2017). However, technical advancements to replace fossil fuels in IWT vessels have lagged behind maritime transport, with fully autonomous electric vessels for IWT still in development (Néméthy et al., 2022). Moreover, fleet configuration discrepancies pose a barrier to IWT development, creating interoperability challenges among different waterways despite their geographic proximity (Koralova, 2017). On the other hand, the IWT fleet faces issues like a shortage of skilled labour, an ageing ship crew, insufficient training and qualification programmes, and dwindling applicants for nautical education programmes (Koralova, 2017; Roso et al., 2020; Vilarinho et al., 2019). Crew members face additional challenges due to changing extreme weather conditions, necessitating specialized education and training to address these new realities (Awal, 2007; Borca et al., 2021; Maternová et al., 2022).

The potential solutions proposed in the literature highlight the projects, frameworks and working papers to formulate policies for accelerating IWT development and designing innovative vessels to modernize the fleet and enhance competitiveness (Oulfarsi, 2016; Sihn et al., 2015), recognizing that improving vessel design, efficiency, and eco-friendliness are imperative for crew, cargo, and environmental safety (Krause et al., 2022; Maternová et al., 2022). Furthermore, advances in ship construction—such as alternative fuel usage, hull and propeller optimization, and onboard air cavity systems—hold promise (Bernardini et al., 2018). Although the emergence of autonomous shipping, aimed at improving safety and efficiency, is gaining traction, its socioeconomic viability requires evaluation (Chen et al., 2016; Peeters et al., 2020). Additionally, implementation of river information services (RIS) and digitization can facilitate information exchange and decision-making among stakeholders (Koralova, 2017).

Efforts to transition from fossil fuels to cleaner energy sources, such as liquefied natural gas (LNG), hybrid-electric or electric power systems, and hydrogen, are happening to optimize efficiency and safety in IWT operations (Bernardini et al., 2018; Breuer et al., 2022; El Gohary et al., 2014; Perčić et al., 2021). However, challenges remain, particularly regarding hydrogen production costs and profitability (El Gohary et al., 2014). Finally, improving crew training and faithfulness to established work and rest standards are crucial for minimizing risks in IWT operations and mitigating human-related incidents (Bernardini et al., 2018; Breuer et al., 2022; El Gohary et al., 2014; Perčić et al., 2021).

Table 16. Barriers and potential solutions for the fleet

Factors	Barrier	Location / References
Governance and policies	Uncertainty regarding the adoption of new regulations	Sweden (Rogerson et al., 2019)
Management	Shortages of maintenance, repair, and overhaul facilities	India (Trivedi et al., 2021)
	Piloting fees	Sweden (Rogerson et al., 2019)
Operational	Low speed	Danube (Maternová et al., 2022) Europe (Meißner & Klein, 2019)
	Low speed and frequency	Europe (Krause et al., 2022)
	Dependence on the current fairway	Danube (Maternová et al., 2022)
	Dependence on meteorological conditions	Danube (Maternová et al., 2022)
	Unsafe local boats	Nigeria (Sumaila, 2013)
Infrastructure and technology	Lack of navigational infrastructure	Sweden (Rogerson et al., 2019) India (Trivedi et al., 2021) Non-classified (Vilarinho et al., 2019)
	Ageing fleet – lack of modernization	Bulgaria (Koralova, 2017)
	Lack of technical advances for fully electric cargo vessels	Europe (Némethy et al., 2022)
Human resources	Lack of qualified crews	Bulgaria (Koralova, 2017) Non-classified (Vilarinho et al., 2019)
	Lack of training centres	Bulgaria (Pfoser et al., 2018)
Factors	**Potential solutions**	**References**
Governance and Policies	Effective regulation and compliance for ships and crews	Vietnam (Nguyen & Nguyen, 2020) Danube (Maternová et al., 2022)
	Policies for fleet modernization	France (Oulfarsi, 2016)
Operational	Implementation or improvement of RIS	Bulgaria (Koralova, 2017)
Infrastructure and technology	Improvement of engines onboard with green technologies	Brussels (Brusselaers & Mommens, 2022)
	Improvement of vessel design and automation	Danube (Maternová et al., 2022) Italy (Bernardini et al., 2018) Europe (Krause et al., 2022) Europe (Chen et al., 2016)
	Innovation on barges	Non-classified (Wiegmans, 2005)
	Alternative fuel for vessels	Non-classified (El Gohary et al., 2014) Italy (Bernardini et al., 2018) Croatia (Perčić et al., 2021)
	Modernization of the fleet, especially in less developed countries, to meet economic and environmental conditions	Danube (Mihic et al., 2011)
	Introduction of alternative fuels	Germany (Breuer et al., 2022)
	Automation of ships in IWT	Europe (Chen et al., 2016)
Human resources	Skilled labour force	Vietnam (Nguyen & Nguyen, 2020) Danube (Maternová et al., 2022) Non-classified (Vilarinho et al., 2019)
	Education and training for crew members	Non-classified (Borca et al., 2021)
	Reduce crew bad working habits and fatigue	Danube (Maternová et al., 2022)

4.2.3. Waterway

In the pursuit of sustainable development of IWT, numerous barriers emerge, often rooted in governance, policy, and infrastructure deficits. Political will is fundamental for fostering IWT growth, requiring incentives to overcome resistance to modal shift (Malkus et al., 2020; Rogerson et al., 2019; Woś et al., 2022). However, disparities in government support for IWT compared to other transport modes reveal a lack of political will, leading to insufficient infrastructure investment

(Malkus et al., 2020). Moreover, geopolitical dynamics further complicate matters, with regions like Latin America and the Caribbean struggling with inadequate regulatory frameworks delaying IWT progress (Jaimurzina et al., 2016).

Beyond policy challenges, managerial attitudes play a crucial role in IWT advancement, requiring modal integration within broader transportation systems (Rohács & Simongáti, 2007; Trivedi et al., 2021; Vilarinho et al., 2019). However, shortcomings in waterway classification, information systems, and navigation aids impede progress, necessitating stakeholder coordination and border control harmonization (Jaimurzina & Wilmsmeier, 2016; Pfoser et al., 2018; Trivedi et al., 2021). On the other hand, operational challenges are exacerbated by climate change and extreme weather events, affecting infrastructure and transport reliability (Hänsel et al., 2022; Néméthy et al., 2022). Water level fluctuations, particularly in Europe, pose logistical challenges, necessitating extensive dredging efforts and sustainable regulatory frameworks (Hakstege & Laboyrie, 2002; Haurie et al., 2009; Koetse & Rietveld, 2009). Despite initiatives like the Room for the River programme, an integrated management approach is indispensable to balance infrastructure needs with environmental conservation (Havinga, 2020). Apart from this, financial constraints emerge in the IWT landscape, with inadequate investment exacerbating infrastructure deficits globally (Gardels et al., 2016). Insufficient lock capacity and maintenance further compound challenges, leading to congestion and delays (Jaimurzina et al., 2016; Néméthy et al., 2022; Yang et al., 2020). The shortage of financial support for IWT infrastructure underscores the need for innovative funding mechanisms and policy reforms (Miloslavskaya & Plotnikova, 2018; Tzannatos et al., 2016).

On the other hand, efforts to push IWT forward involve a diverse selection of public policies and management strategies. As economic activities along waterways often pose environmental challenges, solutions associated with adapted planning elements to safeguard ecosystems and vulnerable species become necessary (Maksin et al., 2017). These solutions entail developing profitable water management plans with ecological considerations, flood protection measures, and reliable navigation infrastructure (Havinga et al., 2006; Woś et al., 2022). Additionally, integrating ecological strategies is recommended to preserve riverside environments (Mihic et al., 2011), alongside sustainable approaches for managing dredged materials, such as increasing budgets and promoting treatment plans (Hakstege & Laboyrie, 2002).

Another essential aspect is evaluating the potential for river exploitation. For instance, the Danube waterway is considered underutilized in some regions, despite its cost-effectiveness and environmental sustainability (Mihic et al., 2011). Furthermore, effective management systems, focusing on legal and financial frameworks, as well as institutional coordination, are vital (Nguyen & Nguyen, 2020). However, inadequate institutional frameworks delay IWT development in some countries due to weak enforcement policies and overlapping administrative systems (Hu et al., 2019; Nguyen & Nguyen, 2020). For instance, in South America (SA), enhancing regional cooperation is pivotal for sustainable IWT development, emphasizing standardization and integrated transportation systems (Jaimurzina & Wilmsmeier, 2016). Moreover, harmonizing legislation for shared basins and digitizing border control processes are also recommended (Marcu Turcanu et al., 2021).

Another important measure is optimizing transport routes and integrating IWT into the broader supply chain (Williamsson et al., 2020; Zhu et al., 2021). By leveraging information technology systems and monitoring tools, emissions can be minimized while strengthening economies (Kotowska et al., 2018; Zhu et al., 2021). Central to this effort is RIS, which acts as a multifaceted management tool that not only ensures safety and efficiency but also supports environmental protection (Maternová et al., 2022; Niedzielski et al., 2021). Finally, to address some financial constraints, establishing waterway maintenance funds and augmenting funding for combined transport emerge as critical imperatives (Fichert, 2017; Nguyen & Nguyen, 2020). Furthermore, public-private partnerships (PPP) offer a promising avenue for channelling investments into inland infrastructure (Miloslavskaya & Plotnikova, 2018). However, such partnerships must carefully weigh socioeconomic and environmental impacts to ensure sustainable development of IWT and protect the diverse function of waterways systems (Jaimurzina & Wilmsmeier, 2016; Yang et al., 2020).

Table 17. Barriers and potential solutions for the waterways

Factors	Barrier	Location / References
Governance and policies	Geopolitical situation to support IWT	Vistula – Poland (Woś et al., 2022)
	Lack of political interest in developing IWT	Lithuania (Malkus et al., 2020)
	Lack of policy and uncertainty regarding regulation – governance issues	India (Trivedi et al., 2021) Vietnam (Nguyen & Nguyen, 2020) Sweden (Rogerson et al., 2019) Croatia (Perčić et al., 2021) Non-classified (Wiegmans, 2005) Non-classified (Vilarinho et al., 2019)
	Lack of environmental legislation that includes renewable energies and sustainability	Non-classified (Vilarinho et al., 2019)
	High costs (port charges, fairway dues, piloting fees, handling costs)	Sweden (Rogerson et al., 2019) Norway (Rodseth et al., 2020)
	Subsidies for other transport modes	Lithuania (Malkus et al., 2020)
	Taxation systems	Non-classified (Li et al., 2016)
	Regulations for dredged material	The Netherlands (Hakstege & Laboyrie, 2002)
	Lack of standards and regulations to improve safety	Indonesia (Tuan, 2011)
	Change in government mindset to promote modal shift	Indonesia (Tuan, 2011)
	Regulatory frameworks	SA (Jaimurzina & Wilmsmeier, 2016)
	Resistance to modal shift	Sweden (Rogerson et al., 2019)

Management	Lack of publicity and supportive initiatives	Sweden (Rogerson et al., 2019)
	Lack of modal integration	India (Trivedi et al., 2021) Non-classified (Vilarinho et al., 2019)
	Lack of harmonization in border controls	Danube (Pfoser et al., 2018)
	Lack of coordination between stakeholders	India (Trivedi et al., 2021)
	Lack of waterways classification	SA (Jaimurzina & Wilmsmeier, 2016)
	Lack of navigation aids	SA (Jaimurzina & Wilmsmeier, 2016)
	Lack of river information services	Non-classified (Pfoser et al., 2018)
Operational	Climate change and extreme weather events	Vistula – Poland (Woś et al., 2022) Europe (Némethy et al., 2022) Germany (Hänsel et al., 2022) Brazil (Barros Cavalcante et al., 2020) Sweden (Rogerson et al., 2019) Non-classified (Vilarinho et al., 2019) Non-classified (Wiegmans, 2005)
	Low stream flow Water level fluctuations	Europe (Meißner & Klein, 2019) Nigeria (Sumaila, 2013) Non-classified (Koetse & Rietveld, 2009) Non-classified (Haurie et al., 2009)
	Inappropriate information systems or standardized IT systems	Sweden (Rogerson et al., 2019) Non-classified (Vilarinho et al., 2019)
	Unorganized operators	Nigeria (Sumaila, 2013)
	Issues in the selection of transport services (costs, transport time, reliability, and transport quality)	Sweden (Rogerson et al., 2019)
	Flexibility, transport time, frequency	Norway (Rogerson et al., 2019)
	Congestion	China (Yang et al., 2020)
	External costs	Non-classified (Hofbauer & Putz, 2020)
Infrastructure and technology	High costs and significant project investment	Vistula – Poland (Woś et al., 2022) USA (Gardels et al., 2016)
	Lack of interlinking (between rivers)	Danube - Rhine (Mako & Galieriková, 2021) India (Trivedi et al., 2021) Europe (Némethy et al., 2022) Non-classified (Vilarinho et al., 2019)
	Lack of government investment and poor infrastructure	Indonesia (Tuan, 2011) Vietnam (Nguyen & Nguyen, 2020) Non-classified (Vilarinho et al., 2019) Lithuania (Malkus et al., 2020) LAC (Jaimurzina & Wilmsmeier, 2016)
	Lack of sufficient draft or clearance under the bridges	France (Oulfarsi, 2016) Poland (Gołębiowski, 2016) India (Trivedi et al., 2021) Europe (Némethy et al., 2022)
	Inadequate depth	India (Trivedi et al., 2021) Romania – Bulgaria (Pfoser et al., 2018) Nigeria (Sumaila, 2013)
	Absence of locks	Europe (Némethy et al., 2022)
	Ageing infrastructure	USA (Némethy et al., 2022) USA (Miloslavskaya & Plotnikova, 2018)
	High-cost capital requirement for infrastructure	India (Trivedi et al., 2021)
Factors	**Potential solutions**	**References**
Governance and regulations	Preparing and implementing waterway master plans	Nigeria (Sumaila, 2013)
	Water management plan	Vistula – Poland (Woś et al., 2022) Germany (Havinga et al., 2006)
	Development and integration of ecological strategies	Danube (Mihic et al., 2011)
	Specific planning solutions to protect the environment, species, and ecosystems	Rhine-Danube (Maksin et al., 2017)
	Planning solutions for sustainable development	Rhine-Danube (Maksin et al., 2017)
	Extension or improvement plans for waterways should be accompanied by fish habitat improvement plans	Germany (Wolter et al., 2004)
	Environmental legislation that promotes the use of renewable energies and other greener solutions	Non-classified (Vilarinho et al., 2019)

	Sustainable strategies for dredged material	The Netherlands (Hakstege & Laboyrie, 2002)
	Exploitation of river potential	Danube (Mihic et al., 2011)
	Information and promotion platforms and activities for shippers and carriers (RIS)	Europe (Kotowska et al., 2018)
	Harmonizing the legislation in shared basins	Danube (Marcu Turcanu et al., 2021)
	Optimization of border procedures	Danube (Marcu Turcanu et al., 2021)
	Classification of waterways	SA (Jaimurzina & Wilmsmeier, 2016)
	Measures to promote the modal shift to IWT	Non-classified (Borca et al., 2021)
	Government subsidies	China (Yang et al., 2020) Brussels (Mommens et al., 2014)
	Taxation procedures	Lithuania (Malkus et al., 2020)
	Tax system reform	Non-classified (Li et al., 2016)
	Prioritizing IWT in local	Non-classified (Li et al., 2016)
	Increasing funding for combined transport	Germany (Fichert, 2017)
	Economic incentives to support infrastructural and operational investments	Europe (Tzannatos et al., 2016)
	Long-term concessions	SA (Jaimurzina & Wilmsmeier, 2016)
	Adapting public-private partnerships strategies	SA (Jaimurzina & Wilmsmeier, 2016) Non-classified (Vilarinho et al., 2019) USA (Gardels et al., 2016)
	Encouraging private sector participation	Nigeria (Sumaila, 2013)
Management	Integrated approach for River management and regulation measures to provide safety against flooding and improve inland waterway transport	Germany (Havinga, 2020)
	Dynamic River Management System	Germany (Havinga, 2020)
	Ecological river stabilization	Vistula – Poland (Woś et al., 2022)
	Effective management system	Vietnam (Nguyen & Nguyen, 2020)
	Coordinated investments that establish strategic corridors that prioritize connections between waterways and other land transport modes such as rail and road	Europe (Kotowska et al., 2018) Danube (Mihic et al., 2011)
	Improvement of regional cooperation	SA (Jaimurzina & Wilmsmeier, 2016)
	Digitalization of processes	Danube (Marcu Turcanu et al., 2021)
Operational	Adaptation to climate change and extreme weather events	Vistula – Poland (Woś et al., 2022) Germany (Hänsel et al., 2022) Europe (Némethy et al., 2022)
	Water level forecasting	Europe (Meißner & Klein, 2019)
	Integration between logistics modalities and boosted information exchange about trip schedules and terminal operation plans	Non-classified (Vilarinho et al., 2019) Danube (Mihic et al., 2011)
	Inclusion of new industries and cargo types	Brussels (Mommens et al., 2014)
Infrastructure and technology	Implementation of models to support decision-making processes	USA (Langdon et al., 2004)
	Construction of infrastructure (dams)	Vistula – Poland (Woś et al., 2022)
	Safe and reliable traffic channels and navigational aids	Vietnam (Nguyen & Nguyen, 2020) Danube (Maternová et al., 2022)
	Implementation of consolidation centres	Brussels (Brusselaers & Mommens, 2022)
	Improvement and maintenance of waterway infrastructure	Danube (Mihic et al., 2011)
	Efficient and safe inland waterway maintenance	Vietnam (Nguyen & Nguyen, 2020)
	Improving river information services, their connectivity, and functionality as regional information and logistic support	Danube (Maternová et al., 2022) Europe (Kotowska et al., 2018) Danube (Mihic et al., 2011)
	Financial mechanisms to support infrastructural and operational investments	Europe (Tzannatos et al., 2016)
	Creating waterway maintenance funds	Vietnam (Nguyen & Nguyen, 2020)

4.3. Objective 3. To contextualize the barriers and potential solutions for developing sustainable IWT in the case of the Magdalena River.

The content analysis employed to assess the interviews with 20 experts in IWT on the Magdalena River facilitated the identification of 51 barriers and 60 groups of potential solutions. These findings were subsequently categorized into subgroups corresponding to the five factors previously outlined (governance and policies, management, operations, infrastructure and technology development, and human resources). Figure 18 illustrates the distribution of the coded data, indicating a predominant focus on governance and policy-related aspects for both barriers and potential solutions.

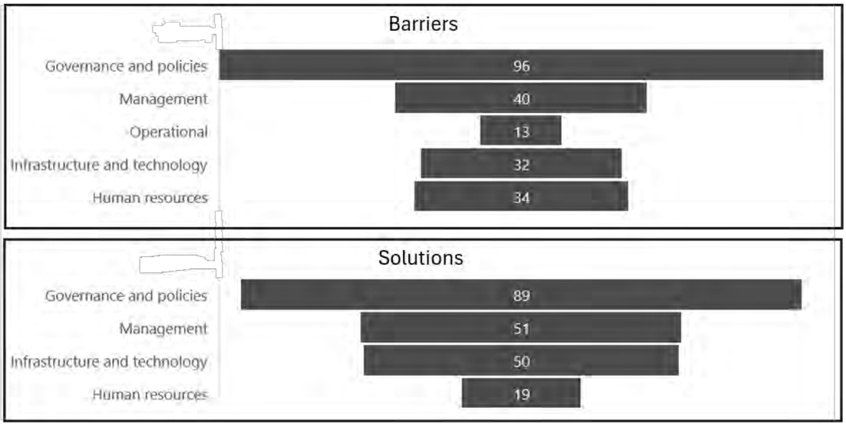


Figure 18. Code overview of barriers and potential solutions for sustainable IWT

The analysis and classification of the barriers highlights issues such as a lack of leadership and homogeneity in public administration, coupled with a fragmented vision of planned and executed activities (Figure 19). Despite several initiatives aimed at promoting IWT, concrete actions and effective progress tracking mechanisms are lacking. This challenge is exacerbated by inadequate stakeholder integration. While public sector experts are attempting to establish collaborative working groups and inter-institutional alliances, the absence of involvement from the private sector and academia impedes comprehensive understanding of sectoral needs. Consequently, this disconnect is leading to deficiencies in decision-making and delayed implementation of new regulations. Moreover, challenges persist due to obsolescent infrastructure, informal fleet operations in remote areas, and insufficient training for crews and public servants, who often operate with limited resources.

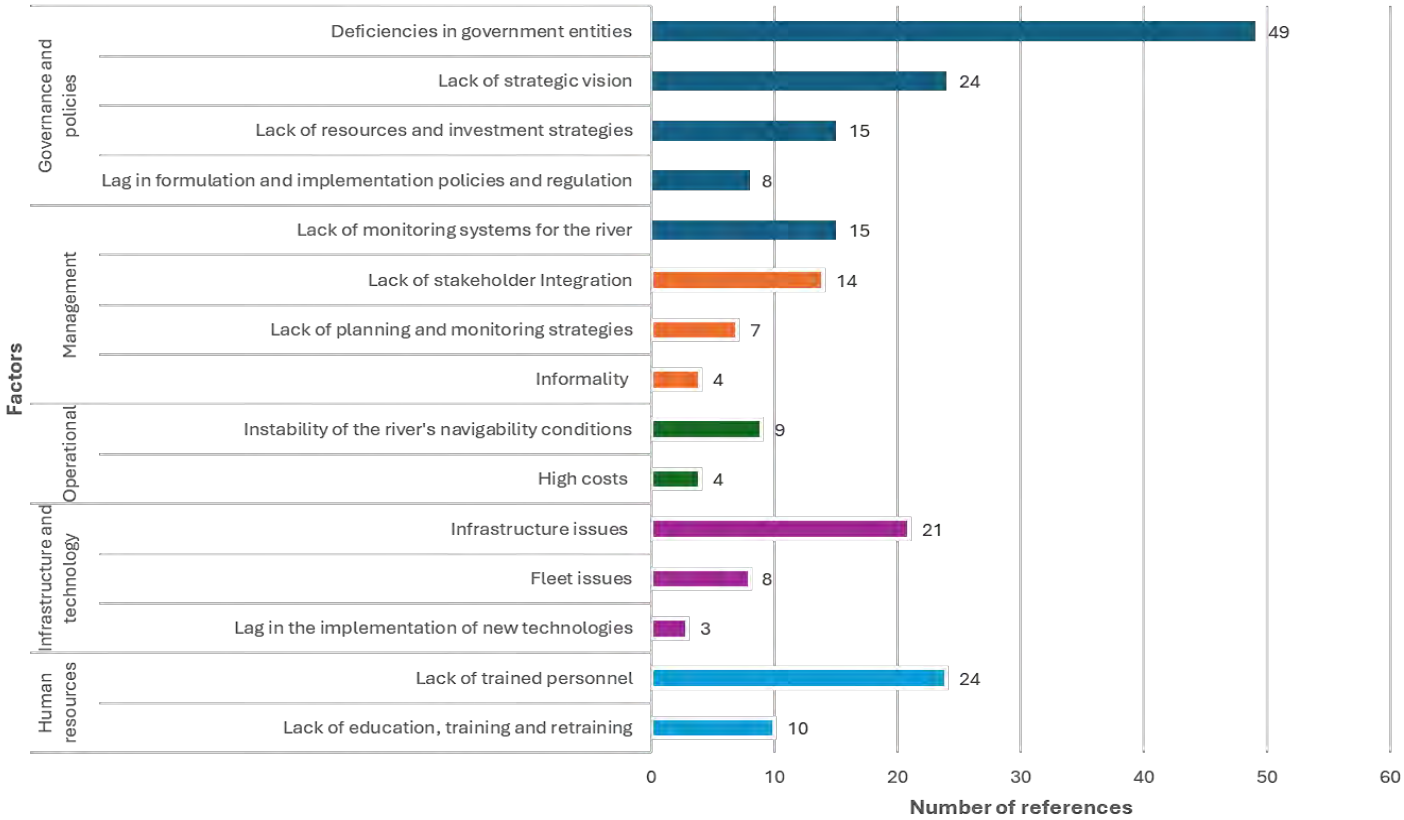


Figure 19. Categorization of barriers to sustainable IWT

On the other hand, Figure 20 shows the potential solutions for sustainable IWT, the need to comprehend the hydrological and morphodynamical characteristics of the Magdalena River basin is highlighted. This understanding is vital for strengthening information systems and decision-making processes across all levels, covering governance and operational aspects such as availability of water depth to navigate in different seasons. Despite the existence of tools facilitating the visualization of certain data, their lack of integration and limited public access underscores the relevance of integrating information, in navigable rivers with expectations of increased cargo and passengers, such as the Magdalena River. Moreover, experts agree on the need to improve infrastructure focused on docks and piers, alongside implementing strategies to ensure the river's continuous utilization, such as night navigation signalling and dredging efforts. To this end, it is crucial to assess the current state of infrastructure and fleets, as well as to devise action plans for modernization and the integration of new technologies tailored to the region's specific needs.

Finally, it is crucial to implement a programme to enhance the capabilities of public officials. Such an initiative would develop a deeper understanding of the challenges and requirements specific to each river basin. If officials were equipped with technical tools, policies could be formulated and decision-making processes conducted with due consideration for environmental protection and the welfare of local populations, while also ensuring economic sustainability to support investment. Furthermore, addressing the deficiency in environmental awareness regarding sustainability issues could be achieved through education and training programmes across all levels of education nationwide.

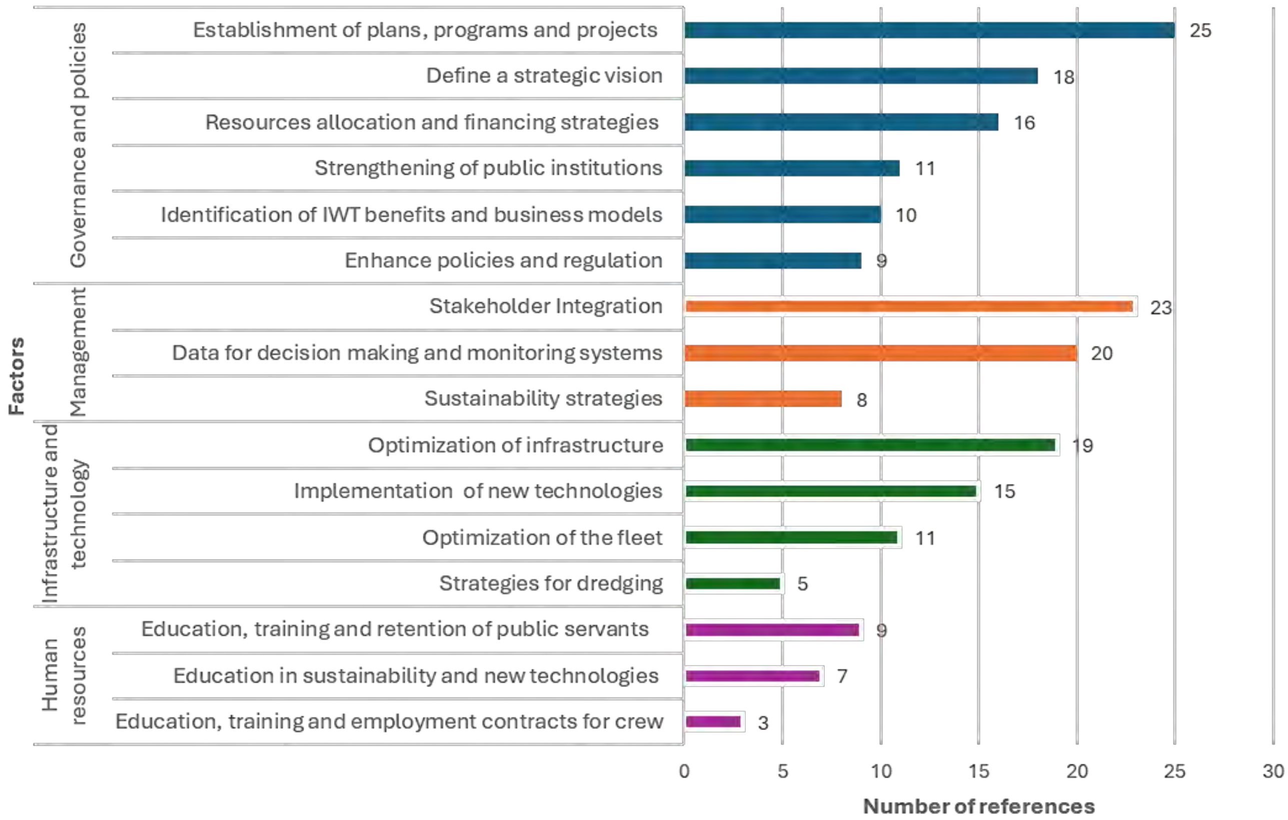


Figure 20. Categorization of potential solutions for sustainable IWT

4.4. Objective 4. To explore the current situation of sustainable development of IWT in the Magdalena River

The study for the Magdalena River secured the opinions of 18 experts in Colombia, from public and private entities and academia. The results are organized into transversal, environmental, social and economic aspects; and a detailed explanation of the results is provided in Article 4. The first part shows the presence or absence of cross-cutting aspects for the Magdalena River: the vision, strategy and monitoring systems have higher values than 50 per cent in the "existing" category, while the sustainability report and RIS have higher values in the "not existing" or "Voluntary/I don't know" categories (Figure 21).

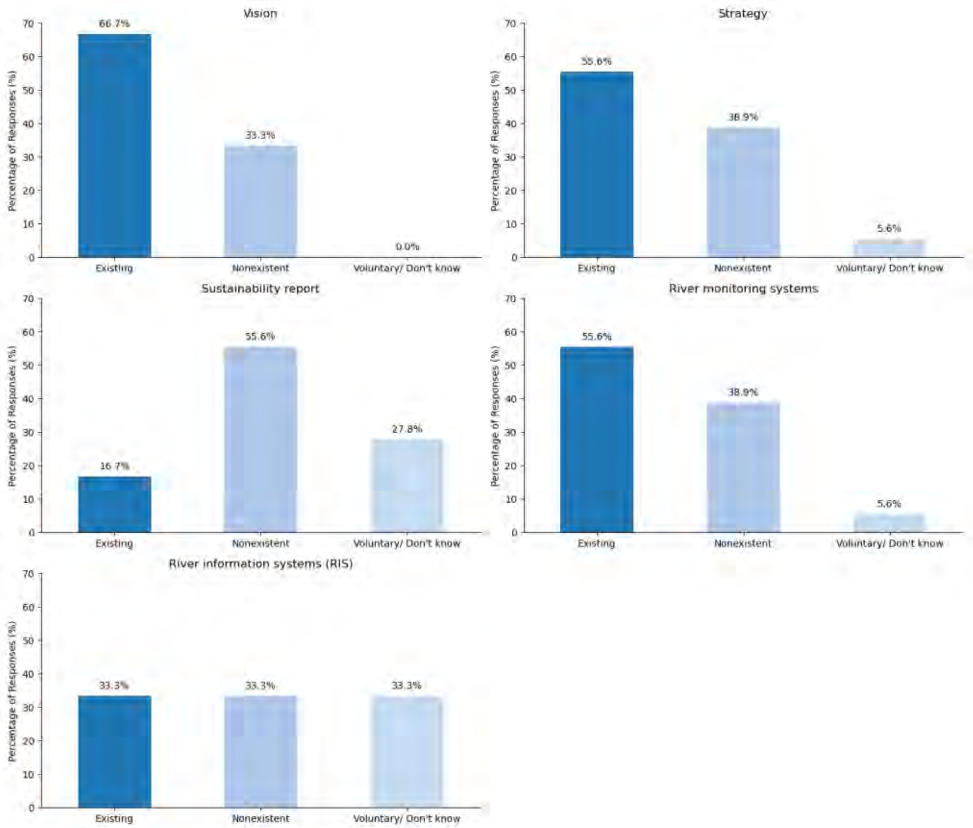


Figure 21. Percentage reporting implementation of instruments for sustainable development of the IWT

Additionally, the survey showed that 50 per cent of the experts believe no anti-corruption policies are in place, although an equal number argue that mechanisms for reporting irregularities do exist. Opinions on data protection laws were divided, indicating a lack of awareness and uncertainty regarding implementation of data protection measures (Figure 22).

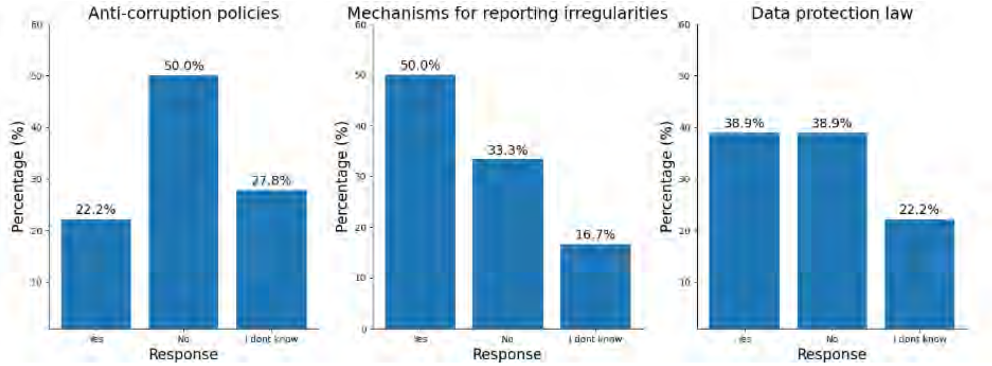


Figure 22. Percentage reporting implementation of other transversal mechanisms

The results concerning environmental plans (Figure 23) shows that most of the environmental plans have a high percentage in the "None" category, with only two exceptions (reduction of water pollution, and ecosystem and biodiversity protection), indicating little progress in implementing these plans associated with the IWT. The average line (21,25)—added to the graph on the basis of the average between the diagnosis, monitoring and implementation phases—gives an average reference value to compare the different levels of progress of the plans. Most of the implementation levels are below this average, which is evidence of a general trend of low implementation of such plans in the IWT sector (Table 18).

Table 18. Descriptive statistics for the analysis of the environmental plans

Environmental policies	*Mean*	*Mode*	*Standard Deviation*
Diagnosis	23	17	9
Monitoring	20	0	23
Implementation	7	6	5
None	35	22	12
I don't know	9	0	8
Not applicable	5	6	4

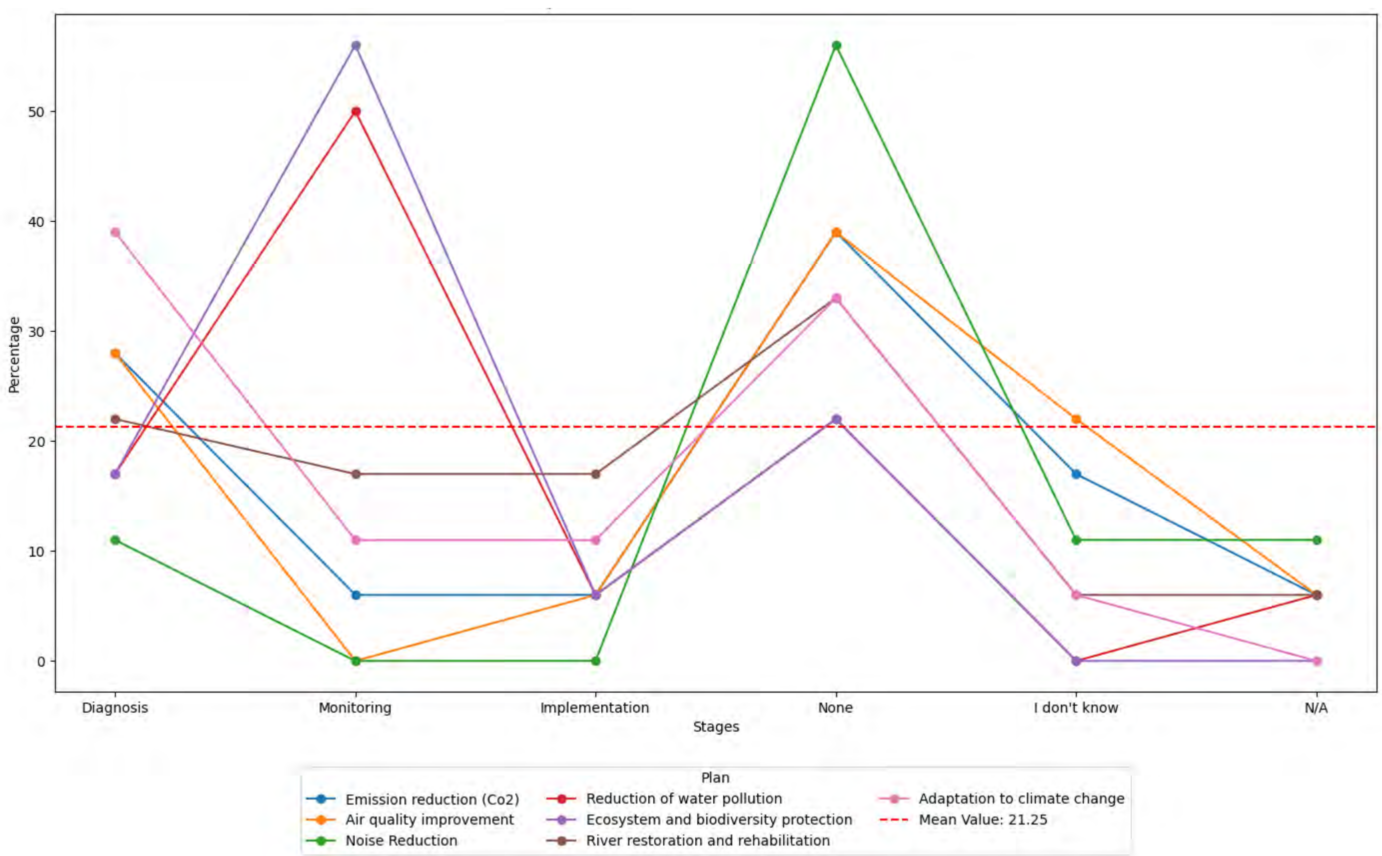
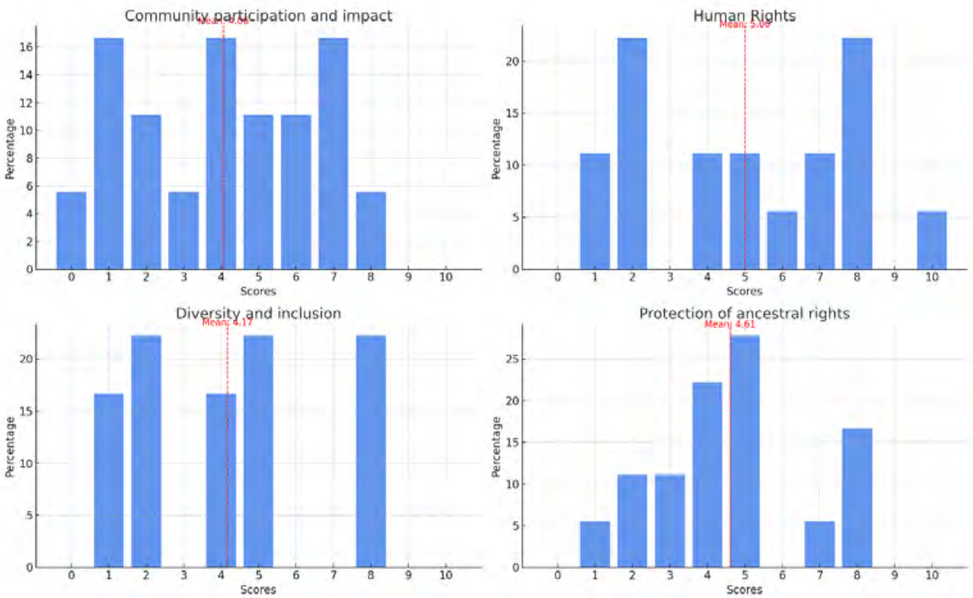


Figure 23. Presence and level of progress of environmental plans

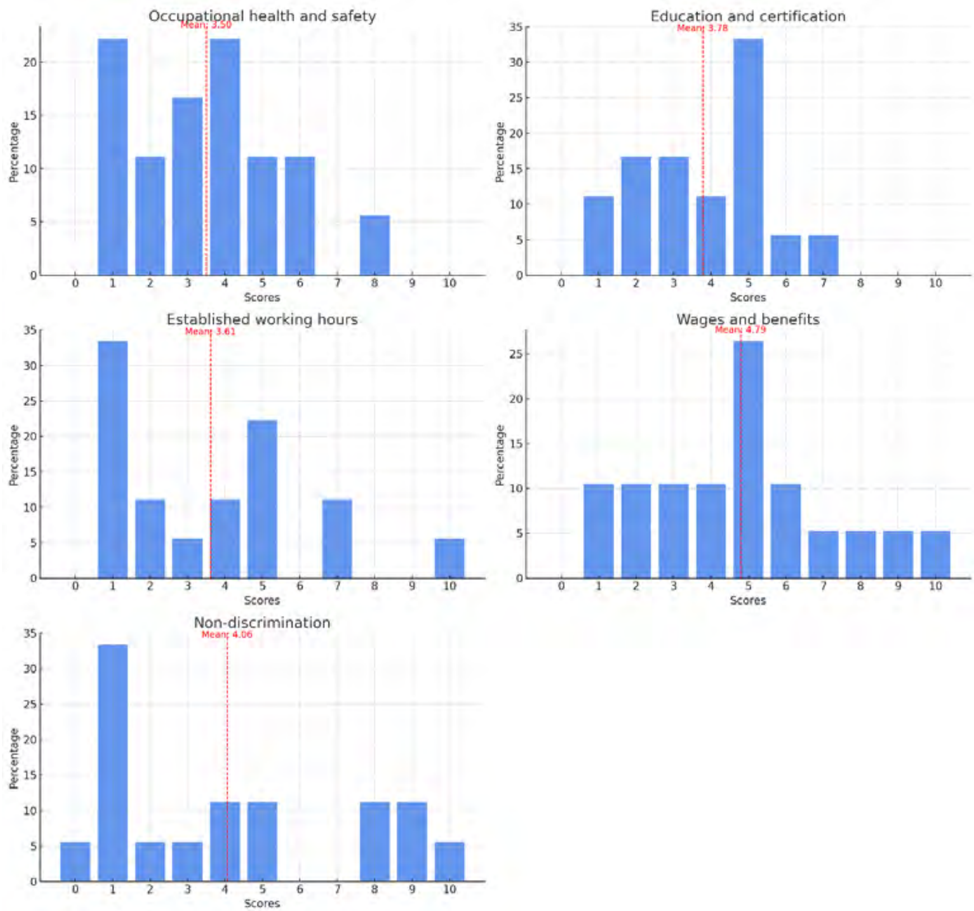
Furthermore, only 39 per cent of respondents believe that IWT facilitates the implementation of new technologies, mentioning items such as satellite navigation systems, cartographic digitization, GPS, pilot schemes for cleaner fuels, autonomous barge operation, and AI in loading and unloading operations. However, the majority (61 per cent) report an absence of such technologies. Additionally, implementation of low or zero-emission technologies is generally seen as low, with 79 per cent of responses rating below 5 on a scale from 0 to 10: in this field, experts mostly mentioned some consultancy work and a few pilot projects in Colombia, not only for the Magdalena River, but in general for Colombia's navigable rivers, indicating limited action in this area.

The third section of the survey covers social aspects. Five labour standards and four aspects of social responsibility programmes were assessed, revealing low and medium compliance averages for both aspects, as shown in Figures 24 and 25.



	Mean	Mode	Standard Deviation
Community participation and impact	4,56	1	2,54
Human rights	5,06	2	2,83
Diversity and inclusion	4,17	2	2,22
Protection of ancestral rights	4,61	5	2,44

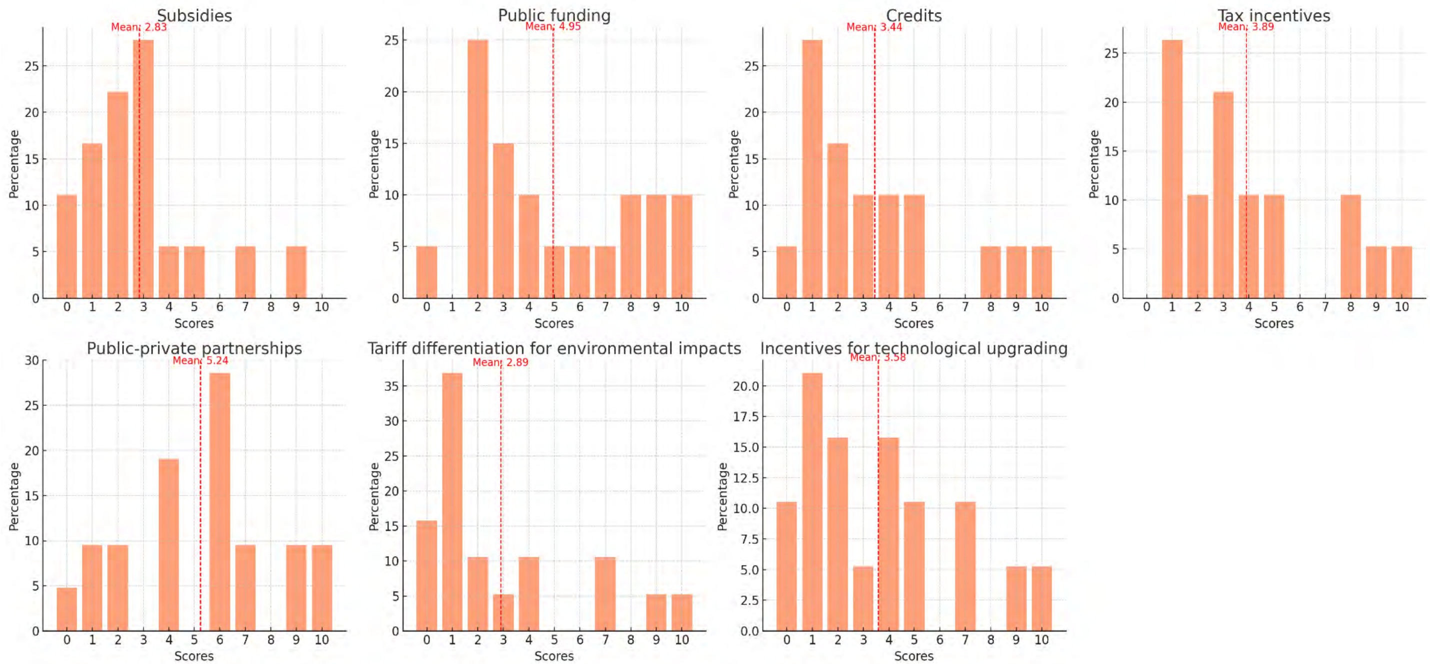
Figure 24. Level of implementation of social responsibility programmes



	Mean	Mode	Standard Deviation
Occupational health and safety	3,5	0	1,6
Education and certification	3,8	0	1,9
Established working hours	3,6	0	1,9
Wages and benefits	4,8	2	1,3
Non-discrimination	4,1	1	1,6

Figure 25. Level of implementation of labour standards

From an economic perspective, Figure 26 highlights the accessibility of various financing strategies for IWT, revealing considerable variability in the implementation of different economic approaches. Most averages range between 2,83 and 5,24, with a maximum standard deviation of 2, indicating generally low implementation of these strategies in Colombia. Public-private partnerships have the highest mean score (5,24), showing the strongest implementation. In contrast, tariff differentiation for environmental impacts has the lowest mode and significant variability, suggesting lower implementation levels.



	Mean	*Mode*	*Standard Deviation*
Subsidies	2,83	1	1,69
Public funding	4,95	1	1,33
Credits	3,44	1	1,43
Tax incentives	3,89	2	1,62
Public-private partnerships	5,24	2	1,81
Tariff differentiation for environmental impacts	2,89	0	2,00
Incentives for technological upgrading	3,58	1	1,27

Figure 26. Accessibility of financing strategies

5. Discussion

The literature review confirmed the research gap outlined in the problem statement regarding the scarcity of studies focusing on waterways or navigable rivers in developing nations. This research, therefore, enriches the academic discussion on the definition of IWT's sustainable development, incorporating the perspective of developing countries. It also facilitates a more comprehensive exploration of Colombia's most significant navigable river. Subsequently, a conceptual framework was proposed, which was intended to assess the current state of IWT and identify potential solutions to overcome barriers that restrict its sustainable development in the country. This section begins with discourse on the concepts surrounding sustainable development within IWT systems, drawing perspectives from various waterways and navigable rivers. It then proceeds to examining barriers and potential solutions observed in various geographic contexts, with particular emphasis on those pertinent to the Magdalena River, the focal point of the empirical investigation. Lastly, the chapter analyses the current state of the Magdalena River compared to the desired state, and reflects on key solutions that could promote progress towards a sustainable IWT system.

5.1. Sustainable development concept from the IWT perspective

This study analysed various definitions of sustainable IWT systems described in the literature, revealing certain limitations in their scope. These definitions often lack a comprehensive vision that integrates economic, social, and environmental aspects. For instance, the definition proposed by Wang et al. (2020) states that "sustainable inland waterways, while expanding bearing capacity to meet the increasing transport needs driven by regional development, must protect major ecological functions of river systems relevant to channel continuity, riparian and floodplain connectivity, flow regime, and biodiversity". However, this definition mainly considers environmental issues and does not emphasize social and economic aspects that are also relevant to its sustainable development. On the other hand, Barros et al. (2022) define sustainable IWT as "the one in which freight increase meets lower environmental and economic costs in waterway developing works and operations, while being resilient to climate change and promoting social equity". Although social and environmental aspects are included in this case, the definition is given in terms of freight transport, leaving aside passenger transport, which could be considered a priority in Colombia due to the lack of other means of transport available. It is therefore evident that the definitions proposed in the literature do not cover all aspects of sustainability, nor the various types of services provided by the IWT.

In this regard, following the system definition proposed by Meadows (2008) this study argues that: in a sustainable IWT system, the primary function is to facilitate the transportation service for people and cargo; moreover, the system comprises three essential physical elements: sustainable ports, waterways, and fleets. These elements are interconnected by key factors, including governance and policies, management, operations, infrastructure and technology development, and human resources. Building on this initial definition of the IWT system, this study has established and validated the definitions of the elements that comprise the system: sustainable river port, sustainable waterway and sustainable river fleet. These concepts contain key elements that can be used in a practical way in both policy and decision-making processes, as they show a revised and prioritized approach to the aspects associated with sustainable development of IWT, not only on the Magdalena River but also on other navigable rivers or waterways with sustainability approaches.

5.2. Barriers to and potential solutions for sustainable development of IWT

The systematic literature review revealed common barriers encountered by developing countries such as India, Viet Nam, and Colombia, as well as emerging waterways like Croatia, Sweden, and Lithuania. These barriers are predominantly associated with a lack of policies, regulatory uncertainty, and insufficient government interest and support for the sustainable development of IWT (Malkus et al., 2020; Nguyen & Nguyen, 2020; Perčić et al., 2021; Rogerson et al., 2019; Trivedi et al., 2021). Moreover, the climate change and extreme weather events have adversely affected IWT systems worldwide, leading to low stream flows and water level fluctuations (Vilarinho et al., 2019; Wiegmans, 2005). This issue is recognized as a significant barrier to IWT development, not only in European waterways but also in countries such as Brazil, Nigeria, and Colombia (Barros Cavalcante et al., 2020; Haurie et al., 2009; Koetse & Rietveld, 2009; Meißner & Klein, 2019; Némethy et al., 2022; Sumaila, 2013). In this regard, there is widespread interest in addressing issues related to environmental protection, ecosystems and the preservation of species. To this end, various measures have been proposed, including plans and regulations that integrate both environmental protection and sustainable development considerations for all activities conducted along the rivers, due to their multiple functions, such as supplying drinking water, and supporting industrial and agricultural activities, among others (Havinga et al., 2006; Maksin et al., 2017; Mihic et al., 2011). Furthermore, the development of sustainable dredging strategies is becoming increasingly relevant, not only in developed countries like the Netherlands but also in Colombia (Hakstege & Laboyrie, 2002).

The solutions proposed for some geographic regions emphasize the generation of incentives such as subsidies, tax reductions, establishment of funds, and other economic stimuli to promote modal shift (Borca et al., 2021; Li et al., 2016; Mommens et al., 2014; Yang et al., 2020). For Colombia, experts emphasize the need for a clear vision of the IWT sector, which includes delineating business models to identify the needs and economic incentives applicable to different navigable rivers and types of cargo or passengers. Additionally, establishing sustainable transport goals is crucial, as the absence of such objectives creates difficulties in the formulation of concrete strategies to reinforce the IWT sector. In line with the above, some authors propose solutions for European waterways associated with the coordination of investments and the generation of strategic corridors, where the use of the IWT is prioritized and new business models are evaluated (Kotowska et al., 2018; Tzannatos et al., 2016). Additionally, strategies such as public-private partnerships (PPPs) are deemed relevant for South American countries, Europe, and the United States alike. However, despite two attempts to establish a PPP for the Magdalena River in Colombia, these initiatives have not materialized. Future studies could examine the success and risk factors associated with the implementation of PPPs in Colombia.

At global level, collaborative efforts involving both the public and private sectors are imperative. This collaborative approach is essential for analysing the prerequisites and devising strategies for implementing suitable business models for each region, while also incorporating emerging industries. Understanding the roles and fostering potential alliances among various stakeholders will contribute to informed decision-making processes. Such processes should adapt to the evolving needs of users, prioritize environmental preservation, and cultivate economically sustainable business models over time.

5.2.1. Barriers

The results reveal that the primary barrier to the sustainable development of IWT is deficiencies in government entities. Experts assert that Colombia suffers from institutional fragmentation due to a lack of clear delineation of institutional roles and boundaries, compounded by an absence of leadership, as no single entity is tasked with overseeing IWT in the country. Consequently, public entity oversight is ineffective, resulting in issues of insecurity, informality and corruption. Furthermore, all Colombian navigable rivers lack a clear vision and defined sustainability standards specifically designed to IWT. This lack of clarity is aggravated by dependence on governing administrations, which often prioritize strategies in their plans for government that differ from those of their predecessors. As a result, there are significant delays in policy formulation and infrastructure investment for the sector, hindering development and progress. Similar barriers have been documented in the literature for other countries. For instance, Lithuania faces challenges due to a lack of political interest (Malkus et al., 2020), while Indonesia requires a shift in government mindsets to support IWT (Tuan, 2011).

In Colombia, as in other regions around the world, various authors have highlighted deficiencies in IWT caused by inadequate governance and policies. This deficiency contributes to uncertainty surrounding its development, as observed in countries such as India (Trivedi et al., 2021), Viet Nam (Nguyen & Nguyen, 2020), and Croatia (Perčić et al., 2021), as well as other regions (Vilarinho et al., 2019; Wiegmans, 2005). In Colombia specifically, regulatory obsolescence and limited implementation—particularly in rural areas affected by socio-environmental conflicts related to illegal activities such as mining and deforestation—alongside the presence of non-compliant actors, impede regulatory compliance and hinder IWT development. However, even in developed countries like Sweden, uncertainty persists due to recent regulations that may raise concerns about personnel requirements, costs, and intermodal connectivity (Rogerson et al., 2019).

The Magdalena River currently lacks comprehensive knowledge of its dynamics, real-time monitoring systems, and historical data needed to generate models and forecasts to deepen understanding of its characteristics. While various public entities are engaged in data collection, this information remains fragmented and, in some cases, is inaccessible to the public. As a result, strengthening monitoring and information systems is crucial for river operations. To address this, a thorough analysis of parameters and active information systems across different public entities in Colombia is imperative to understand the current status and propose measures for enhancement. Furthermore, the Magdalena River lacks strategies for monitoring both existing infrastructure and the current state of the fleet. In Colombia, high informality rates and scarce infrastructure and personnel resources within public institutions pose challenges in covering the extensive water resources across the country, and the absence of a complete inventory obstructs the establishment of plans and projects and significantly affects safety.

In operational terms, IWT on the Magdalena River faces various challenges, particularly concerning long-range cargo navigation. The sections between the Caribbean ports and inland ports up to Barrancabermeja are significantly affected by fluctuations in water levels and low stream flow. These barriers are prevalent in waterways and navigable rivers globally, and while the unique characteristics of the Magdalena River are understood, future studies could explore strategies implemented in other waterways to address these challenges (Haurie et al., 2009; Koetse & Rietveld, 2009; Meißner & Klein, 2019; Sumaila, 2013). Additionally, barriers such as the absence of signalling and information systems for decision-making—along with the lack of infrastructure planning forcing convoy fragmentation at bridge crossings—impede the development of low-cost and highly reliable operations.

In both Colombia and India, experts and academic literature indicate high infrastructure costs and the need for significant capital investment for development (Trivedi et al., 2021). These challenges are exacerbated by delays in the construction of docks and piers, leading to increased issues of informality and insecurity in providing passenger and short-distance cargo transportation services. At ports at the mouth of the Magdalena River where both maritime and river activities occur, there is a lack of incentives to implement sustainability-focused strategies aimed at reducing air emissions, noise or land congestion, or promoting intermodality. This observation aligns with the findings of Gonzalez Aregall et al. (2018), who identified several green port strategies in South America.

On the other hand, despite the Magdalena River boasting the most modern fleet of all of Colombia's navigable rivers, particularly for long-distance cargo transportation, certain barges transporting hydrocarbons still do not meet double-hull specifications, with plans to extend the deadline beyond 2027. Furthermore, vessels providing short-range services are aged and lack modern technologies. This—coupled with the absence of policies outlining plans, projects, and incentives for modernization and technological upgrades—impedes progress towards more sustainable transportation in the country.

In Colombia, there is a lack of environmental awareness among the population regarding sustainability and environmental issues. This, combined with deficiencies in crew training and the limited number of training centres available, poses significant barriers. These challenges, as reported by experts interviewed in Colombia, are also observed in other regions, such as Bulgaria, and unspecified areas documented in the literature (Koralova, 2017; Vilarinho et al., 2019). Additionally, there is evidence of issues regarding the training and knowledge of public officials, intensified by high staff turnover and deficiencies in the recruitment system, which fails to provide guarantees or job security for trained public servants.

5.2.2. Potential solutions

To strengthen the sustainable development of IWT in the Magdalena River, it is imperative to establish a clear vision for IWT across all waterways in the country. This vision must be complemented by comprehensive plans, programmes, and projects with short, medium, and long-term goals and indicators. These actions should prioritize environmental protection and social welfare while also considering evaluation of business models to ensure economic sustainability over time. Similar research outcomes were obtained by Langdon et al. (2004) in the case of the United States. Furthermore, this must be accompanied by the evaluation of current regulations and their updating, considering the implementation of new technologies framed in the use of renewable energies and other greener solutions. Such actions have been documented in the literature, focusing on environmental preservation (Maksin et al., 2017; Wolter et al., 2004), implementation of ecological strategies (Mihic et al., 2011), and formulation of policies for managing dredged material (Hakstege & Laboyrie, 2002), among other issues.

On the other hand, a critical aspect of governance is the ability to create economic strategies and incentives to encourage utilization of IWT. These strategies could include tax procedures and reforms (Li et al., 2016; Malkus et al., 2020), economic incentives (Tzannatos et al., 2016), subsidies (Mommens et al., 2014; Yang et al., 2020) and the establishment of public-private partnerships (Gardels et al., 2016; Jaimurzina & Wilmsmeier, 2016; Vilarinho et al., 2019). Although the empirical research on the Magdalena River highlights the need for economic incentives similar to those proposed in existing literature in developed countries, this is the first research on sustainable development of the most important navigable waterway in Colombia (Magdalena River), and a further initial step in addressing this important issue in developing countries. However, research is essential to identify the most effective strategies for promoting and stimulate IWT in Colombia and to adopt appropriate business models to support its economic sustainability.

In addition to the above, implementing any type of solution requires the integration and cooperation of various stakeholders (Hu et al., 2019; Kotowska et al., 2018). For the Magdalena River case, it is recommended to foster agreements between the public and private sectors, prioritizing decision-making based on technical and environmental information, with academia playing a crucial role. Moreover, establishing connections that facilitate exchange of sustainable best practices and the establishment of international cooperation to strengthen them is essential in Colombia. Furthermore, as highlighted by the respondents, there is a need to generate data and strengthen river monitoring systems. The information about geographical data, traffic and vessel information, hydrological and meteorological data, among others, enhance the understanding of basin characteristics and assists the generation of forecasts aimed at policy and regulation implementation, informed decision-making in operations, and environmental protection strategies. These outcomes are aligned with the findings of the authors investigating European waterways (Ambra et al., 2019; Kotowska et al., 2018; Mihic et al., 2011).

Although the challenges of having modern infrastructure adapted to the needs of IWT have been reported in IWT systems globally (Krause et al., 2022; Oganesian et al., 2021; Vilarinho et al., 2019; Woś et al., 2022), in the case of the Magdalena River, especially in remote regions where transportation of people and cargo occurs in smaller vessels, dock and pier infrastructure is precarious. Some alternatives, such as the construction of "standardized docks" or the establishment of pilot projects, are options to improve these conditions. Furthermore, the river requires investment projects aimed at dredging, digital navigation aids (cartography), and infrastructure adaptation to connect with other modes, especially road transportation. However, this should only be done after evaluating business models and including new industries. For example, similar suggestions in European waterways were provided in Bu & Nachtmann, (2021); Mommens et al., (2014); Roso et al., (2020) and Sihn et al., (2015). Additionally, while automation and digitalization strategies prevail in maritime ports for international transportation (Krause et al., 2022), their implementation in IWT is crucial and should start to be prioritized, especially in ports supporting the operations of long-range vessels.

Compared to maritime vessels, there are fewer studies on the transition of the fleet engaged in inland navigation to alternative energy sources and autonomous navigation (Némethy et al., 2022). However, various studies emphasize that fleet modernization, especially in less developed countries, provides both environmental and economic benefits (Mihic et al., 2011). In this sense, Colombia is currently developing a pilot project for the implementation of an electric boat for school transportation, the results of this initiative should be used to evaluate the drivers, barriers and possible solutions for the implementation of this type of technology in the Magdalena River. Likewise, innovation, hull and engine design improvement, and automation are relevant strategies for the sustainable development of IWT (Bernardini et al., 2018; Brusselaers & Mommens, 2022; Chen et al., 2016; Krause et al., 2022; Maternová et al., 2022), for this reason, the Colombian shipbuilding industry must be integrated into strategic sustainability initiatives for the IWT in the country.

Although the Magdalena River in Colombia is considered the waterway with the most modern fleet, several strategies must be implemented to renew barges still operating with single-hull designs for hydrocarbon transportation, as well as smaller vessels with shorter life cycles. This could begin with small actions such as replacing two-stroke engines with more efficient four-stroke engines that emit lower levels of pollutants. In terms of human resources, programmes for educating, training, and retaining public servants are required for the Magdalena River and

Colombia in general. Public institutions are responsible for generating regulations and plans aimed for developing IWT, and are also responsible for ensuring compliance with current regulations, which directly affect user safety and environmental protection. Regarding crews, several actions need to be adjusted to address the challenges brought by new technologies and energy sources. In this regard, training centres should be strengthened, and their curricula should be adapted to the sector's new needs. Additionally, labour regulations for onboard personnel need to be reviewed to make them more flexible and adapt them to the characteristics of onboard operations, which differ significantly from standard land-based activities.

5.3. Current state of sustainable development of IWT for the Magdalena River case

Figure 27 illustrates the conceptual framework that facilitated analysis of the main barriers and potential solutions for the sustainable development of the IWT from a change management perspective guided by the forcefield theory described in section 2.3. Additionally, the study established the characteristics of sustainable IWT and through the answers provided by the experts determined the distance between the "desired state" and the "current state" for the Magdalena River. Although most of the experts argued that there a vision and strategy exist for the sustainable development of the IWT, when contrasted with the results obtained in the environmental, social and economic aspects, progress in implementing actions associated with sustainability are at low levels of development. This could indicate that the current vision and strategy are not aligned with sustainability issues, that levels of progress are low or that there is a lack of knowledge in both public and private entities about their implementation.

The literature review shows the need to establish environmental standards for the protection of rivers that fulfil transport functions, and highlights the relevance of maintaining river health and protecting ecosystems (Sommerauerová et al., 2018; Wang et al., 2020), protecting the ecological functions of watercourses (Havinga et al., 2006; Mihic et al., 2011), preserving biodiversity (Wang et al., 2020), ecological conservation and restoration (Wang et al., 2020), low energy consumption energy efficiency (Mihic et al., 2011; Sommerauerová et al., 2018), and climate change resilience (Barros et al., 2022; Havinga, 2020; Havinga et al., 2006), among others. However, the results indicate that the Magdalena River is in the initial stages of most environmental plans, with the notable exceptions of the "Reduction of Water Pollution" and "Ecosystem and Biodiversity Protection" plans, which are more advanced. Given the river's crucial functions, such as supplying drinking water and supporting agriculture, aquaculture, tourism, and other sectors, priority should be given to implementation of these plans. These sectors are fundamental for the well-being of the 79 per cent of Colombia's population residing along the river (Cabarcas & Peñaranda, 2023), highlighting the need for comprehensive and effective environmental management to ensure sustainable development in these regions.

This study analysed five labour standards and four aspects of social responsibility programmes, showing low and medium compliance averages for both aspects, demonstrating the importance of strengthening monitoring and control mechanisms by public entities, as well as the need to promote education and research in order to establish efficient and effective operations (Rohács & Simongáti, 2007; Wiercx et al., 2019). On the other hand, for the Magdalena River, there are stretches where the only available means of transport is IWT. Therefore, its development should be a priority to ensure the well-being and guarantee the rights of the populations living along its banks, given that these regions face high levels of informality, high fuel costs, low levels of technological development, and poorly developed infrastructure.

Among the barriers raised by the interviewees, the lack of business models and the lack of integration of stakeholders towards a modal shift from road transport to IWT were highlighted. However, the experts argue that modal shifts are usually motivated by economic incentives such as tax reductions, subsidies or higher cost-benefit ratios, as well as the implementation of new regulations encouraging use of the new mode, while for the Magdalena River the survey shows that the implementation of such economic incentives is low and the implementation of environmental regulations to motivate the shift is also in its early stages. In this regard, consistent with the findings of this research, Mihic et al. (2011) and Rohács & Simongáti (2007) argue that clear legislation and policies to promote IWT and preparedness levels for a modal shift from road transportation to IWT are crucial aspects for strengthening and implementing a sustainable IWT system.

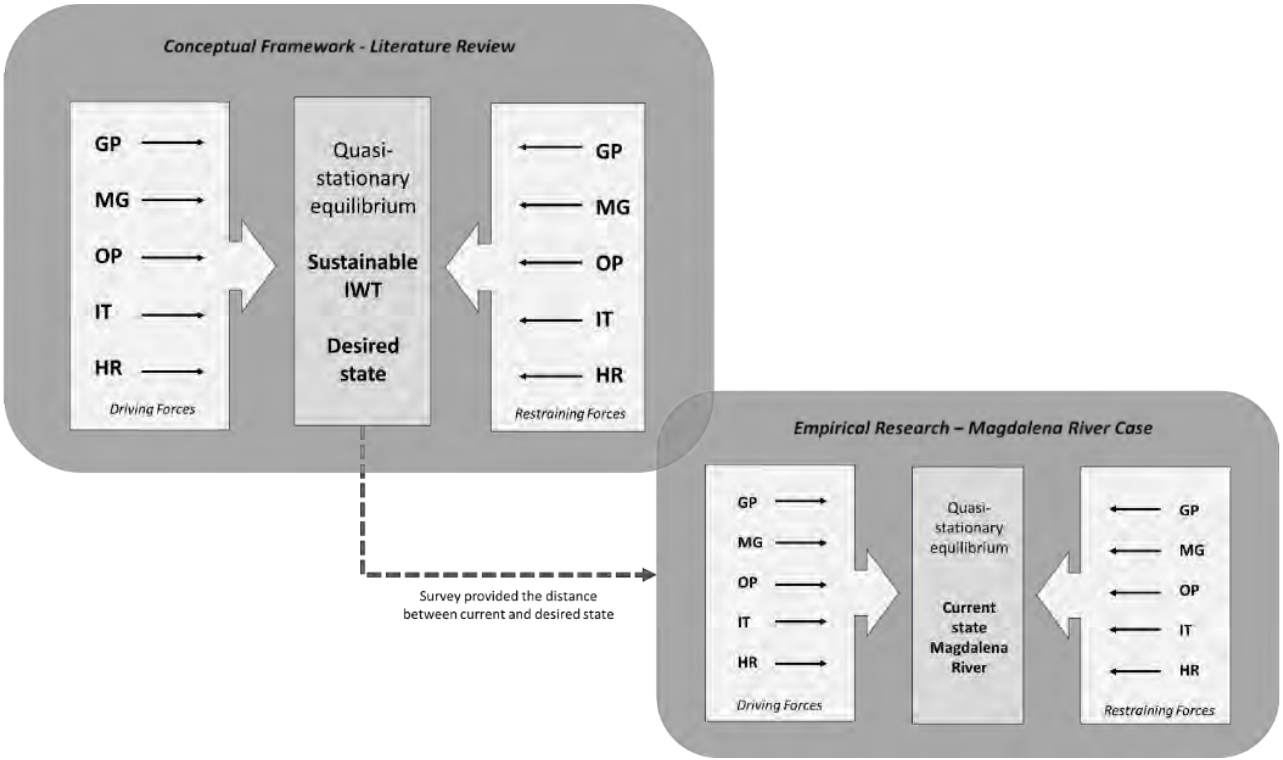


Figure 27. Illustration of the conceptual framework and empirical research

6. Conclusions

This study offers a comprehensive perspective on the sustainable development of IWT, defining it as a system consisting of three key components: waterways, inland fleets, and ports. These elements work together to facilitate the continuous flow of cargo and passengers. The research highlights five crucial factors—governance and policies, management, operations, infrastructure and technology, and human resources—that impact the sustainable development of IWT in a region. Additionally, the study identifies the environmental, social, and economic benefits of IWT implementation, such as reductions in pollution, alleviation of congestion, cost savings, and support for rural development. Moreover, the research outlines a framework for addressing barriers to and proposing solutions for the sustainable development of IWT. It emphasizes the need to integrate environmental and social considerations into IWT development, including adapting infrastructure and regulations to ensure equity for riparian regions. The study also notes that shifting transport modes, such as moving from road to IWT, can reduce external costs related to congestion, climate change, habitat loss, accidents, and infrastructure wear. However, overcoming these challenges requires government support for integrating IWT with other transportation systems, developing economic strategies for infrastructure investment, and investing in innovative technologies to improve management and operations.

The study emphasizes the need for basin-specific research, identifying a significant gap in the evaluation of Latin America's extensive waterway systems. While much research has been concentrated on Europe and Asia, particularly China, there is a notable lack of studies and solutions focused on the development of waterways in Latin America, despite their potential. On the other hand, the case study found that the main barriers to IWT development in the Magdalena River stem from the lack of governance and policies, both generally and specifically for the Magdalena River. Experts suggest that addressing these issues requires a clear vision from the government regarding resource allocation and efforts to promote sustainable IWT. They also emphasize the need for understanding the roles of various public entities and establishing a central leadership entity to ensure coordinated efforts toward common goals. Furthermore, enhancing data collection and processing is crucial for understanding river dynamics, with real-time public access to this information improving decision-making for public policies, infrastructure investments, and transport planning, also, updating port infrastructure and fleet databases will aid in the modernization and technological advancement of IWT.

Training and retraining personnel in state institutions and operational roles is crucial for adapting to new technologies and efficient processes. Experts also highlight the importance of developing clear business models that involve all stakeholders, including local communities, academia, and the private sector, to support sustainable IWT development. Strengthening IWT could enhance well-being in remote areas along the Magdalena River by reducing illicit activities, protecting society, boosting the economy, and fostering development in vulnerable regions. Additionally, there is a notable lack of academic literature on IWT in Latin America, particularly in Colombia, underscoring the need for future research on the proposed solutions and stakeholder roles. The final part of this research assesses the extent to which transversal, environmental, social, and economic aspects are implemented, revealing low levels of adherence to the proposed characteristics. While the study sheds light on the current state of the Magdalena River—Colombia's most important navigable river in terms of IWT—its findings are valuable for identifying priorities to improve IWT also for other navigable rivers in the country. Additionally, some results may be applicable more broadly, serving as a reference for decision-making, evaluations, and policy development in IWT systems across different waterways.

Academic research on IWT boosted since IWT has been studied mainly in the context of developed waterways located in Europe, the United States and China, while literature on developing countries is scarce. Particularly for South America, despite the continent's extensive water system, there are several deficiencies and barriers to IWT's development, and academic research has been limited. In this regard, this research is contributing to reducing the gap in the academic research about IWT in South American waterways, with a focus on the Magdalena River in Colombia. Furthermore, this study enabled the IWT to be described using system theory concepts and sustainable development concepts for identifying and defining the main elements comprising the system: inland river ports, the waterway and the inland river fleet.

One of the main conceptual contributions of this research is the generation of definitions associated with sustainable development of IWT, which have proven to be applicable in diverse geographical contexts, as the definitions were proposed and validated by experts at global level, enriching academic discussions on sustainable development and IWT. However, these definitions are even more relevant in regions with developing waterways or navigable rivers, where IWT requires further strengthening and formalization. In these contexts, the vision is not clear and the establishment of short-, medium- and long-term goals within a well-defined framework is needed. On the other hand, the use of force field theory concepts allowed the identification of the restraining and driving forces in a sustainable IWT system, which were operationalized as barriers to and potential solutions for sustainable development of IWT. This research presents a framework that incorporates the main barriers and potential solutions in various contexts at global level; these results can be evaluated and incorporated in different contexts serving as a framework not only in a conceptual manner but also with practical implications for different waterways or navigable rivers.

The outcomes of this research might have valuable practical contributions. This dissertation addresses critical challenges faced by the IWT sector in Colombia, with a particular focus on the Magdalena River. The research highlights a significant lack of vision and coherent business models, and delays in regulation and resource allocation, all of which hinder the sustainable development of IWT. Additionally, the study underlines the impact of corruption, illegal activities (such as mining and deforestation), and ineffective control mechanisms, particularly in remote regions, which compromise the security of IWT operations. The practical contribution of this dissertation lies in its comprehensive analysis of the current state of IWT in Colombia, specifically regarding sustainability. By identifying low-to-medium levels of compliance with sustainable development characteristics, the research provides a foundation for proposing actionable solutions, which include the development of a clear vision, strategy, and goals tailored to the IWT sector.

Furthermore, the dissertation offers a framework that policymakers and decision-makers can utilize to enhance the sustainability of IWT, taking social, economic, and environmental aspects into account. The study emphasizes the importance of localized approaches, as sustainability drivers may vary across regions. Additionally, the research advocates the education and training of decision-makers, the implementation of infrastructure projects, and the adoption of new technologies as essential steps toward achieving a more sustainable IWT system. The findings and recommendations presented in this dissertation serve as a guide for the Government of Colombia and other stakeholders in developing short-, medium-, and long-term strategies for sustainable IWT development. By revisiting and realigning current policies and strategies with sustainable practices, this research offers a practical pathway for strengthening the IWT sector, ultimately improving access to essential services such as health care, education, and mobility in the regions that rely on this vital mode of transport.

This dissertation has several limitations, particularly in terms of methodology and generalization. While all the methodological approaches were executed with rigour, each method inherently carries its own limitations, which are addressed in the methodology section. The author opted for a mixed methods approach as a strategy to mitigate the individual limitations of each method. In this case, the systematic review of the literature served as the conceptual foundation for the research (Creswell & Creswell, 2018). However, the scarcity of publications on waterways or navigable rivers in Latin America especially in Colombia is acknowledged as a limitation, as there is limited scientific information describing IWT in the study area (Magdalena River). To address this gap, interviews and questionnaires were employed to supplement the data. Nonetheless, the author acknowledges the inherent limitations of these methods, such as potential bias in responses, challenges in recruitment, and limitations in sample size, among others (Creswell & Creswell, 2018).

On the other hand, generalization has been criticized by some quantitative researchers because qualitative research can be impressionistic and subjective, and is difficult to replicate (Bryman, 2016). Although the author understands these limitations – and some of the findings of this study will be applicable to a particular case (Colombia – Magdalena River) which cannot be fully generalized to other waterways or riparian countries – some other aspects of sustainable development and its characteristics and definitions can be generalized as they were not only validated by experts in the Magdalena River, but also by other international opinions during the survey phase, leading to a *moderatum* generalization (Bryman, 2016).

Based on the results obtained in this research, further research is needed to investigate the main business models that can be used in the country's navigable rivers, including strategies and incentives applicable to the region. Furthermore, it is necessary to understand the availability and applicability of new technologies, for all three elements (fleet, waterway and river inland ports), as well as the implementation of projects for monitoring and data collection, and also the establishment of RIS. Finally, it is necessary to understand interaction between the stakeholders and determination of how they can work in a coordinated manner to establish plans, programmes and projects that encourage the development of the IWT, assessing the positive impact or risks that this could entail for the country.

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Appendix 1: Questions for the semi-structured interview

Personal information

1. Could you please describe your role and responsibilities at (organization)?
2. How long have you been in the position?

Definition of sustainable development of IWT in the Magdalena River

1. What do you understand by "sustainable development of IWT”?
2. What strategies are currently being implemented for sustainable development of IWT? (Could you please provide examples for social, economic and environmental strategies).
3. What strategies are missing for the sustainable development of IWT? (Could you please provide examples for social, economic and environment).
4. What types of strategies will be implemented for the sustainable development of IWT? (Could you please provide examples for social, economic and environment)

Analysis of IWT in the Magdalena River

1. Which of these categories best describes your opinion on the sustainable development of IWT in Colombia?

   a. I strongly support it.
   b. I somewhat support it.
   c. I do not support nor oppose it.
   d. I somewhat oppose it.
   e. I strongly oppose it.

For those who answer "a", "b", or "c":

   a. How do you support sustainable development of IWT?
   b. Do you have financial or human resources available to support it?
   c. Do you work together with other stakeholders to achieve sustainable development of IWT? With whom? How?

d. Who do you think opposes the sustainable development of IWT?
e. Under what conditions would you choose not to support sustainable development of IWT in Colombia?

For those who answered "d" or "e":
a. Why do you oppose to sustainable development of IWT in Colombia?
b. In what manner would you demonstrate this opposition?
c. Do you work together with other stakeholders to oppose sustainable development of IWT? With whom? How?
d. Who do you think opposes the sustainable development of IWT?
e. Under what conditions would you come to support to sustainable development of IWT in Colombia?

Barries and solutions for sustainable development of IWT in the Magdalena River

1. Which are the main barriers for sustainable development of IWT in Colombia?
2. How can the barriers be overcome?

Appendix 2: Questionnaire

Introduction

Thank you for agreeing to participate in this research survey, which is conducted as part of a dissertation for the Ph.D. program in Maritime Affairs at the World Maritime University in Malmo, Sweden. The dissertation focuses on "Understanding inland waterway transport from a sustainable perspective: The Colombian case".

The information gathered through this questionnaire will be utilized for research purposes and will contribute to the dissertation and academic papers, which will be publicly available online.

Your personal details will remain confidential and will not be disclosed. You have the option to withdraw from the study at any point. All research data will be securely stored on a virtual drive associated with a World Maritime University email address and will be erased upon completion of the degree.

Your participation in this survey is greatly valued.

Natalia Calderón
PhD Student – World Maritime University
w1803084@wmu.se

Introduction
I consent to my personal data, as outlined above, being used for this study. I understand that all personal data relating to participant is held and processed in the strictest confidence.

- o Yes, please proceed to the questionnaire
- o No, I would like to exit.

Personal information

1. Which of the following stakeholder groups do you belong to?

- o State Entities

- o Shipping companies - Shipowners
- o Riverine Communities
- o River Ports
- o Seaports
- o Academy
- o Other ________

2. Choose one of the following elements of the river transportation system in which you consider yourself an expert:
- o Fleet
- o Waterway or navigable river
- o River ports

Sustainable development of inland waterway transport - Definitions

3. Organize the following items of the sustainable inland waterway transport service according to their importance:
   Accessible
   Acts within the national, regional or international value chain
   Autonomous (unmanned)
   Available
   Efficient
   Generates zero or low emissions
   Inclusive
   Improves the quality of life of the population
   Allows access to basic services
   Protect available natural resources
   Resilient
   Safe

In this section we would like you to give us your opinion regarding the following definitions…

4. We define **sustainable river port** as an "infrastructure on the edge of a body of water that facilitates the safe transfer of passengers or cargo, on which zero or low emissions technologies operate and possess social responsibility and environmental protection standards". To what extent do you agree with this definition?

0	1	2	3	4	5	6	7	8	9	10

If you consider that there is a more appropriate definition for a **sustainable river port**, please write it in the following space:

___

5. We define **sustainable navigable river** as a "body of water that is naturally navigable or intervened, that possesses a navigation classification system (PIANC, 2020) and environmental and social regulatory frameworks implemented". To what extent do you agree with this definition?

0	1	2	3	4	5	6	7	8	9	10

If you consider that there is a more appropriate definition for a **sustainable navigable river**, please write it in the following space:

___

6. We define **sustainable river fleet** as a "set of vessels that comply with national or international safety and social protection regulations and standards, generate zero or low emissions, and the stakeholders jointly seek the optimization and resilience of the services". To what extent do you agree with this definition?

0	1	2	3	4	5	6	7	8	9	10

If you consider that there is a more appropriate definition for a **sustainable river fleet**, please write it in the following space:

___

Transversal aspects

Considering that the government or state of each country must consider some aspects to support the sustainable development of river transport, the following questions seek to understand your opinion on such activities.

7. The river on which you have experience is:

- o A waterway
- o A navigable river
- o Not sure

8. Does the river on which you have experience has a classification?

- o Yes
- o No
- o Not sure

9. On the river where you have experience, which of the following instruments for the development of inland waterway transport are present or non-present and which are voluntary or compulsory?

Instruments	Present	Non-present	Compulsory	Voluntary
Vision				
Strategy				
Sustainability report				
River information services (RIS)				

10. Does the river in which you have experience have anti-corruption policies?
- o Yes
- o No
- o I don't know

Does the river in which you have experience have whistleblowing mechanisms in place?
- o Yes
- o No
- o I don't know

11. Does the river in which you have experience have a data protection law?
- o Yes
- o No
- o I don't know

Environmental aspects

12. What is the level of development at which the following environmental plans are for the selected element (fleet, waterway or navigable way, river port)?

Plan	None	Diagnosis	Monitoring	Implementation	I don't know	N/A
Emission reduction (Co2)						
Air quality improvement (e.g. reduction of particulate matter, NOx, SOx)						
Noise Reduction						
Reduction of water pollution						
Ecosystem and biodiversity protection						

River restoration and rehabilitation						
Adaptation to climate change						

13. In the selected element (fleet, waterway or navigable river, river port) do they use or facilitate the implementation of new technologies?
- o No
- o Yes… What technologies? ________

14. What advances are there in the implementation of technologies with zero or low emissions in the selected element? Where 0 is not implemented and 10 is fully implemented.

0	1	2	3	4	5	6	7	8	9	10

Social Aspects

15. In the selected river there are sections where the only form of access to basic services such as mobility, health or education, among others, is the use of river transport?
    - o No
    - o Yes ...

How developed is the selected element (fleet, waterway, inland waterway, river port) in these regions? Where 0 is not developed and 10 is fully developed.

0	1	2	3	4	5	6	7	8	9	10

16. How well implemented are the following labour standards? Where 0 is not implemented and 10 is fully implemented.

Occupational health and safety	0	1	2	3	4	5	6	7	8	9	10
Education and certification	0	1	2	3	4	5	6	7	8	9	10
Established working hours	0	1	2	3	4	5	6	7	8	9	10
Wages and benefits	0	1	2	3	4	5	6	7	8	9	10
Non-discrimination	0	1	2	3	4	5	6	7	8	9	10

17. How advanced are the following social responsibility programmes in the selected element (fleet, waterway or navigable river, river port)? Where 0 is not advanced and 10 is fully advanced.

Community participation and impact	0	1	2	3	4	5	6	7	8	9	10
Human Rights	0	1	2	3	4	5	6	7	8	9	10
Diversity and inclusion	0	1	2	3	4	5	6	7	8	9	10
Protection of ancestral rights	0	1	2	3	4	5	6	7	8	9	10

Economic Aspects

For freight transport, on the selected river, is there a higher cost-benefit of using inland waterway transport compared to other means of transport?

- o Yes
- o No
- o Not calculated
- o o I don't know

For passenger transport, in the selected river, is there a higher cost-benefit of using river transport compared to other means of transport?

- o Yes
- o No
- o Not calculated
- o o I don't know

18. To what extent are the following financing strategies accessible to the selected element (fleet, waterway, inland waterway, inland port)? Where 0 is not accessible and 10 is fully accessible.

Subsidies	0	1	2	3	4	5	6	7	8	9	10
Public funding	0	1	2	3	4	5	6	7	8	9	10
Credits	0	1	2	3	4	5	6	7	8	9	10
Tax incentives	0	1	2	3	4	5	6	7	8	9	10
Public-private partnerships	0	1	2	3	4	5	6	7	8	9	10
Tariff differentiation for environmental impacts	0	1	2	3	4	5	6	7	8	9	10
Incentives for technological upgrading	0	1	2	3	4	5	6	7	8	9	10

19. To what extent are the following elements the responsibility of the public and/or private sector?

Elements	Publico	Privado	Ambos
Maintenance of available infrastructure			
Fleet maintenance			
Renewal or modernisation of infrastructure			
Information systems management			

Appendix 3: Papers included in this thesis

Paper 1	Calderón-Rivera, N., Bartusevičienė, I., & Ballini, F. (2024). Sustainable development of inland waterways transport: a review. *Journal of Shipping and Trade, 9(1), 3. https://doi.org/10.1186/s41072-023-00162-9*
Paper 2	Calderón-Rivera, N., Bartusevičienė, I., & Ballini, F. (2024). Barriers and solutions for sustainable development of inland waterway transport: A literature review. *Transport Economics and Management, 2: 31-44. https://doi.org/10.1016/j.team.2024.01.001*
Paper 3	Calderón-Rivera, N., Bartusevičienė, I., & Ballini, F. (Under review). Barriers and solutions for sustainable development of IWT in Colombia: The Magdalena River case.
Paper 4	Calderón-Rivera, N., Wilmsmeier, G., Bartusevičienė, I., & Ballini, F. (Under review). Analysing sustainable development of inland waterway transport in Colombia: The Magdalena River case.

Paper I

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Journal of Shipping and Trade

REVIEW

Open Access

Sustainable development of inland waterways transport: a review

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Abstract

Over the years, the demand for transportation has experienced a consistent rise, which has exacerbated a multitude of issues including environmental, visual, and noise pollution, congestion, land use conflicts, and various other related challenges. In this regard, the pursuit of alternatives aimed at mitigating these adverse effects stands as a priority for governments and policymakers. Consequently, inland waterway transport (IWT) emerges as an appealing solution, due to its advantages across the social, environmental, and economic considerations. However, in relation to IWT the concept of sustainable development is insufficiently investigated. The objective of this paper is to undertake a comprehensive review of how the concept of sustainable development is addressed and applied within the framework of IWT systems. To achieve this goal, a systematic literature review was meticulously conducted, utilizing three academic databases (Scopus, Google Scholar, and EBSCO). The review process yielded a total of 51 papers that proved to be pertinent and relevant to the subject matter. The comprehensive literature review facilitated the delineation of the principal elements, factors, and characteristics of the IWT system, as well as the primary drivers for its sustainable development. However, the implications for further research were identified, such as a comprehensive examination of each case due to the distinct geographical, social, economic, and political conditions inherent to each individual basin. That is essential for understanding the unique barriers present within each context and for formulating viable solutions aimed at fostering and incentivizing the sustainable development of IWT systems.

Keywords: Sustainable development, Inland waterway transport, System, Drivers

Introduction

Transportation plays a fundamental role in the socio-economic development of countries, especially in critical activities such as commuting, energy supply, goods allocation, and tourism, among others (Rodrigue 2020a). However, some aspects such as pollution, congestion, and overdependence of road transport, pose several challenges for the industry, which must establish strategies for its sustainable development (Schiller et al. 2010). Today, the transport industry is highly dependent on fossil fuels, and various environmental and social disadvantages have been reported since the 70's road network expansion (Schiller et al. 2010). In this regard, and understanding the relevance of transportation for society, in 1987, the World Commission on Environment and Development posed the concept of sustainable development as a development of the present without compromising the resources of future generations (Brundtland 1987). This definition has been widely applied to transportation development and sustainable transport systems, proposing a balance between environmental, social, and economic aspects (Rohács and Simongáti 2007).

Various authors argue that sustainable transport must ensure the basic needs of individuals and society efficiently and affordably, limiting the generation of emissions and waste and reducing the consumption of non-renewable resources (Rohács and Simongáti 2007; Schiller et al. 2010). Moreover, developing sustainable transportation requires innovative solutions to improve performance in the different modes as well as measures to reduce negative externalities (Rodrigue 2020b). These externalities mainly focus on air, water, land and noise pollution, greenhouse gas emission, congestion, accidents, and excessive land use (Demir et al. 2015; van Lier and Macharis 2014). Given the preceding, the use of inland waterway transport (IWT) is considered an appropriate tool for the sustainable development of transport. In that sense, various European countries, the United States, and China have developed more robust IWT systems and recognize its socio-economic and environmental benefits (Williamsson et al. 2020; Miciuła and Wojtaszek 2019; Notteboom 2012; Institute for Water Resources 2012).

Wang et al. (2020) identified the most representative inland waterways in the world according to their bearing capacity and socio-economic index, being the basins of the Rhine, Volga, Yangtze, Pearl, and Amazon, which top the list. In fact, much of the literature on sustainable development of the IWT is focused on European or Asian countries; however, other developing countries such as India, Indonesia, Nigeria, and Nepal, among others, have documented the state of their waterways, the challenges, and possible solutions for its development (Achmadi et al. 2018; Emmanuel et al. 2018; Rasul 2015; Trivedi et al. 2021). It is worth mentioning that for South America, which possesses critical hydric resources and relevant basins such as Amazon, Orinoco, Paraná, and Magdalena, not only scientific research is scarce, but also the development of IWT has been framed in the limited budgetary investment since it has not been constituted as a priority in public spending, added to weaknesses of institutional nature and regulatory frameworks (Jaimurzina and Wilmsmeier 2017).

Currently, for hinterland transportation, the road is the dominant transport means. However, numerous social, economic, and environmental drawbacks have been associated with automobile dependency, such as greenhouse gas emissions, oil dependence, traffic issues (noise, visual intrusion, and congestion), increasing social health costs due to accidents, sedentarism, pollution, isolation of neighbourhoods, social and accessibility inequality, among others (Schiller et al. 2010). Despite the above, transportation is a condition for development, and the search for alternatives to alleviate these problems is necessary. Therefore, modal shift from road to rail and IWT has gained relevance to be considered as a tool to develop sustainable transportation; in addition to that, governments and some international institutions such as the European Commission have developed policy documents to support and incentive this modal change (Jonkeren et al. 2019; Mihic et al. 2011).

This paper has been divided into five parts. Section "Methodology" describes the method applied to the paper. The results will be presented in Section "Results", addressing the concept of sustainable development of IWT, followed by the description of the elements, factors, and characteristics that constitute IWT systems, and the drivers for sustainable development of IWT system. Finally, the discussion and conclusions are presented in Sections "Discussion" and "Conclusions".

Methodology

To conduct the systematic literature review, the authors followed the process suggested by Snyder (2019), consisting of four phases, starting with the design and conduct of the research, followed by the analysis and the report.

During the first stage, the systematic literature review was designed and is described in Table 1. Three research questions were formulated: *a. How is sustainable development addressed and applied in inland waterways transport systems? B. How can inland waterways transport system be defined, and what elements and factors constitute it? c. What are the drivers to develop inland waterway transport?* The strategy for selecting literature involving inclusion and exclusion criteria was established. To select the relevant literature, the authors established "inland waterway" and "sustainab*" as the key words. The search was limited to key words included in the title, abstract and key words using "Scopus", "Google Scholar" and "EBSCO" as the databases for the paper selection.

Table 1 Stages followed in the systematic literature review

Research questions	
a. How is sustainable development addressed and applied in inland waterways transport systems? b. How can inland waterways transport system be defined and what elements and factors constitute it? c. What are the drivers to sustainable development of inland waterway transport?	
Identification of key words	
"inland waterway" AND sustainab* (The use of asterisk will allow the selection of publications that contain the words "sustainable" "sustainability")	
Inclusion criteria	Exclusion criteria
Academic Journals—Reports—Book chapters Full access to text Research covering sustainable development of IWT	Articles that are not directly focused on inland waterway transport Repetitive studies found in the different databases
Stages for filtering data Stage one: Eliminating duplicates Stage two: Application of inclusion and exclusion criteria on title, abstract, and key words Stage three: Application of inclusion and exclusion criteria on full text Stage four: If necessary, the inclusion of articles using a snowballing technique	
Papers identification	Papers selection
Scopus: 424 Google Scholar: 354 EBSCO: 221 Total: 999	After the title, abstract, and keywords review Excluded papers after applying inclusion and exclusion criteria: 923 Selected papers: 76
Papers selection After full-text review Excluded papers after applying inclusion and exclusion criteria: 33 Selected papers using snowballing: 8	
Selected literature: 51 papers	

Source Compiled by the authors

In the following phase, a pilot test was applied to revise the quantity of information; the three stages for data selection were conducted, starting with duplicate elimination, inclusion and exclusion criteria application, and the use of the snowballing technique. Finally, after applying the stages for filtering data, 44 papers were identified. The research resulted in 424 from Scopus, 354 from Google Scholar, and 221 from EBSCO. Finally, following the stages for filtering and selection, 51 papers were used to conduct the systematic literature review.

Results

Bibliographic analysis

VOSviewer software was utilized to develop the bibliographic analysis (van Eck and Waltman 2010). Figure 1 shows the distribution of the papers published by year starting from 1994 to middle 2022.The research into the sustainable development of IWT dated back to 1994; however, a notable surge in publications was observed in 2016. A country-wise citation analysis reveals that Begum, the Netherlands, and China account for the majority of publications, indicating a predominant focus on the development of studies in European countries.

Figure 2 illustrates a bibliographic analysis employing high co-occurrence of key words. Three primary clusters are discernible: the blue cluster pertains to topics related to freight transportation, ships, and inland navigation; the red cluster encompasses subjects associated with sustainable transport, development, and waterway transport; and the green cluster focuses on inland waterway transport. Notably, the prevalence of studies conducted within the European Union is evident in the green cluster.

Finally, Figs. 3 and 4 shows the bibliographic coupling using the citation analysis of the papers and the bibliographic coupling networks of the authors. The last highlights just one cluster with three authors, reflecting the extent to which these authors share citations with each other. The strength of their relationship is directly proportional to the number of publications cited in common, a higher count indicating a stronger connection between them (Perianes-Rodriguez et al. 2016).

Reviewing the concept of "Sustainable Development of IWT"

Although most of the literature on IWT deals with the concept of sustainable development, few papers present a definition in this regard. In most cases, reference is

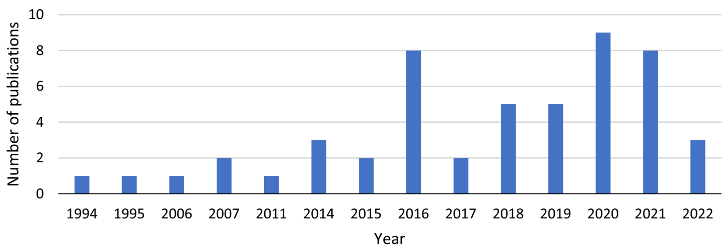

Fig. 1 Number of papers published annually. Source: Drawn by the authors

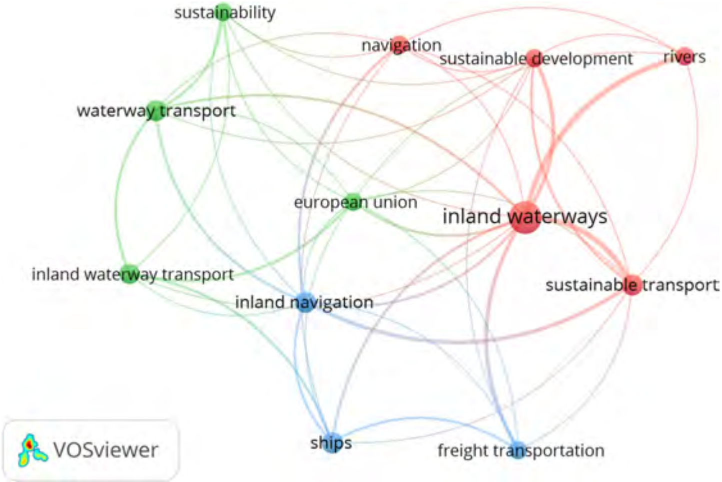

Fig. 2 Co-occurrence analysis of the key words. Source: Map obtained using VOS viewer

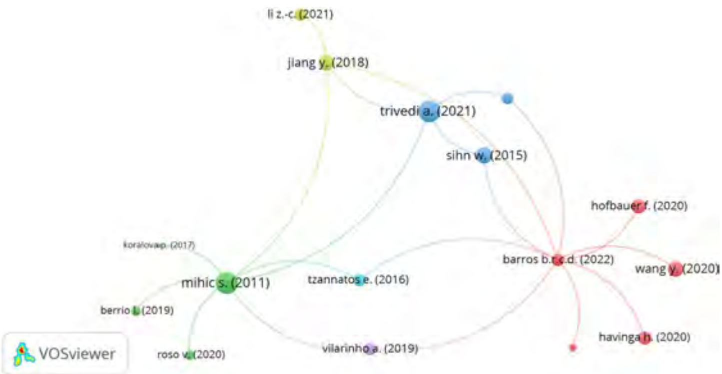

Fig. 3 Citation analysis using the identified papers. Source: Map obtained using VOS viewer

made to the definition proposed by the World Commission on Environment and Development in 1987, which reads Sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987).

On the other hand, Rohács and Simongáti (2007) embrace the definition of sustainable transport following the guidelines of the European Union, which contains three main points, basic access and development needs of individuals, affordable and efficient transportation, and limit emissions and use renewable resources. Recently, Wang et al. (2020) suggested that "Sustainable inland waterways should meet the needs of navigation without compromising the health of riverine ecosystems". Finally,

Fig. 4 Citation analysis using bibliographic coupling networks focused on authors. Source: Map obtained using VOS viewer

Barros et al. (2022) defined sustainable IWT as "the one in which freight increase meets lower environmental and economic costs in waterway developing works and operations, while being resilient to climate change and promoting social equity."

Table 2 Characteristics of sustainable development of IWT

Characteristics of sustainable development of IWT	Literature
Environmental	
Maintenance of river health and protect ecosystems	Sommerauerová et al. (2018), Wang et al. (2020)
Protect ecological functions of watercourses	Havinga et al. (2006), Mihic et al. (2011), Wang et al. (2020)
Preserve biodiversity	Wang et al. (2020)
Riverine nature rehabilitation	Havinga (2020)
Ensure flow regime	Wang et al. (2020)
Design river training works to prevent erosion and avoid dredging operations (if required)	Havinga et al. (2006)
Ecological conservation and restoration	Wang et al. (2020)
Low energy consumption energy efficiency	Mihic et al. (2011), Sommerauerová et al. (2018)
Climate change resilience (flood protection)	Barros et al. (2022), Havinga (2020), Havinga et al. (2006)
Socio-economic	
Encourage education and research	Rohács and Simongáti (2007)
No represent threat to the public health	Sommerauerová et al. (2018)
Guaranty riparian connectivity	Wang et al. (2020)
Clear legislation and policies for the promotion of IWT	Mihic et al. (2011), Rohács and Simongáti (2007)
Appropriate infrastructure and maintenance	Wang et al. (2020)
Poses the ability to move people and goods in an affordable, fairly, and efficient way	Rohács and Simongáti (2007), Wang et al. (2020)
Investment projects to buy or improve fleet for cargo and passenger transport	Mihic et al. (2011), Barros et al. (2022), Mihic et al. (2011)
Preparedness to modal shift from road to IWT	Mihic et al. (2011)
Develop stronger information systems for safety and operations	Barros et al. (2022), Mihic et al. (2011)
Efficient and effective operations on terminals	Wiercx et al. (2019)
Optimization of pre/end haulage activities of IWT	Wiercx et al. (2019)

Source Compiled by the author

Nevertheless, diverse authors have discussed various characteristics to explain the concept of sustainable development of IWT. For the present research, the sustainable development of IWT can be understood as the development of the IWT, which promotes better environmental practices and considers socio-economic aspects, such as those listed in Table 2.

IWT as a transport system

The definitions of systems have been approached from multiple disciplines, and systems have been classified in several ways (by discipline, size, location, and functions, among others); however, the choice is made depending on the purpose of use (Ackoff and Gharajedaghi 1996). Jackson and Keys (1984) defines a system as a group of at least two interrelated elements connected to each other directly or indirectly. From the author's perspective, this definition can be complemented by Ackoff and Gharajedaghi (1996), who defined a system as a "functioning whole that cannot be divided into independent parts." Moreover, systems are characterized according to the way they interact with their surroundings; these can be open, closed, or isolated. In that regard, most human systems are open, given that societies are based on trade and the exchange of goods. Besides, every system possesses a boundary with which it interacts with the environment (Fieguth 2021).

Another important notion proposed by Fieguth (2021) is the concept of *systems of systems*, referring to an interacting collection of systems that are not just a more extensive system. On the other hand, the performance of the systems not only depends on the performance of the parts, but it also falls on the relationships between the elements of the system and its interactions; therefore, the best way to interpret the problems and propose solutions to them is to obtain an interdisciplinary and inclusive perspective using different perspectives and points of view (Ackoff 1994).

Considering the points mentioned above, the authors define IWT as a transportation system that possesses three main elements: first, waterways as the means to develop inland waterway transportation; second, inland fleet or inland waterway vessels; and the third element, which is divided into two categories inland river ports and seaports, as the nodes or links to develop IWT operations (Fig. 5). To that effect,

Fig. 5 Physical elements of Inland waterway transport system. Source: Drawn by the authors

IWT can be considered more as a social system as the system and its essential parts possess purposes. Furthermore, IWT acts as a system of systems since it belongs to the transportation system. Moreover, IWT is considered an open system due to its interaction and exchange with the environment and the other transportation systems, mainly road, maritime, and rail transport.

Previous research findings argue that the key elements of the management of IWT are the fleet, inland ports, waterways, and locks (Koralova 2017). Moreover, (Barros et al. 2022) grouped IWT activities into five clusters: development works; operation and maintenance; inland ports, and governance issues. Nevertheless, after analysing and classifying the selected articles, the most relevant topics addressed in the literature are focused on the assessment and understanding of the fleet, ports, and waterways to support the sustainable development of IWT, highlighting the benefits or drivers and the challenges for its development (Table 3). Having as a reference the identified elements of the IWT system, some factors and their characteristics were identified and classified in categories as shown below.

Ports (Inland River ports—Seaports)

Even though the term "Inland Port" has been widely discussed in the literature, Rožić et al. (2016) argue that it refers to those facilities that prolong the activities of seaports. Nevertheless, for this research, the authors will adopt the definition of inland river port proposed by Wiegmans et al. (2015) as "transportation infrastructures along waterways with facilities and equipment for loading and unloading ships." Although there are some differences between the two types of ports, the elements and characteristics described in Table 4 are applicable to both cases, so they will not be presented independently.

First of all, the governance scheme of ports and how policies are implemented are essential factors for the sustainable development of the IWT. Coordinated and independent regimes are part of the differences in governance and administration of each waterway and require in-depth analysis to establish the best practices in each case (Li et al. 2021). In this respect, the selected governance mode has to generate financial frameworks that directly impact the construction or improvement of port infrastructures and docks (Nguyen and Nguyen 2020), as well as the management strategies in terms of planning, construction, maintenance, and disposal of ports (Rožić et al. 2016; van Lier and Macharis 2014).

Table 3 Classification of the approaches found in the literature review

Topic	Articles
Sustainable development of IWT	7
Fleet	6
Ports	5
Waterway	4
Fleet/Port—Fleet/Waterway—Waterway/Fleet/Port	3
Specific case study	7
Others	19
Total	51

Source Compiled by the authors

Table 4 Factors and features of ports

Element	Factors	Features	References
Ports	Governance and Policies	Regulatory frameworks	Li et al. (2021)
		Investments schemes (public and private)	Li et al. (2021)
		Financial frameworks	Nguyen and Nguyen (2020)
	Management	Planning	Rožić et al. (2016)
		Construction, maintenance, and disposal	van Lier and Macharis (2014)
	Operational	Barge handling at ports	Oganesian et al. (2021)
		Port equipment and yard configuration	Wiercx et al. (2019)
	Technology and Innovation	Implementation and optimization of digital applications	Oganesian et al. (2021), Rožić et al. (2016)
	Infrastructure	Improvement of port infrastructure to support IWT	Bu and Nachtmann (2021)
		Facilities and equipment	Rožić et al. (2016)
		Private investment to boost IWT	Bu and Nachtmann (2021)
		Capacity of cargo collection and distribution	Rožić et al. (2016)
		Construction or expansion of inland river ports	Vilarinho et al. (2019)
	Human resources	Skilled labor force	Koralova (2017), Pfoser et al. (2018), Vilarinho et al. (2019)

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On the other hand, optimization of handling activities in IWT terminals and seaports, including the analysis of yard configuration, is necessary to perform optimal operations (e.g., analysis of reach stackers and terminal yard cranes) (Oganesian et al. 2021). Moreover, the uncertainty of barge handling and loss of time in seaports decrease the reliability of IWT (Wiercx et al. 2019). Apart from that, the optimization and implementation of digital applications for data exchange and cargo operations will impact the capacity to plan, direct, and monitors vessel traffic, optimizing cargo reception and storage, especially for container transshipments and transport (Oganesian et al. 2021; Rožić et al. 2016).

For sustainable development of IWT, the assessment of ports infrastructure and equipment to support IWT operations is a priority; this can lead to the construction of intermodal terminals to improve logistics performance or the expansion of main ports in some strategic geographical location, to improve the capacity of cargo collection, distribution, and performance in general (Bu and Nachtmann 2021; Rožić et al. 2016; Vilarinho et al. 2019). Finally, from a human resources perspective, currently, the is a staff shortage in ports and the requirement for a skilled labour force to support IWT operations (Koralova 2017; Pfoser et al. 2018; Vilarinho et al. 2019).

Fleet

IWT fleet is mainly dominated by self-propeller vessels and convoys of barges. The characteristics of the fleet used for IWT vary according to the characteristics of the waterways (Table 5). For example, not all ships that sail on the Rhine can sail on the Danube despite their close geographical location (Mako and Galieriková, 2021). Koralova (2017)

Table 5 Factors and features of Inland Fleet

Element	Factors	Features	References
Fleet	Governance and Policies	Promotion of green technologies Fleet characterization	Mako and Galieriková (2021), Perčić et al. (2021)
	Management	Enforcement of policies and regulations	Awal (2007)
		Harmonization of regulations for vessels between sheered basins	Mako and Galieriková (2021)
		Assessment of external costs (for construction, maintenance, and disposal of the fleet)	van Lier and Macharis (2014)
		Safety (design and regular check)	Maternová et al. (2022)
	Operational	Regular line services	Koralova (2017)
		Optimization of transport routes Improvement of fleet scheduling	Zhu et al. (2021)
	Technology and Innovation	Alternative power systems and alternative fuels	El Gohary et al. (2014), Perčić et al. (2021)
		Vessel design optimization to improve efficiency	Bernardini et al. (2018), Koralova (2017), Sihn et al. (2015)
		Inclusion of autonomous shipping for IWT	Chen et al. (2016)
		Modernization of the fleet	Mihic et al. (2011), Vu (2011)
		Information and communication applications (RIS)	Niedzielski et al. (2021)
	Human resources	Qualified vessels crews Training and certification Working conditions	Koralova (2017), Maternová et al. (2022), Pfoser et al. (2018)

Source Compiled by the authors

describes the fleet as an indicator of performance and competitiveness and argues that technical specifications, carry capacity, equipment, safety, and security, are the competitive advantages compared to other transport modes. For that reason, the understanding of the characteristics of the fleet is an essential input for policymakers not only for the development of IWT regulations but to promote green technologies for the IWT fleet.

Although IWT stands out for its low rates of incidents and accidents (Gołębiowski 2016), various authors have conducted analyses focusing on the underlying causes of such incidents and proposed strategies for their mitigation. These analyses have emphasized the importance of rigorous enforcement of policies and regulations governing the inland fleet, alongside the adoption and integration of advanced technologies associated with river information systems as a robust communication network aimed at proactively preventing such occurrences (Awal 2007; Koralova 2017; Niedzielski et al. 2021). Moreover, from a managerial perspective, harmonizing regulations is indispensable in shared basins to ensure the cargo flow and reliability of IWT (Mako and Galieriková 2021; van Lier and Macharis 2014). In addition to the foregoing, other characteristics in terms of establishment of regular line services, optimization of transport routes, and improvement of fleet scheduling are required to improve and strengthen not only the operational performance but the emissions reduction and energy saving (Koralova 2017; Zhu et al. 2021).

Technology and innovation in the inland fleet constitute one of the most important factors for the sustainable development of IWT. These relate mainly to the modernization of the fleet (Mihic et al. 2011; Vu 2011), the use of alternative fuel and power systems (El Gohary et al. 2014; Perčić et al. 2021), the optimization of vessel design to improve the efficiency (e.g., hull improvement, adaptable draft using ballast tanks, adaptation to serve other industries as car transport) (Bernardini et al. 2018; Koralova 2017; Sihn et al. 2015); the inclusion of autonomous shipping (Chen et al. 2016); and the implementation or improvement of information and communication applications to support crew members choosing adequate speed for fuel optimization and knowledge about waterway meteorological conditions (Niedzielski et al. 2021). Finally, the most important feature when talking about the IWT fleet is the crew members that operate it; this personnel requires appropriate working conditions and the formulation of solid training and certification programs to provide qualified vessel crews, as well as the adaptation or implementation of training directed to the use of new technologies (Koralova 2017; Pfoser et al. 2018).

Waterway

Van Dorsser (2016) defines inland waters as waters not categorized as 'sea'; this definition includes canals, rivers, lakes, and some estuarial waters. Inland waterways systems provide several socio-economic and environmental functions, being the most important: fresh water supply, safety against flooding, and inland waterway transport (van Dorsser 2016; van Vuren et al. 2015). Moreover, other important economic features rely on waterways, such as tourism, agriculture, and industry (Konings and Weigmans 2016). For the purposes of this study, Table 6 shows four waterway factors and the main characteristics identified during the literature review.

Diverse governance models for IWT have been established worldwide. First, a centralized governance model with special administrations for each basin that manages the operational activities and has the responsibility for the infrastructure and the development of IWT. In other cases, local governments are responsible for those activities on behalf of the central government (Jiang et al. 2018). Regardless of the governance models, several regulations and long-term master plans are required to support IWT's sustainable development; moreover, the participation of public and private sectors is indispensable to stimulate a modal shift from road and rail to IWT (Bu and Nachtmann 2021; Chen et al. 2016; Havinga 2020; Malkus et al. 2020; Nguyen and Nguyen 2020; Roso et al. 2020). Other necessary environmental regulations that include integrated ecological strategies, such as emission reduction and implementing subsidies related to environmental sustainability, are a priority (Barros Cavalcante et al. 2020; Mihic et al. 2011; Vilarinho et al. 2019). On the other hand, policies that promote economic incentives and regulate the operational and economic activities of IWT should be addressed, especially in shared basins (Barros Cavalcante et al. 2020; Malkus et al. 2020; Nguyen and Nguyen 2020; Niedzielski et al. 2021; Rohács and Simongáti 2007; Tzannatos et al. 2016).

From a managerial view and due to the multiple functions of waterways, Havinga et al. (2006) argue that "river measures should be designed in such a way that they cause only local effects and do not affect the entire system." This statement is supported by Maksin et al. (2017) since the consequences of these interventions are of great relevance in rivers that share their basin. For this reason, the design of dynamic River management

Table 6 Factors and features of Inland Waterways

Elements	Factors	Features	References
Waterways	Governance and Regulations	Diverse governance models	Jiang et al. (2018)
		Coordinated legislative bodies	Sommerauerová et al. (2018)
		Road maps and long-term master plans with well-defined priorities	Havinga (2020), Havinga et al. (2006), Rohács and Simongáti (2007)
		Policies to promote and support IWT	Roso et al. (2020)
		Public and private sector participation in decision-making	Chen et al. (2016), Nguyen and Nguyen (2020)
		Local and regional policies that stimulate modal shift from road to IWT	Bu and Nachtmann (2021), Malkus et al. (2020)
		Long-term strategies to develop IWT passenger transport	Vu (2011)
		Prioritize or increase the investment in IWT infrastructure	Oulfarsi (2016)
		Integrated ecological strategies	Mihic et al. (2011)
		Environmental policies and legislation emission reduction	Barros Cavalcante et al. (2020), Vilarinho et al. (2019)
		Subsidies related to environmental sustainability efforts	Barros Cavalcante et al. (2020)
		Legislation that guarantees freedom of navigation (e.g., European Union)	Niedzielski et al. (2021)
		Clear taxation systems and procedures (particularly in shared basins)	Malkus et al. (2020), Rohács and Simongáti (2007)
		Compensations for stoppage	Niedzielski et al. (2021)
		Regulations for the operational management	Nguyen and Nguyen (2020)
		Economic incentives to support technical and operational investments	Tzannatos et al. (2016)
	Management	Dynamic river management	Havinga (2020)
		Adaptative management-based strategies	Barros Cavalcante et al. (2020)
		Strategical transnational planning for sustainable development of shared basins	Maksin et al. (2017)
		Stakeholder identification and participation in preparation and implementation programs	Havinga (2020), Roso et al. (2020)
		Mental shift to support modal shift	Roso et al. (2020)
		Administrative and institutional systems to support IWT	Mihic et al. (2011)
		Standardized management for shared basins	Mako and Galieriková (2021)
		Transnational cooperation for shared basins	Pfoser et al. (2018)
		Clear of institutional structure	Nguyen and Nguyen (2020)
		Clear border controls requirements	Pfoser et al. (2018)
		Established charges and fees	Pfoser et al. (2018)
	Operational	Connectivity and interoperability among various waterways, industrial centers connected with other transport means	Koralova (2017), Mako and Galieriková (2021), Sidaway et al. (1995), Vilarinho et al. (2019)
		Environmental factors (wind, current, waves, ice formation)	Chen et al. (2016), Koralova (2017)
		River Information Services (RIS) to harmonize information	Koralova (2017), Mihic et al. (2011)

Table 6 (continued)

Elements	Factors	Features	References
		RIS for traffic and transport services	Koralova (2017), Maternová et al. (2022), Mihic et al. (2011), Niedzielski et al. (2021)
	Infrastructure	Infrastructure development and improvement (Navigable waterways with sufficient depth, locks, and bridges)	Bu and Nachtmann (2021), Chen et al. (2016)
		Investment and improvement (traffic channels, signal buoys, bridges, and well-connected ports)	Nguyen and Nguyen (2020)
		Optimal maintenance programs	Havinga (2020), Havinga et al. (2006)
		Sustainable river training	Havinga (2020), Havinga et al. (2006)
		Quality infrastructure	Sommerauerová et al. (2018)
		Maintenance of waterways	Mihic et al. (2011)
		Strategies for investment and financing infrastructure (e.g., implementation of PPP)	Miloslavskaya and Plotnikova (2018)
		Develop waterway infrastructure to improve connectivity between strategic regions (e.g., Czech Republic and Germany)	Cempírek and Čejka (2017)
		Improve waterway network and connectivity with other transport modes	Mako and Galieriková (2021), Nguyen and Nguyen (2020), Sidaway et al. (1995)
		Integration between transport modes	Vilarinho et al. (2019)
		Financial frameworks	Nguyen and Nguyen (2020)

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and adaptative management-based strategies will protect the ecological functions of the waterway and promote transnational cooperation for shared basins (Barros Cavalcante et al. 2020; Havinga 2020; Mako and Galieriková, 2021; Pfoser et al. 2018).

On the other hand, infrastructure is essential for developing any means of transport. For IWT is critical the improvement of navigable waterways with sufficient depth, traffic channels, signal buoys, bridges, locks, bridges and well-connected ports (Bu and Nachtmann 2021; Chen et al. 2016; Nguyen and Nguyen 2020). Moreover, implementing optimal maintenance programs that possess integrated solutions and creating long-term master plans to ensure navigation and other functions of the systems, such as fresh water supply, flood protection, and agriculture, among others (Havinga 2020; Havinga et al. 2006). Additionally, improvement and maintenance of IWT infrastructure to meet the current transport requirements entail programs that consider sustainable river training, which should include sediment management to avoid degradation of the bed of the basin and the water levels, and structural measures such as fixed layers, groyne adaptations, bendway weirs, bottom vanes, since dredging is not a sustainable solution over time (Chen et al. 2016; Havinga 2020; Havinga et al. 2006).

Finance challenges for IWT infrastructure have been reported since the mid-eighteenth century (Sidaway et al. 1995). Since then, there is necessary to create financial frameworks and identify strategies for investment, such as public private parentships (PPP) with the participation of private and public stakeholders (Jiang et al. 2018; Miloslavskaya and Plotnikova 2018; Nguyen and Nguyen 2020). These strategies should include waterways maintenance funds and capital investment for infrastructure construction (Nguyen and Nguyen 2020). Considering that the development of waterway infrastructure will improve connectivity between urban areas and strategic regions that can serve as logistics centres and help maintain connections with other transportation modes (Cempírek and Čejka 2017; Sidaway et al. 1995; Vilarinho et al. 2019).

Drivers for sustainable development of inland waterway transport system

IWT represents one of the most important strategies to achieve sustainable development in hinterland transportation for its ability to meet massive demand and improve economic and environmental performance (Oulfarsi 2016). In fact, the European Union has recognized the importance of waterborne transport as a critical factor for developing sustainable transportation (Rodseth et al. 2020). Moreover, IWT provides solutions for economic development, population growth, and climate change (Wang et al. 2020). Added to this, modal shift and intramodality are one of the four targets identified by seaports to improve their environmental performance; although this goal has been set mainly in Europe, North America, and Asia, for Middle East, African, and South American ports, it has been less prioritized (Gonzalez Aregall et al. 2018).

Benefits of IWT act as drivers for IWT development (Roso et al. 2020). For the purpose of this research, drivers are defined as the characteristics or activities that incentive or generate some benefit in one or more of the three pillars of sustainable development (social, economic, and environmental).

Environmental drivers

Currently, the hinterland transport sector consumes a large amount of energy; however, when comparing the different modes, IWT is the one that performs the best (Rohács and Simongáti 2007). The oldest paper that described IWT as a sustainable transportation system was published by Blonk (1994), and described IWT as an energy and environmentally-friendly transport mode due to its low levels of pollution and noise and highlights its exemplary record in terms of safety.

Emissions have a relevant impact on global warming, climate change, acidification, human and ecosystem toxicity, and eutrophication (Tzannatos et al. 2016). Among all modes of internal transport, IWT is considered the most environmentally friendly due to its performance in terms of CO_2 release (Jonkeren et al. 2019). In fact, measurements of greenhouse gas emissions for IWT are approximately 40% lower than road transport (Hofbauer and Putz 2020). Moreover, a river convoy generates four times less CO_2 and emits 2.6 times fewer greenhouse emissions than road transport (Oulfarsi 2016).

Another essential matter is that IWT consumes less fuel per ton-kilometre than trucks (Rohács and Simongáti 2007); indeed, diesel consumption of IWT is lower than road and rail transportation (Gołębiowski 2016). In that sense, energy consumption is about 75% less than road; besides, noise pollution and land use are lower compared with other hinterland transportation modes (Gołębiowski 2016; Mihic et al. 2011). Tzannatos et al. (2016) calculated the number of vehicles required to transport 2000 tons in all available means of transport; the results showed that the use of 77 trucks, 16 train wagons, and only two ships or barges would be required. For that matter, Roso et al. (2020) argue that a barge can replace between 70 and 80 trucks that travel to the same place. Demonstrating the advantages of IWT in terms of energy efficiency that is not only reflected in the reduction of fuel costs but also in the environmental performance.

Several authors emphasize the potential of waterborne to reduce pollution and road congestion due to its high carry capacity per vessel unit and the availability to transport oversize and large volumes of cargo rod (Koralova 2017; Rodseth et al. 2020). However, when comparing transportation speed, IWT is the slowest hinterland transport mode; therefore, it is mainly attractive for the transport of non-perishable products (Barros et al. 2022), including construction materials, agricultural raw materials, petroleum products, coal, and in some cases, such as in northern Europe (the Netherlands, Belgium, and Germany) container cargo (Gołębiowski 2016; Rogerson et al. 2019; Sidaway et al. 1995). Furthermore, the improvement and optimization of inland vessels could improve efficiency and provide several environmental and economic benefits (Bernardini et al. 2018).

Finally, the adoption of greener solutions, such as promoting the use of renewable energies instead of fossil fuels (for cranes, fleets, and other port requirements), added to water management plans that take into consideration ecological conditions should be a priority among policymakers worldwide (Woś et al. 2022).

Economic drivers

Countries near the Flow of the rivers have demonstrated economic growth over time (Mihic et al. 2011). Commercial benefits of IWT have been reported since 1995, Sidaway et al. (1995) underline the advantages related to low-cost transportation of heavy and bulk goods, when speed is less relevant than materials flow, exist appropriate loading and unloading facilities, and there are safety procedures to handle of large volumes. Moreover, according to Gołębiowski (2016), external costs related to IWT are 19 euros less per 1000 ton-km compared to road. In fact, in Poland, Woś et al. (2022) assessed different means of transportation, and the cost–benefit analysis concluded that waterways base model investment is profitable using the Vistula River and stands out savings in costs related to cargo, accidents, congestion, pollution, emissions, among others.

Several economic activities could be improved or implemented along with IWT development as tourism, hydroelectric production, or the inclusion of new trades (Woś et al. 2022). For instance, Sihn et al. (2015) assess the automotive industry in order to distribute cars via IWT from the production plants to the distribution centres due to the facilities and easy access to inland waterways and the increasing industry of car manufacturing. On the other hand, Mommens et al. (2014) argue that using intermodal transport for palletized goods in Brussels-Capital Region has economic potential and can be successfully transported by barges.

There are multiple benefits in terms of increased capacity and productivity of ports, road congestion reduction, rural and regional development, and improved environment (Roso et al. 2020). Furthermore, from the cost reduction perspective, IWT is the cheapest transport mode and generates less external costs in comparison with the road (Cempírek and Čejka 2017; Gołębiowski 2016; Maternová et al. 2022; Mihic et al. 2011). Moreover, saving costs related to flood losses (agriculture), accidents, pollution, climate change, noise, congestion, and transport costs, represent an economic advantage of IWT development (Woś et al. 2022).

Projections about infrastructure investments predict that the return on investment takes a little longer until the threshold is reached due to the geographical, economic, and political conditions of each basin that require different levels of capital spending (Rohács and Simongáti 2007). In that sense, establishing strategies to attract new freight flows, key stakeholders' participation, and subsidy implementation are required to promote and incentivize modal shifts. In that regard, trust and confidence in local authorities are required, and companies appreciate the support and the strategies to reduce the tensions when there is an intention to invest in IWT (Roso et al. 2020).

Social drivers

IWT supports rural development and is relevant to passenger transport, especially in regions where road access is almost nil (Awal 2007; Berrio et al. 2019; Vu 2011). In addition to that, IWT impacts the well-being of the citizens due to the increase in goods transportation and the positive effects of flood stabilization (Woś et al. 2022). Indeed, improving IWT could be a solution for isolating remote rural areas due to the support in access to basic needs such as education, health care, and governmental services (Vu 2011).

In some countries in Asia (China, Cambodia, India, Indonesia, Thailand, and Vietnam), IWT plays an essential role in the economic development and welfare of people in rural areas; moreover, it can alleviate costs related to congestion, reduce accidents and noise and increase accessibility to global markets (Knapčíková and Kaščák, 2019; Vu 2011). Some authors, based on literature and statistics, recognize IWT as one of the safest means of transport due to its low number of fatalities or injuries (Koralova 2017; Rohács and Simongáti 2007). Besides, IWT can contribute to diminishing road congestion which is one of the major issues related to hinterland transportation, constituting one of the predetermining aspects for modal shift since congestion generates inconveniences that impact on the reliability of land transport modes (Roso et al. 2020).

Discussion

Although all the literature reviewed in this research contains information related to sustainability or sustainable development of the IWT, of the 51 reviewed papers, only three propose a definition as shown in Section 3.1. However, these three definitions are broad and do not describe the specific features that should be developed or carried out when it comes to the sustainable development of the IWT. In this sense, this paper presents a list of characteristics that serve as a guide for the implementation of sustainable IWT systems. Nevertheless, given the varying characteristics or geographic, social and political diversity of each region, it is necessary to analyse the specific conditions of each basin in order to adapt the definition to each circumstance, understanding that sustainability or sustainable development are not static elements with an immovable specific purpose, but rather it requires flexible plans that adapt not only to the needs of each region, but to the new technologies and social requirements that they entail.

On the other hand, when referring to the sustainable development of IWT, it is imperative to consider the vital roles that waterways play within society. These roles encompass not only the provision of water for human consumption but also encompass activities such as fishing and agriculture. Furthermore, waterways serve as a source for hydroelectric power generation in certain regions across the globe. In this context, the sustainable advancement of IWT must align harmoniously with strategies that aim to preserve the multifaceted functions of rivers, thus striving for equilibrium between economic and social development and the conservation of natural resources. It is at this juncture where the comprehension of the elements and attributes inherent to IWT systems becomes pivotal. Such comprehension forms the foundation for comprehending a system that demands adapted strategies and solutions for its development.

Few authors have addressed the measurement of sustainability or sustainable development of IWT. In some cases, reference is made to recommendations proposed by international institutions or organizations. For example, the European Union recommended measuring external costs to measure the environmental sustainability of transportation (Bu and Nachtmann 2021). Furthermore, Sommerauerová et al. (2018) argue that EUROSTAT possesses two indicators to measure sustainable development in the transport sector; the first one, and not applicable for the purposes of this research, is the share of collective transport modes, and the second measurement the share of rail and IWT in total inland freight. On the other hand, Rohács and Simongáti (2007) proposed a list of indicators to measure sustainable transport and grouped it among economic, environmental, and social indicators; these indicators are very general but could be adapted particularly for IWT. Particularly for IWT, Maksin et al. (2017) suggest the assessment of planning solutions for IWT and propose some activities and measures. Moreover, Wang et al. (2020) assessed the performance of the longest basins in the world using some indexes related to consistency, exploitation ratio, ecological pressure, and eco-efficiency, suggesting a balance between the economic growth and the ecological health of the basins.

Congestion problems and environmental damage caused by transport have been reported since 1994 and continue increasing (Blonk 1994). In the same vein, the demand for transportation has increased and is expected to continue with this trend. Therefore, the implementation of sustainable practices for transportation development has increased, and IWT is seen as an alternative to meet the demand for transportation and its sustainable development (Chen et al. 2016). Notwithstanding the numerous advantages and drivers mentioned in the literature regarding the use of IWT worldwide. These advantages refer mainly to the reduction of emissions and pollution, either thanks to the optimization of the use of fuels, the implementation of new technologies on board ships, or the development of alternatives to replace fossil fuels. Although one of the most significant disadvantages of the IWT is its slow speed, which would denote an inability to operate in short distances, Gołębiowski (2016) states that due to the high congestion in the areas near the ports, the profitability of the IWT in terms of distance has decreased from 350 to 400 to 60 km. This shows that although the development of the IWT has been slower compared to other means of transport, every day, it gains relevance among policymakers and stakeholders involved in the IWT system.

Even though there are several alternatives proposed in the literature to optimize and promote the use of the IWT to achieve a modal shift from road and rail in specific cargo categories, today, some issues need to be solved or improved. For instance, alternative power systems for inland waterway vessels are scarce, and shipping emission decarbonization has been focused on seagoing vessels (Perčić et al. 2021). In fact, in Croatia, the inclusion of electric road transport has been encouraged, but shipowners have not received this kind of incentive (Perčić et al. 2021). While El Gohary et al. (2014) propose using hydrogen for IWT vessels; however, several economic considerations must be considered given the high investment costs required for its use. Additionally, other measures, such as the imposition of strict regulations around meeting sustainable environmental goals and the remotion of fossil fuel subsidies in the European Union with the aim of incentivizing energy-efficient technologies, could incentivize the modal shift to IWT (Perčić et al. 2021; Roso et al. 2020).

Currently, IWT infrastructure is aging since it has not been prioritized as a strategic matter, while the road transport infrastructure has been strengthened (Vilarinho et al. 2019). In general, the distribution of public spending between different transport means is usually unequal; Oulfarsi (2016) argues that French infrastructure investment was 66% to road transportation while 1% to IWT. One of the most relevant problems to developing IWT is the lack of financing for infrastructure, Miloslavskaya and Plotnikova (2018) suggest the implementation of public private partnerships and user fees to meet the requirements of the state, industry, and society.

On the other hand, Trivedi et al. (2021) argue that IWT poses numerous challenges to its implementation, being the lack of governance and policy the most critical barrier to developing IWT in India due to its inhibiting impact on other factors such as infrastructure improvements and the participation of the private sector because of the high costs associated with this type of transport. Finally, there is a need for available information and research to understand not only the unique hydrological characteristics of each basin but its commercial and infrastructure, and managerial requirements to support modal shift and policymakers' decisions to develop sustainable IWT systems (Berrio et al. 2019; Vilarinho et al. 2019).

Conclusion

Although some authors have addressed the definition of sustainability or sustainable development of the IWT, this study presents a more comprehensive perspective that encompasses the essential characteristics necessary for the for sustainable development of IWT systems. Additionally, it has enabled us to delineate IWT as a system comprising three fundamental components: waterways, inland fleets, and ports (comprising inland river ports and seaports). These components interact cohesively, facilitating the continuous flow of cargo and passengers. Moreover, this research has identified five factors relevant to each of these elements, all possessing distinct characteristics that, in accordance with their performance, foster the optimal development of IWT within a specific region. Furthermore, this study contributed by pinpointing the primary drivers for the sustainable development of IWT, highlighting the key environmental, social, and economic benefits linked to its potential to mitigate air and noise pollution, alleviate congestion, reduce costs, and promote rural development and well-being.

The predominant geographic focus of the studies incorporated within this review are centered on Europe and Asia. Only two articles within the study touched upon certain facets of Latin America, notwithstanding the extensive presence of waterways in the region. Considering this geographic bias, prudence is warranted when contemplating the generalizability of the findings derived from this review. In view of the above, while numerous characteristics and drivers for the sustainable development of the IWT sector can be broadly conceptualized, it is imperative to conduct a comprehensive analysis specific to each basin. Such an analysis must consider various factors, including but not limited to geographical, environmental, social, economic, and infrastructural considerations. This multifaceted examination will facilitate the understanding of the primary challenges and barriers within each unique context, as well as the identification of viable solutions and alternatives. These insights are crucial for the formulation and implementation of policies aimed at fostering, promoting, and allocating resources towards the sustainable development of the IWT.

Future studies should consider the involvement of stakeholders and the benefits arising from their active engagement in the decision-making process. These studies should also examine investment strategies and incentives geared towards sustainable development, with a primary focus on both social and environmental impacts. Additionally, there is a need to explore business strategies to ensure that projects remain economically viable and do not incur financial insolvency. Furthermore, it is relevant to conduct a thorough evaluation of the primary barriers and potential solutions in the context of sustainable IWT development, tailored to the unique characteristics of each waterway. This approach enables the formulation of strategies that take into consideration geographical disparities, environmental considerations, cultural diversity, and the safeguarding of water resources, which serve a multitude of vital functions for ecosystems and society. Finally, it is imperative to comprehend IWT systems in regions beyond Europe and China, as these regions possess significant potential that is presently undervalued.

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Barriers and solutions for sustainable development of inland waterway transport: A literature review

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ABSTRACT

Inland waterway transport (IWT) is recognized by its social, environmental, and economic advantages if compared with other transportation means. Nevertheless, several barriers have been identified which require the implementation of solutions that lead to the sustainable development of IWT. After reviewing the literature, this paper presents a framework of barriers and solutions for the sustainable development of IWT. The data were classified within the main elements of the IWT system: ports, fleet, and waterway, and subsequently grouped into one of the five proposed factors (governance and policies, management, operational, infrastructure and technology, and human resources). The basis for the enhancement of IWT is the attitude and change of mindset of governments towards IWT development. From there, several solutions can be implemented, such as policies that stimulate IWT growth aligned with the environmental requirements of each basin and encourage the private sector to take part in the search for alternatives in Favor of IWT development as a reliable, sustainable, and economically viable means of transport.

1. Introduction

Numerous nations globally possess navigable waterways, each embodying significant value due to their multifaceted and indispensable functions for society and the populations situated along their deltas. These functions encompass fundamental roles in ensuring safety against flooding, providing a secure source of fresh water, fostering agricultural activities, facilitating inland waterway transport (IWT), and various other vital contributions [23,30]. The most extensive waterway networks are situated in China, Russia, and Brazil. Nonetheless, the significance of IWT transcends these nations and extends to European countries and the United States. In fact, China is endowed with three significant rivers, the Yangtze, Pearl, and Yellow rivers, which establish crucial hinterland connections for the distribution of local production and facilitate access to the seaport of Shanghai, on which 4886 million tons of cargo were transported in 2013 [30]. In Europe, IWT assumes significance as 21 out of the 28 member states possess inland waterways, the network predominantly comprises the Rhine-Main-Danube Corridor, fostering connectivity among 15 European nations. However, 50% of the network is located mainly in France, Germany the Netherlands, and Belgum. Despite the significant cargo volume of 535 million tons attributed to IWT in 2023, China's transportation performance in IWT has been historically higher than that of the European Union. This performance is comparable to that of the United States, which transported 581 million tons through IWT in the same year [15,30]. Conversely, while Brazil holds the third position among countries boasting the world's most extensive navigable waterways, merely 22% of these watercourses are utilized for cargo transportation. This limited usage can be attributed primarily to the considerable distance from major production centers and lower investments in infrastructure when compared to China and Europe [15].

Several authors have emphasized the multiple benefits associated with IWT development in terms of education, innovation, access to new markets and technologies, passenger transportation capacity, shipping saving costs, and employment capacity, especially in Europe [43,69,78]. Moreover, other added benefits related to the industry development such as the safety of cargo and people, good environmental performance, material supply, cost-efficient transport for bulk cargo, and the interconnection between seaports, inland river ports, and waterways [78]. In fact, low costs and safety of cargo handling are some of the advantages reported in the literature since 1995 [65]. Nevertheless, IWT, as the other transportation means, also generates some external costs related to accidents, noise, congestion, habitat damage, air pollution, climate change, and well-to-tank emissions [25]. However, these

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costs are lower than road and rail transportation, making IWT a more sustainable transportation option [25]. Furthermore, the continuous increase in cargo and container traffic and the rise of congestion in big cities near seaports lead to the promotion of alternatives such as IWT [64]. Despite the above, IWT is not yet prepared to handle such an increase [64], and new investments in infrastructure are required for its sustainable development [64].

Although the benefits of a modal shift to IWT are numerous, from a business perspective, choosing IWT instead of road transport requires political support and some economic interventions that encourage such a change, especially if some weaknesses such as low speed, high investment requirements, and high dependence on infrastructure are considered [77] [64]. Moreover, underdeveloped waterways are caused by local governments' need for knowledge and prioritization of IWT [37]. As a matter of fact, a need for more infrastructure to develop ports has been reported since 1994, especially for inland waterways ports [6]. Added to the necessity of fleet modernization is a fundamental step to meet the economic and environmental conditions for sustainable IWT [46].

In order to overcome these barriers and achieve sustainable development of IWT, investments in infrastructure and maintenance are required, as well as the protection of the ecological functions of the rivers, as well as their conservation and restoration [76]. Furthermore, sustainable IWT systems need to improve or develop safe and reliable traffic channels [50], navigational aids [44], programs for the maintenance of waterway infrastructure [46], and efficient and safe waterway maintenance [50]. Several integrated measures are required to manage and mitigate adverse effects on rivers, instead of specific programs that only cover individual functions, aligned with the development of policies that use an integrated approach for river management and regulation measures to provide safety against flooding, protect the environment and improve IWT becomes indispensable [3,23].

This paper aims to review the available literature about the sustainable development of IWT, focused on the main barriers and possible solutions for its development worldwide, and thus provide a conceptual framework using the three main elements of the IWT system (ports, fleet, and waterway). The paper has been divided into six segments, including **the introduction.** Section 2 will describe the method applied to collect and analyse de literature, followed by the third and fourth sections, where the main barriers and solutions to the sustainable development of IWT are presented. Finally, Sections 5 and 6 present the discussion and conclusions of the research.

2. Methodology

This study conducted a systematic literature review; this method can potentially overview a specific topic from a theoretical and conceptual perspective [63]. The research followed the guidelines proposed by Snyder [68]; it consists of four phases: the design of the review, then conducting the review, analysing the information, and ending with the writing of the report.

During the first stage, the systematic literature review was designed and is described in Table 1. Two research questions were formulated: *a. What are the barriers to the sustainable development of inland waterways transport systems? b. What are the solutions to overcome the barriers to the sustainable development of inland waterways transport systems?* Furthermore, the strategy for selecting literature involving inclusion and exclusion criteria was established. The search was limited to keywords included in the title, abstract, and keywords using "Scopus", "Google Scholar" and "EBSCO" as the databases for the paper selection.

In the following phase, a pilot test was applied to revise the quantity of information; the three stages for data selection were conducted, starting with duplicate elimination, inclusion and exclusion criteria application, and the use of the snowballing technique. The research resulted in fifteen from Scopus, 529 from Google Scholar, and forty-six from EBSCO. Finally, after applying the stages for filtering data, sixty-

Table 1
Stages followed in the systematic literature review.

Research questions	
a. What are the barriers to the sustainable development of inland waterways transport systems? b. What are the solutions to overcome the barriers to the sustainable development of inland waterways transport systems?	
Identification of keywords	
("inland waterway") AND (sustainab*) AND (measure* OR action* OR polic* OR solution OR driver* OR barrier* OR obstacle* OR issue*)	
Inclusion Criteria	**Exclusion criteria**
Academic Journals – Reports - Book chapters	Articles that are not covering barriers and solutions for IWT development
Full access to text	Repetitive studies found in the different databases
Stages for filtering data	
Stage one: Eliminating duplicates	
Stage two: Application of inclusion and exclusion criteria	
Stage two: Snowballing technique application	
Papers identification	**Papers selection**
Scopus: 115	Excluded papers after applying inclusion and exclusion criteria: 627
Google Scholar: 529	
EBSCO: 46	Selected papers: 63
Total: 690	Selected papers using snowballing: 16
Selected literature: 79 papers	

Source: Compiled by the authors.

three papers were identified.

Moreover, sixteen were included using the snowballing technique, and a total of **seventy-nine** studies (during the period of 1994–2022) were included in the review.

Different classifications for characterizing activities, issues, barriers, solutions, and measures have been explained in existing literature. Nonetheless, to enhance comprehension and organization, this study introduces five overarching categories that consolidate previous categorizations. Governance and policy (GP) refer to those aspects related to the governance systems applicable to the IWT as well as all those policies adopted by governments or organizations that contribute to the decision-making process, serving as guidelines to meet specific objectives that promote the sustainable development of the IWT, considering the protection of the environment and the socio-economic development of the waterway. In addressing matters pertaining to management (MG) and operations (OP) and to establish a clear distinction between the two, we adopt the definition proposed by Tako and Robinson [71]. This definition distinguished a separation based on the temporal nature and frequency of actions. Accordingly, actions requiring 2 to 5 years for implementation are categorized as management-oriented, involving long-term strategies and infrequent execution. Conversely, actions that can be rapidly implemented on a day-to-day basis or within a few months fall under operational aspects. Moreover, considerations related to the development of infrastructure and technology (IT) are consolidated to understand the fundamental deficiencies in terms of infrastructure and identify applicable solutions for the waterway, ports, and fleet. This grouping encompasses aspects of innovation and technological advancement. Finally, the human resources (HR) factor covers all aspects related to the personnel who perform functions either as part of the crews on board or carrying out tasks related to IWT in ports.

Table 2 shows the different classifications found in the literature, as well as the classification proposed by the authors, which will be used to describe the main barriers and solutions for the sustainable development of the IWT. Furthermore, a distinction is drawn between those categories associated with the fleet, ports, and waterways.

3. Results

The barriers and solutions obtained through the seventy-nine selected papers were classified within the main elements of the IWT system: ports (Fig. 1), fleet (Fig. 2), and waterway (Fig. 3), and

Table 2
Classification of factors for sustainable development of IWT.

Classification based in literature		Classification proposed by the authors					Element of IWT		
Classification	Author	GP	MG	OP	IT	HR	Port	Waterway	Fleet
Technical	Trivedi et al. [72]				X			X	
Infrastructural	Trivedi et al. [72]				X		X	X	X
Regulatory	Trivedi et al. [72]	X					X	X	X
Geo-Political	Trivedi et al. [72]	X					X	X	X
Financial	Trivedi et al. [72]	X	X	X	X	X	X	X	X
Development works	Barros et al. [3]				X			X	
Operations	Barros et al. [3]			X				X	
Ports	Barros et al. [3]		X	X	X		X		
Governance	Barros et al. [3]	X						X	
Manpower	Maternová et al. [44]					X			X
Management	Maternová et al. [44]		X						X
Materials	Maternová et al. [44]			X	X				X
Machines	Maternová et al. [44]				X				X
Methods	Maternová et al. [44]		X						X
Mother Nature	Maternová et al. [44]		X					X	X
Inland waterways infrastructure	Kotowska et al. [32]		X					X	
Quality of hinterland connections	Kotowska et al. [32]		X		X		X		
Administrative	Kotowska et al. [32]		X				X	X	
Quality of barge services	Kotowska et al. [32]		X	X	X		X		X
Information and promotion	Kotowska et al. [32]			X				X	X
Innovations	Kotowska et al. [32]				X				X
Regulatory	Rogerson et al. [60]	X					X	X	X
Financial	Rogerson et al. [60]		X	X	X		X	X	
Service quality	Rogerson et al. [60]			X			X		X
Market characteristics	Rogerson et al. [60]			X	X			X	X
Works	Barros et al. [3]	X						X	
Operations	Barros et al. [3]			X				X	X
Ports	Barros et al. [3]		X	X			X		
Governance	Barros et al. [3]	X					X	X	X
Infrastructure management activities	Nguyen, Nguyen [50]				X		X	X	X
Regulatory activities	Nguyen, Nguyen [50]	X					X	X	X
General activities (support)	Nguyen, Nguyen [50]	X	X	X	X	X	X	X	X

Source: Compiled by the authors.

subsequently grouped into one of the five proposed factors (governance and policies, management, operational, infrastructure and technology, and human resources).

3.1. Ports

3.1.1. Barriers

Although little attention is paid to inland river ports compared to seaports, they play a fundamental role as nodes in the transport chain [67]. Currently, there is a need to create intermodal terminals as expanded facilities with connection between them, these can improve issues related to road and port congestion, lack of storage capacity and unavailability of physical space in some regions where the expansion of port facilities is difficult [75]. Promoting a modal shift from road to waterways is essential to strengthen and incentivize IWT and thus compete with other transport modes [7]. Nevertheless, even though international organizations such as the European Commission, the European Sea Ports Organization (ESPO), and the American Association of Port Authorities (AAPA), among others, have promoted the inclusion of environmental and green management policies for seaports operations, few regulations encourage the inclusion of IWT, or incentive inland river ports and its connection with the main seaports [19].

The uneven development of waterways and the infrastructure to support IWT has become more evident worldwide. For instance, the Danube basin possesses the most and less economically developed countries in the European Union due to unequal infrastructure growth and a lack of technical equipment [47]. The above is compounded by other problems associated with the lack of cooperation among ports, differences in working hours, and the broad range of languages spoken along the basin [58,60]. Moreover, from an operational perspective, other factors related to added costs for transshipments and lack of reliability of barge handling, due to it is not a priority in seaports, make the use of the IWT less attractive compared to other transport means [33, 53]. On the other hand, deficiencies in infrastructure for IWT development and the necessity to adapt facilities to sea-river vessels have been reported since more than 25 years ago [6], added to the lack of investment in maintenance and construction of inland river ports [27,60,72, 75]. This is joined by a scarce skilled labour force and the reduced port staff due to the decrease in cargo flows in some countries [31,75].

3.1.2. Solutions

The lower level of economic development of waterways directly impacts the industry's performance in the region [47]. Countries with developed IWT systems focus their efforts on generating policies for their promotion and infrastructure maintenance and possess specialized institutions with unified plans and development strategies, as is common in Europe and the United States [28]. On the other hand, in countries with low development of waterways, their actions aim to start operations and attract cargo flow [60].

Stakeholder cooperation and interinstitutional participation are relevant strategies to improve the quality of hinterland connections between inland and seaports [26,32]. In addition to that, Li et al. [36] suggested coordination strategies between vessels and terminals to alleviate long waiting times for load and unload operations, especially in seaports, since inland vessels are not a priority. On the other hand, connectivity does not simply refer to connecting river and land maritime routes; it also requires digitization and automation in operations that involve ship, port, logistic operators, and authorities which allows for monitoring operations, integration of IWT with other transport modes and to reduce transshipment costs [32,46,79,87].

Another solution proposed to minimize the delivery time of goods is the use of multimodal chains that allow products to be moved rapidly [75]. In the case of operations with seaports, priority is given to large-tonnage ships to take advantage of the port's infrastructure in

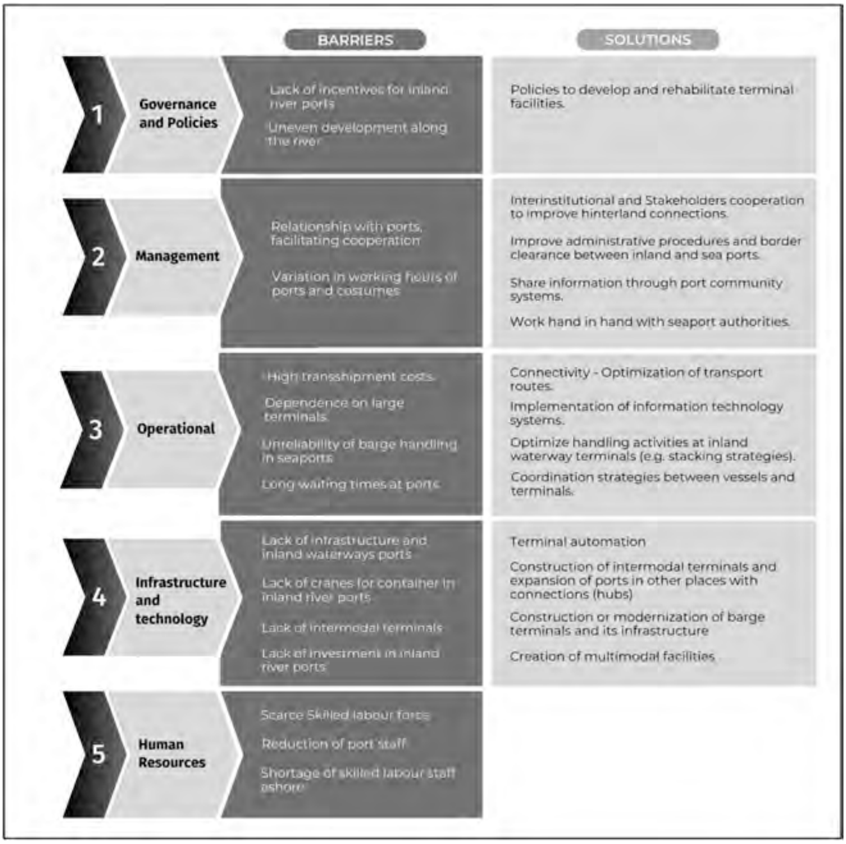

Fig. 1. Barriers and solutions for the ports,
Source: Compiled by the authors.

terms of dock occupation and use of port equipment (e.g., cranes, trucks, reach stacker). For this reason, solutions such as the use of multimodality and the application of models or systems that allow the interaction of stakeholders, as well as the use of adequate infrastructure, are some of the alternatives to overcome the barriers in the development of the IWT [53,86]. Moreover, the creation of automated barge terminals and floating container terminals, as well as multimodal facilities, could deal with barge congestion [53]. In terms of efficiency, Gołębiowski [18] argues that the use of IWT was profitable for distances between 350 and 400 km, today this concept has changed to 60 km, which is why some intermodal terminals are being located 15 km from seaports, in order to minimize congestion of the ports and fulfil functions of storage, fumigation and cargo/costumes clearance.

The barriers and solutions for the ports have been summarized and classified in Fig. 1.

3.2. Fleet

3.2.1. Barriers

In transportation, travel time is one of the most crucial factors in the choice of transport. However, IWT has been associated with low speed compared with other transport means, making it suitable for large quantities of cargo and oversized loads [33,44,45]. Nevertheless, other issues such as long waiting times in seaports to load or unload cargo due to the lack of priority for inland vessels at seaports, the dependence on meteorological conditions, and the lack of navigation infrastructure, among others, exacerbate the current situation [36,44,75]. Moreover, IWT is vulnerable to weather variation due to the direct impact on vessel navigability and water level fluctuations [11]. Meteorological changes related to freezing, floods, and droughts impact not only reliability but also the cost of IWT operations [62].

Currently, the need to modernize the river fleet and implement new technologies that improve energy efficiency and contribute to the sustainable development of IWT is imminent [31]. Nevertheless, technical advances to replace fossil fuels in IWT vessels are lagging behind compared to maritime transport. Indeed, for IWT, fully autonomous electric vessels have not been developed yet [49]. However, this type of investment holds high financial risks and uncertainty, causing absence or lack of interest to invest in the waterways vessels [31]. Furthermore, the differences in the configuration and dimensions of the fleet

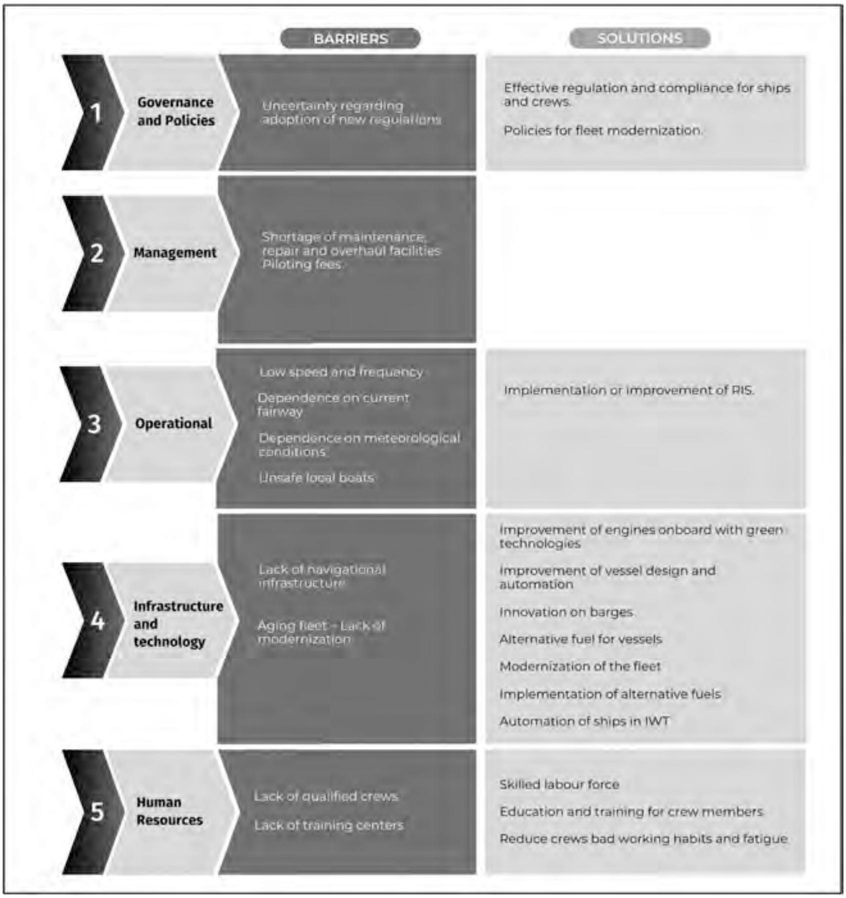

Fig. 2. Barriers and solutions for the fleet.
Source: Compiled by the authors.

constitute a barrier to developing IWT since this generates a lack of interoperability among various waterways, such as the Danube and Rhine, despite their closeness and connection [31].

Today IWT industry is facing issues associated with the shortage of skilled labour force, aging of ships crews, together with insufficient training and qualification, and the decrease in applicants for nautical education programs [31,62,75]. In addition, crew members have a more significant challenge dealing with the effects of the climate crisis due to the changing extreme weather conditions; this is why special education and training are required to face these new challenges [2,7]. In fact, between 2000 and 2020, 17% of the accidents reported on the Danube were caused by insufficient crew training [44].

3.2.2. Solutions

Globally diverse international projects have developed frameworks and working papers to generate policies to speed up IWT development and the design of innovative vessels to modernize the fleet and enhance the competitiveness of IWT [55,66]. Nevertheless, in some countries such as Bulgaria, the Danube fleet consists of self-propelled vessels or convoys of pushed barges between 20 and 50 years old; the lack of modernization results from credit organizations arguing uncertainty and high financial risks, being imminent the need to establish policies that support the modernization of the fleet [31,55]. Moreover, improvement of vessel design in terms of efficiency, appropriateness (according to the waterways), and greener design are fundamental requirements to assure the safety of the crew, cargo, and environment [33,44]. Other advancements in ship construction, such as using alternative fuels, hull and propeller optimization, and implementing air cavity systems on board, are gaining relevance [4].

Furthermore, autonomous shipping is becoming relevant and attract the attention of academia and industry due to its ability to improve not only the safety but the efficiency of IWT [13]. The levels of automation that are being developed for IWT will improve its competitiveness and contribute to the acceleration of modal shift. For instance, Peeters et al. [56] propose the Inland Shore Control Centre with the aim of monitoring and controlling inland vessels, installing onboard the necessary

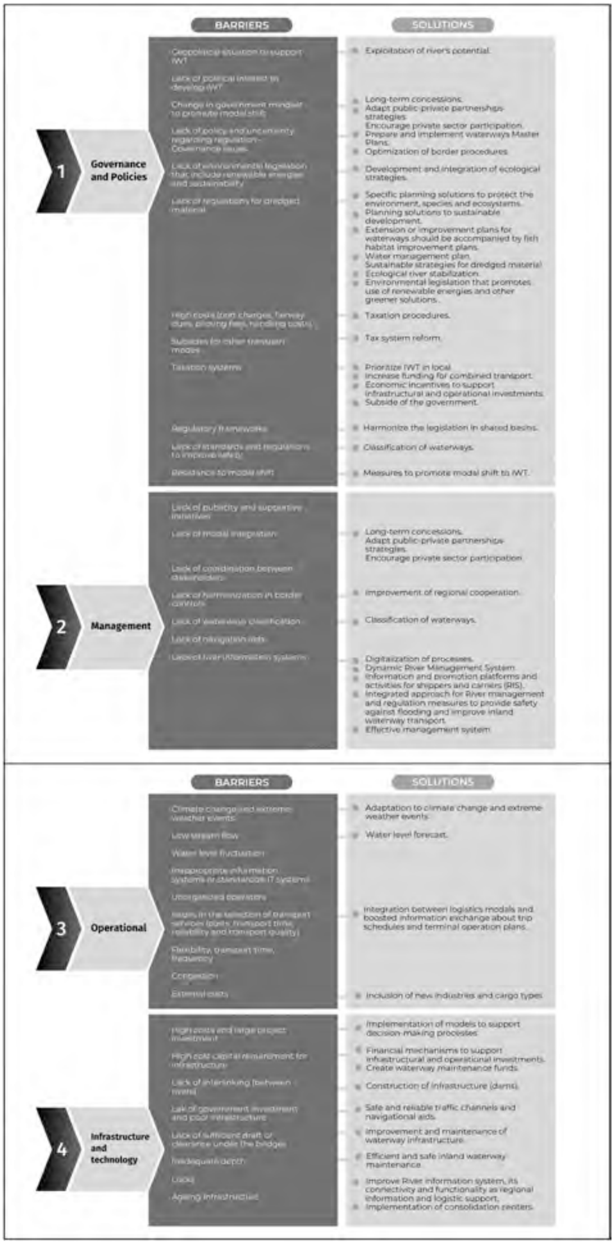

Fig. 3. Barriers and solutions for the waterway.
Source: Compiled by the authors.

systems to achieve situation awareness and sensemaking on the remote controller. Even though the author argues that the socioeconomic viability of these systems should be reviewed, the automation and modernization of transport is a growing reality nowadays. As in the maritime sector, for IWT the near future cover unmanned or autonomous operations in waterways [56]. The above should be accompanied by the implementation of River Information Systems (RIS) to allow the exchange of information between stakeholders and transport operators to use and make decisions based on harmonized information and good communication between all the actors [31].

On the other hand, the transportation industry has been developing strategies to migrate from fossil fuels to cleaner energy and thus optimize efficiency and safety during operations. Even though most of the studies carried out on ship emissions and possible alternatives for their reduction have focused mainly on seagoing vessels [13], for inland ships, energy efficiency must be evaluated case-by-case since the conditions of speed and energy demand vary depending on the characteristics of each basin in terms of meteorological or seasonal conditions and variation of depth on waterways [57]. In this regard, for replacing fossil fuels with other greener alternatives to substitute diesel onboard ships, Liquefied Natural Gas (LNG), hybrid-electric or electric power systems, and hydrogen are the proposed solutions reported in the literature [4,8,14,57]. However, sources such as hydrogen possess some complications due to production plants require significant investments to be produced in a totally green way, and its profitability depends on the selling price of hydrogen [14].

Finally, several authors argue that the human factor is crucial in accidents and incidents on IWT. However, proper crew training and compliance with the standards established for work and rest times are essential to minimize risks in IWT and to minimize lousy working habits and fatigue [7,44,50,75].

Fig. 2 presents a summary and categorization of the barriers faced by the fleet as well as the corresponding solutions.

3.3. Waterways

3.3.1. Barriers

Several barriers have been associated in the literature with governance and regulations. IWT development requires political interest to reduce uncertainties and establish a set of incentives or subsidies to overcome the resistance to modal shift [41,60,84]. In some countries, the development of IWT is under appreciate, while other transport modes are supported and subsidized by the government [41]. This demonstrates a lack of political interest in developing IWT, triggering little investment in infrastructure [41]. Another critical factor is the geopolitical characteristics of the region to support investment and development of IWT infrastructure on the basins [84]. For instance, Jaimurzina & Wilmsmeier [27] argue that countries in Latin America and the Caribbean face incomplete, obsolete, or non-existent regulatory frameworks to support IWT development.

Apart from the governance and policy schemes, the managerial attitude towards IWT possesses a vital role in its development, being the modal integration of IWT into the national or regional transportation systems as a starting point [61,72,75]. Nevertheless, today, waterways classification, information systems, and navigation aids are underdeveloped in some regions, and there is a need for stakeholder coordination and harmonization of border controls to improve IWT reliability [27,58,72].

From an operational perspective, climate change and extreme weather events such as heat waves and heavy precipitation that result in flooding affect not only the infrastructure but also the performance of transport systems, which generates a lack of reliability, delays, and congestion [21]. Moreover, the uncertainty of weather fluctuations and their predictability worsen the situation [49]. Water level fluctuation is expected to affect mainly the natural waterways in Europe, directly impacting freight costs due to waterway vessels' ability to use part of their maximum capacity [22,29]. In that sense, dredging is needed to support IWT in the majority of the basins; for instance, in the Netherlands, between 30 to 35 cubic meters of dredged materials are removed, and regulations that balance the high economic costs of sustainable solutions and the actual budget should be implemented [20]. Although in Europe, there are some programs such as Room for the River, the Delta Program for Rivers, Sustainable Fairway Rhine Delta, and the Water Framework Directive dedicated to providing safety against flooding and generating a balance between nature, landscape, and cultural heritage, an integrated management approach is required to meet the diverse functions of river basin including IWT [23].

Furthermore, the infrastructure investment deficit for IWT is a relevant issue reported worldwide; in fact, high costs and extensive infrastructure require long-term strategies to maintain or improve IWT infrastructure [17]. Moreover, insufficient lock capacity cause long waiting time and congestion of barges in some regions. For instance, Yang et al. [85] describe congestion problems in strategic points such as the Three Gorges Dam in China. Likewise, Jaimurzina & Wilmsmeier [27] report a lack of investment in Latin America and the Caribbean, and Némethy et al. [49] argue an increase in voyage time due to lock capability in Europe, and the lack of maintenance of the North American infrastructure, since the construction of most dams, levees, and locks dates back to the 20th century.

One of the main problems faced globally by IWT is the lack of financial support, even further when the industry requires high investments for the construction and maintenance of IWT infrastructure [47]. Although every country applies different policies to support and incentivize IWT, establishing mechanisms to support infrastructural and operational investments is required [74]. In France, Salah (2016) argues the existence of inequality of investment distribution, being the road investment superior to IWT (66,31% and 1,05%, respectively). In the case of Vietnam, user fee collection is not used for infrastructure development, and the participation of the private sector is limited [50]. Although in Croatia the government stimulates the purchase of electric vehicles, this kind of state aid does not exist for shipowners, instead Croatian policies support diesel power vessels giving them some subsides, the later proves the need to update policies involving all the stakeholders in the transport sector [57]. On the other hand, the charges for the use of the waterways and their investments in infrastructure vary from one country to another; in the case of Sweden, the financing is made with the collection of said fees, while in the Netherlands, the public sector is responsible for the maintenance and investments [62].

3.3.2. Solutions

Measures related to public policies and management tools have been widely reported in the literature to promote IWT from different approaches. Nevertheless, some economic activities of the waterways generate negative environmental impacts. Therefore, it is essential to develop specific planning solutions that protect the environment, specifically in vulnerable areas such as the habitats and species that inhabit these ecosystems [40]. In that sense, developing a profitable water management plan with ecological and social conditions considering flood protection and reliable navigation conditions is required [24,84]. Moreover, integrating ecological strategies that preserve the environment of the riverside areas is also suggested [46]. On the other hand, sustainable strategies for dredged material, such as increasing the budget for dredging operations, increasing the location for dredged materials, and promoting treatment plans, were proposed by Hakstege & Laboyrie [20] considering the large amount of material generated in The Netherlands.

Therefore, assessing and understanding the river exploitation potential become indispensable; for instance, Mihic et al. [46] argue that the Danube waterway, which connects ten countries in Europe, is unexploited despite being the cheapest and most environmentally viable transport mode. In addition to the above, an effective management system that focuses on legal and financial frameworks and coordinates the institutional structure (public and private stakeholders) is crucial [50]. In fact, in some countries (e.g., Vietnam, Colombia), the institutional framework and management sector limit the development of IWT systems, due to weak enforcement policies and overlapping legal and administration systems, besides the excess of policymakers, authorities, and international organizations which instead of generating barriers for the development of IWT, should accomplish strategic functions to facilitate the development of hinterland transportation [26,50].

Another relevant solution is the improvement of administrative procedures; in some cases, administrative paperwork (e.g., exports through seaport) not only generates high costs but also can cause delays of more than 14 days per container, due to border clearance between inland and sea ports [32,59]. This is why a revision and unification of the regulatory framework for freight transport and working hand in hand with seaport authorities are relevant for sustainable development of IWT systems [16,32,55].

For Latin America and the Caribbean, Jaimurzina & Wilmsmeier [27] argue that the improvement of regional cooperation is a crucial strategy to develop regional standards and strategies to promote sustainable development of IWT addressing the social, economic, and environmental dimensions for the local, national and regional improvement of this promising means of transport. Furthermore, IWT should be integrated into the co-modal transportation system at the national and regional levels [27]. Another essential regional aspect is harmonizing legislation for shared basins and digitalizing processes related to border controls and loading/unloading cargo [43].

Optimization of transport routes and the enhancement of the role of IWT in the supply chain are crucial factors to integrate and develop IWT [80,87]. In this respect, measures intended for the implementation and improvement of information technology systems that integrate IWT in sea-land planning, and models that incorporate tug routing and barge transshipment choices, are becoming relevant, thereby minimizing the carbon emissions and improving the economic performance [32,87]. Moreover, the implementation of monitoring systems to control traffic, prevent delays, and synchronize all the actors in loading and unloading activities, together with the inclusion of physical internet and synchro modality could be an essential step to promote using IWT [1,46].

The above can be linked to the River Information System (RIS), which is based on the interaction of devices, software, and operators and provide services such as a vessel traffic control system, announcements to captains (NtS), electronic ship reporting, electronic navigation maps, among others [51]. Furthermore, RIS can serve as a comprehensive management system, which enables to achieve more efficient use of fleet and infrastructure, improve communication between waterway users, and facilitate the exchange of information, schedules, and operational plans between public and private stakeholders, although in some regions international cooperation is required to improve regional information and logistic support [46]. It is worth highlighting that RIS entails safety efficiency and environmental protection for IWT operations [44,51]. In order to strengthen the proposed technological measures, it becomes indispensable to develop Information and promotion platforms for shippers and carriers, some examples of IWT/Seaport interactions has been described in the literature, such as project ALICE for the European Union waterways, and the implementation of improved port community system currently used in large ports [1,32,59]. However, the adaptation will require massive use of AIS signals, and some synergies, interdisciplinary research, and innovation are required to accomplish this goal, as well as some subsidies to stimulate modal shift and taxation procedures that stimulate the use of IWT and increase the sustainability of the transport system [32,37,41,48].

Today, water level fluctuation and extreme weather events due to climate change are considered relevant operational barriers for IWT. Nevertheless, the development of a hydrological forecast that provides information about water levels, stream velocities, and maximum drafts, among others, could be relevant to improve the operational decision-making processes, reducing costs and its connection with RIS serve to assure safety [45].

Considering the lack of financial resources for developing and maintaining infrastructure to support IWT, measures aimed at creating waterway maintenance funds and increasing funding for combined transport are crucial for its development [16,50]. For instance, in Ukraine, which possesses three of the five largest rivers in Europe (Dnieper, Danube, and Southern Bug), developing an appropriate infrastructure and optimal operational conditions that allow it to become competitive compared to the rail and road is a priority. However, since this competitiveness will not be achieved in the short term, transport technologies, seaports, and state incentives will be required [34]. Apart from that, improving connections, and designing an integrated transport system, added to the presence of authority control points and application of models, are critical topics for future planning scenarios and policies assessment [5]. Another strategy could be the implementation of consolidation centres for diverse types of cargo in cities that possess the natural waterways to support urban development. For instance, in Brussels, due to the increase of the population and the requirements that it entails in terms of infrastructure for housing and other activities, the implementation of consolidation centre is a relevant solution for improving their transport requirements [9].

Currently, public-private partnerships (PPP) are a tendency reported by Miloslavskaya & Plotnikova [47]; the authors describe its application in Germany and China and highlight its benefices in easing public-sector debt and expenditure obligations. The adaptation of PPP can leverage investments in inland infrastructure [75]. For example, countries in the EU can benefit from joint projects and institutions that finance the development of the IWT network [47]. However, PPP should consider socioeconomic impacts and the environmental and social issues derived from these strategies without ruling out that the support of conventional funding is also required in specific conditions such as the Three Gorges Dam in China, where congestion is increasing and causing cargo delays [27,85].

Fig. 3 presents a compilation and categorization of the barriers faced by the waterways, along with their corresponding solutions.

4. Discussion

4.1. Governance and policies

Various governance regimes applied to IWT were identified; some countries use local administrations, while in some cases, the central government oversees the administration of the IWT. Moreover, in other cases, both regimes are applied in the same country to manage different waterways, which can lead to uneven development of the IWT system due to differences in economic incentives and the infrastructure available [38]. For instance, in China Li et al. [37] argue the necessity for a taxation system reform since, in some regions where IWT governance is not centralized, municipalities receive only 10% of the benefits of IWT. Furthermore, it can thus be suggested that governments should reduce the resistance to change, starting with a mind shift and their supportive attitude towards implementing more sustainable transportation means, such as IWT.

Furthermore, the enactment of policies can significantly contribute to the advancement of IWT [42]. For instance, Europe has White Papers encompassing diverse facets of transport integration, including IWT, within its Trans-European Transport Network (TENT-T). These documents acknowledge the potential of IWT in terms of cost-effectiveness, environmental sustainability, energy efficiency, and safety levels, advocating for its incorporation in hinterland cargo transportation. Furthermore, initiatives such as NAIADES II and NAIADES III, exemplify programs implemented within the European countries to actively foster the development of IWT [42]. Moreover, additional initiatives, such as PLATINA, have played a crucial role in identifying key stakeholders for the execution of the NAIADES program. Offering technical expertise across diverse activities, PLATINA has actively supported the enhancement and maintenance of waterways, the modernization of fleets, the integration of ecological strategies, and the formulation of traffic models to advance specific facets of IWT [46]. In addition to that, concerning the Rhine delta, the "Room for the River" project presented comprehensive solutions for the upkeep of the fairway, aiming to achieve the prescribed navigation requirements [24]. Other countries such as Vietnam and China have recognized the relevance of the generation of strong legal frameworks and policies and regulations that contain some reforms to the current system in order to support the use of the IWT, in fact China generated the "window opportunity" for the transportation of containers on barges, resulting in the largest market of this type in the world [10,50].

Given the above, IWT can be developed through the application of policies and regulations that stimulate and encourage the modal shift from road to IWT, as well as joint work between all stakeholders, whether they are public or private entities. However, these policies and regulations must contemplate waterway's master plans that assure river morphology and minimization of fauna disturbance [3], integrating strategies that preserve and enhance the ecological conditions of the riverside areas [3,46], in conjunction with the protection of the ecosystem, and the complete services of waterways related to freshwater supply, protection against flooding, renewable energy generation and river transportation [23,40,84]. Moreover, generating policies aimed at creating economic stimuli becomes relevant, either through implementing subsidies or reforming tax systems. On the other hand, considering the high costs associated with the operation and infrastructure of the IWT, it is considered relevant to evaluate the relevance of other strategies, such as adopting PPPs and long-term concessions.

4.2. Management

Another important challenge for sustainable development IWT is the administration of waterways, especially in shared basins, where the regulations for vessels, crew members, and other border and port obligations are not harmonized. From a managerial perspective, barriers related to the lack of investment in the waterways mainly focused on the deficiencies in the RIS, the classification of the waterways, especially in Latin America and the Caribbean, and their maintenance and signalling, requires especial attention and coordination among the stakeholders. On top of that, digitization and shared information is considered essential to feed the information systems and models; these will impact not only the operational requirements but the decision-making processes for investment and development of IWT. This is why cooperation between stakeholders and working hand in hand with the local, national, and regional authorities is essential.

4.3. Operational

Although IWT is characterized by its large cargo volume capacity, it possesses some disadvantages associated with low speed and high dependence on certain weather conditions for its operation. Additionally, IWT is not considered a priority, especially in large maritime terminals, where the fleet faces long waiting times in ports and high costs associated with transshipments, generating a lack of reliability. In addition, unorganized operators disconnected from the RIS could overcome various barriers with its implementation, due to their benefits focused on optimizing connectivity and selecting transport routes, as well as handling activities at ports and the water level forecasts.

4.4. Infrastructure and technology

Infrastructure development constitutes the backbone of IWT. Nonetheless, various deficiencies on that respect are described in the literature mainly associated with the shortage of inland river ports or intermodal terminals, an aging fleet, and the lack of innovation for inland vessels. These are linked with the elevated costs and high requirements in terms of dredging programs and the construction of other infrastructure such as locks and bridges, among others. Added to this, there is a lack of prioritization by governments for the investments in infrastructure that supports sustainable development IWT, some authors argue that technological improvements, as well as the implementation of new businesses that motivate the modal shift are essential for the sustainable development of IWT [3,12,69].

Considering the above, implementing new technologies is a decisive factor, beginning with the modernization of the fleet, which must consider the use of alternative fuels, automation of systems, and sustainable engines on board the IWT fleet [9]. Besides, although several innovation improvements on barges have been addressed and assessed, Wiegmans [77] suggests that fleet solutions should be focused on the creation of new markets such as palletized cargo transport or dedicated barges and sea–river transport, accompanied by policies that allow them to be strengthened. On the other hand, another important measure to overcome barriers is the implementation of information systems that collect and process data to support vessels and traffic management, and decision-making processes. These systems use models that provide information to optimize investments and support operations using economic analysis, engineering reliability, and environmental data while generating a positive impact on the economic and environmental performance of IWT [3,35].

4.5. Human resources

Finally, the skilled labour force for IWT, both on land and on board, has decreased, and some issues related to bad work habits that trigger fatigue of the personnel on board were found in the literature. However, the human factor is the less developed topic when it comes to barriers and solutions for the sustainable development of IWT. This also accords with our earlier observations [3], which showed that the social and people aspects of sustainable development of IWT require the performance of other studies focused on understanding social aspects as a relevant factor for the improvement of the transportation system, together with the implementation of policies to encourage new generations to be part of the IWT.

4.6. Other considerations

In addition to previous considerations, certain challenges linked to market characteristics can impede the inclination toward modal shift to IWT. The primary barriers encompass cost-related factors (such as pre- and post-haulage goods handling, competition pricing, piloting fees, and port charges), deficiencies in infrastructure, water levels, and, in some instances, ice formation. Nevertheless, the key solutions to overcome these barriers aim to attract sufficient cargo volumes to reach economies of scale. This involves promoting platforms that facilitate information sharing to identify intermodal connections, existing goods flows, and fostering coordination among various stakeholders. Additionally, the inclusion of new markets, such as the automotive industry, containers, and palletized cargo, is advocated [10,48,62,66].

On the other hand, when contemplating the development of IWT, it is essential to consider additional aspects related to the geographical layout of inland ports. For instance, some authors have delineated port system development through conventional models like port setting, port expansion, and port specialization. Moreover, contemporary perspectives, such as port regionalization, Inside-Out and Outside-In development, and hybrid approaches incorporating elements of the latter three, have also been expounded upon in the literature [52,82]. The regionalization model described by Notteboom & Rodrigue [52], suggests expanding the definitions proposed in the classic models, in order to include two fundamental aspects: first the integration of the 'offshore' hubs such as the Bahamas, Oman, Malaysia, and Malta cases; and second, the incorporation of centers or terminals for hinterland cargo distribution as active nodes, taking into account the local constraints in terms of need of land expansion and global changes associated with production and consumption. Moreover, Wilmsmeier et al. [81] suggest two development models: Outside-In and Inside-Out. The former entails development droved by sea-related elements such as port authorities, terminals, and ocean carriers, exemplified by Rotterdam and Antwerp. Conversely, Inside-Out development is prompted by inland intermodal terminals collaborating to attract cargo flows to the region. This model seems more prevalent, primarily due to public sector initiatives. Nevertheless, the effectiveness of these initiatives requires assessment to prioritize and coordinate actions at the local and regional levels. Further research can focus on exploring barriers and solutions proposed in different models, particularly in developing countries, to offer region-specific solutions based on individual needs.

5. Conclusion

This paper provided a framework for understanding the barriers and proposed solutions that lead sustainable development of IWT. It is essential to consider the various functions that waterway systems fulfil; since the sustainable development of IWT cannot ignore environmental and social requirements and must adapt the infrastructure works and the regulations for ships and their crews, in policies that guarantee social and economic equity of the riparian regions.

Moreover, modal shift positively affects the reduction of external costs associated with congestion, climate change, loss of habitat, accidents, and infrastructure [9]. However, numerous barriers must be overcome, starting with governments that support and prioritize the integration of IWT with other transportation systems, developing economic strategies to support infrastructure building and maintenance, and the investment of innovative technologies to improve management and operation requirements.

Finally, given the particular characteristics of each basin, it is necessary to conduct studies that focus particularly on each waterway. Although numerous studies were carried out in Europe and Asia (mainly in China), this study found that despite the vast waterway system located in Latin America and its great potential, few studies contemplate its evaluation, barriers, and possible solutions for its development.

Authors' contributions

NC IB FB designed the methodological approach. NC conducted research collecting and analysing data. All authors read and approved the final manuscript.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The data used for the systematic literature review is available using search engines mentioned in the article.

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Not applicable.

ANNEX A. List of literature included in the review

No.	Title	Year	Methods	Country/Region	Authors
1	An Overview of Promising Alternative Fuels for Road, Rail, Air, and Inland Waterway Transport in Germany	2022	Not clearly specified	Germany	Breuer et al. [8]
2	Climate services in support of climate change impact analyses for the German inland transportation system	2022	Models	Germany	Hänsel et al. [21]
3	Development of an advanced, efficient and green intermodal system with autonomous inland and short sea shipping - AEGIS	2022	Not clearly specified	Europe	Krause et al. [33]
4	Environmental Viability Analysis of Connected European Inland–Marine Waterways and Their Services in View of Climate Change	2022	Literature review	Europe	Némethy et al. [49]
5	Inland waterway transport and the 2030 agenda: Taxonomy of sustainability issues.	2022	Taxonomies or typologies	General	Barros et al. [3]
6	Revealing Causal Factors Influencing Sustainable and Safe Navigation in Central Europe	2022	Hazards identification	Europe - Danube	Maternová et al. [44]
7	Taxonomy of inland waterway transport operation sustainability issues: A review	2022	Systematic literature review	General	Barros et al. [3]
8	The effects of a water-bound construction consolidation centre on off-site transport performance: the case of the Brussels-Capital Region	2022	External Cost Calculations	Brussels	Brusselaers, Mommens [9]
9	The Energy Potential of the Lower Vistula River in the Context of the Adaptation of Polish Inland Waterways to the Standards of Routes of International Importance	2022	Multi-criteria analysis	Poland	Woś et al. [84]
10	Analysis of Some Essential Aspects Related to the Navigation Conditions on the Danube River	2021	Quality Function Deployment	Danube River	Marcu Turcanu et al. [43]
11	Barriers to inland waterways as a sustainable transportation mode	2021	A dematel-ISM based approach	India	Trivedi et al. [72]
12	Container barge (un)reliability in seaports: a company case study at the port of Antwerp	2021	Case Study	Antwerp	Oganesian et al. [53]
13	Crises and Their Effects on Freight Transport Modes: A Literature Review and Research Framework	2021	Systematic literature review	Europe	Borca et al. [7]
14	Electrification of inland waterway ships considering power system lifetime emissions and costs	2021	Life-cycle assessments (LCAs)	Croatia	Perčić et al. [57]
15	Green logistics oriented tug scheduling for inland waterway logistics	2021	Mixed Integer Programming (MIP) model	General	Zhu et al. [87]
16	Inland navigation on the Danube and the Rhine waterways	2021	Not clearly specified	Europe	Mako, Galieriková [39]

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17	Literature review and comparative analysis of inland waterways transport: "Container on Barge"	2021	Literature review and comparative analysis	Europa - Asia - EEUU	Bu, Nachtmann [10]
18	RIS system to improve the efficiency of IWT	2021	Review of the status of RIS	Poland	Niedzielski et al. [51]
19	Strategic planning of inland river ports under different market structures: Coordinated vs. independent operating regime	2021	Model	China	Li et al. [38]
20	AEGIS: Advanced, efficient and green intermodal systems	2020	Not clearly specified	Europe	Rodseth et al. [59]
21	An Inland Shore Control Centre for Monitoring or Controlling Unmanned Inland Cargo Vessels	2020	Experiments - Tests	Europe	Peeters et al. [56]
22	Business models for dedicated container freight on Swedish inland waterways	2020	Stakeholder oriented multi-actor multi-criteria analysis (MAMCA) - Case study	Sweden	Williamsson et al. [80]
23	Drivers and Barriers for Inland Waterway Transportation	2020	Interviews	Sweden, Belgium, the Netherlands, Germany and Great Britain	Roso et al. [62]
24	External Costs in Inland Waterway Transport: An Analysis of External Cost Categories and Calculation Methods	2020	Systematic literature review	General	Hofbauer, Putz [25]
25	Inland water transport applicability for sustainable sea port hinterland infrastructure development. Klaipeda sea-port case	2020	Case study - Mathematical models	Klaipeda	Malkus et al. [41]
26	Legal, Institutional and Financial Solutions for the Sustainable Development Strategy of Inland Waterway Transport in Vietnam	2020	Not clearly specified	Vietnam	Nguyen, Nguyen [50]
27	Modal shift to inland waterways: dealing with barriers in two Swedish cases	2020	Case Study	Sweden	Roso et al. [62]
28	Pricing and subsidy models for transshipment sustainability in the three gorges dam region of China	2020	Model	China	Yang et al. [85]
29	Problems and challenges facing the Nigerian transportation system which affect their contribution to economic development of the country in the 21 century.	2020	Not clearly specified	Nigeria	Onokala, Olajide [54]
30	Sustainability of global Golden Inland Waterways	2020	Models	General	Wang et al. [76]
31	Towards sustainable river management of the Dutch Rhine River	2020	Historical review and trends	Dutch Rhine River	Havinga [23]
32	Challenges and opportunities for the development of river logistics as a sustainable alternative: a systematic review	2019	Systematic literature review	General	Vilarinho et al. [75]
33	Collaborative Fleet Deployment and Routing for Sustainable Transport	2019	Analytical model	The Netherlands	Ypsilantis, Zuidwijk [86]
34	Inland waterway terminal yard configuration contributing to sustainability: Modelling yard operations	2019	Model	General	Wiercx et al. [79]
35	Inland waterway transport: challenges and prospects	2019	Not clearly specified	General	Wiegmans, Konings [78]
36	Integrated planning of inter terminal transport between sea port and inland terminals	2019	Literature review	General	Hu et al. [26]
37	Probabilistic Shipping Forecast	2019	Hydrological Forecasts	Europe	Meißner, Klein [45]
38	Strategic modelling of passenger transport in waterways: The case of the Magdalena River	2019	Model	Colombia	Berrio et al. [5]
39	Towards freight transport system unification: reviewing and combining the advancements in the physical internet and synchromodal transport research	2019	Systematic literature review	European Union	Ambra et al. [1]
40	Ukraine's river transportation potential: Between business and sustainable development	2019	Survey - Questionnaire	Ukraine	Krykavskyy, Shynkarenko [34]
41	A global review of the hinterland dimension of green port strategies	2018	Qualitative review of grey and secondary literature	General	Gonzalez Aregall et al. [19]
42	An Innovative Concept for Inland Waterway Vessels	2018	Model test to hull design	General	Bernardini et al. [4]
43	Analysis of the impacts of different modes of governance on inland waterway transport development on the Pearl River	2018	System dynamic (SD) models	China	Jiang et al. [28]
44	Current situation and optimization of inland waterway infrastructure financing	2018	Case study	USA, Russia and Germany	Miloslavskaya, Plotnikova [47]
45	Inland Shipping to Serve the Hinterland: The Challenge for Seaport Authorities	2018	Multiple case study	Europe	Kotowska et al. [32]
46	Same river same rules? – Administrative barriers in the Danube countries	2018	Focus group - Survey	Danube	Pfoser et al. [58]
47	Stimulating inland waterway transport between seaports and the hinterland from a coordination perspective	2018	Not clearly specified	General	Li et al. [36]
48	Sustainable development indicators of selected European countries in the field of transport sector	2018	Indicators assessments	Europe	(Sommerauerová et al., 2018) [69]
49	Future of the Inland Waterway Transport	2017	Not clearly specified	Czech Republic	Cempírek, Čejka [12]
50	Inland river ports. In Inland waterway transport: challenges and prospects	2017	Not clearly specified	General	Slack, Comtois [67]
51	Specifics of the Danube fleet management (trends and perspectives for development)	2017	Life-cycle assessment (LCA)	Danube - Bulgaria	Koralova [31]
52	The impacts of spatial planning on the sustainable territorial development of the Rhine-Danube Trans-European Transport Corridor through Serbia	2017	Standard (or adapted) strategic environmental effect	Serbia	Maksin et al. [40]
53	P3 Solutions for the Nation's Inland Marine Transportation System	2016	Not clearly specified	USA	Gardels et al. [17]
54	An inland waterway freight service in comparison to land-based alternatives in South-Eastern Europe: Energy efficiency and air quality performance	2016	Document analysis	Europe	Tzannatos et al. [74]

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55	An institutional analysis of the evolution of inland waterway transport and inland ports on the Pearl River	2016	Not clearly specified	China	Li et al. [37]
56	Inland navigation and a more sustainable use of natural resources: networks, challenges and opportunities for South America	2016	Not clearly specified	South America	Jaimurzina, Wilmsmeier [27]
57	Inland Waterway Transport: An overview	2016	Not clearly specified	General	Konings, Weigmans [30]
58	Inland water transport in Poland	2016	Not clearly specified	Poland	Gołębiowski [18]
59	Path Planning for Autonomous Inland Vessels using A*BG	2016	Modied A* algorithm (A*GB)	Europe	Chen et al. [13]
60	Policies for inland waterway transport: needs and perspectives	2016	Not clearly specified	General	Maraš [42]
61	Transport of goods in France	2016	Not clearly specified	France	Oulfarsi [55]
62	A Green and Economic Future of Inland Waterway Shipping	2015	Not clearly specified	Mainly Europe	Sihn et al. [66]
63	A modal shift of palletized fast moving consumer goods to the inland waterways: a viable solution for the Brussels-Capital Region?	2014	Location- and feasibility analysis	Brussels	Mommens et al. [48]
64	The Use of Hydrogen as a Fuel for Inland Waterway Units	2014	Not clearly specified	Egypt	El Gohary et al. [14]
65	Building Sustainable Policy Framework for Transport Development: A Review of National Transport Policy Initiatives in Nigeria	2013	Policy evaluation	Nigeria	Sumaila [70]
66	Passenger Inland Waterways a Sustainable Transport Mode	2011	Literature review, surveys and observations	Indonesia	Tuan [73]
67	Policy and promotion of sustainable inland waterway transport in Europe – Danube River	2011	Not clearly specified	Europe - Danube	Mihic et al. [46]
68	Specialized Planning Issues: A Policy Perspective on Sea-Rail and Sea-River Connections	2011	Not clearly specified	Europe	Schinas, Dionelis [64]
69	Inland Transport and Climate Change a Literature Review	2009	Literature review	General	Haurie et al. [22]
70	The impact of climate change and weather on transport: An overview of empirical findings	2009	Not clearly specified	United States	Koetse, Rietveld [29]
71	A study on inland water transport accidents in Bangladesh: Experience of a decade (1995-2005)	2007	Accident analysis	Bangladesh	Awal [2]
72	The role of inland waterway navigation in a sustainable transport system	2007	Not clearly specified	General	Rohács, Simongáti [61]
73	Recent training of the lower Rhine River to increase Inland Water Transport potentials: a mix of permanent and recurrent measures	2006	Not clearly specified	The Netherlands	Havinga et al. [24]
74	Evaluation of potentially successful barge innovations	2005	Not clearly specified	Europe	Wiegmans [77]
75	A model of navigation-induced currents in inland waterways and implications for juvenile fish displacement	2004	Model	Germany	Wolter et al. [83]
76	Future utilization and optimal investment strategy for inland waterways: New model from U.S. Army corps of engineers to assist policy makers	2004	Models	United States	Langdon et al. [35]
77	Strategies for management of dredged materials in the Netherlands	2002	Not clearly specified	The Netherlands	Hakstege, Laboyrie [20]
78	Transportation via Canals: Past, Present and Future	1995	Not clearly specified	Europe - USA - UK	Sidaway et al.)[65]
79	Short Sea Shipping and Inland Waterways as Part of a Sustainable Transportation System	1994	Not clearly specified	Europe	Blonk [6]

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Paper III

Barriers and solutions for sustainable development of IWT in Colombia: The Magdalena River case

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Abstract
In Colombia, inland waterway transport (IWT) has historically played a crucial role in technology adoption and development. However, due to the dominance of road transport, it has received insufficient attention, resulting in slow progress in policies, regulations, infrastructure, and human capital. This study, conducted through semi-structured interviews with 20 experts from various public and private institutions, aimed to identify key barriers and solutions for the sustainable development of IWT on the Magdalena River. Findings were categorized into five factors: governance and policies, management, operations, infrastructure and technology, and human resources. The research highlights the necessity of a clear vision on the sustainable development, prioritizing actions to comprehend and consider specific in the context of Magdalena River, such as understand river characteristics, enhance infrastructure and security, reduce informality, and uplift the quality of life for riverside communities. Future studies are encouraged to utilize these insights to prioritize solutions and assess their impact on the sustainable advancement of IWT.
Keywords: Inland waterway transport, sustainable development, barriers, solutions, Magdalena River, Colombia.

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1. Introduction

Inland waterway transport (IWT) is not only esteemed as one of the oldest modes of transport but also distinguished by its remarkable efficiency and relatively low levels of pollutant emissions compared to other transport modes (Barros et al., 2022; Kotowska et al., 2018; Rogerson et al., 2019). Globally, over 50 countries boast navigable waterways exceeding 1,000 km in length, with China (110,000 km), Russia (102,000 km), Brazil (50,000 km), and the USA (41,009 km) leading in terms of extensive waterway networks. Notable river basins such as the Rhine, Volga, Yangtze, Pearl, and Amazon stand out for their carrying capacity and socio-economic significance (Konings & Weigmans, 2016; Wang et al., 2020). However, despite the fact that Colombia ranks sixth in the world in terms of the longest navigable waterways (Konings & Weigmans, 2016), the development of navigable rivers in the country have been neglected, receiving minimal attention in existing literature regarding their promotion and enhancement.

The Magdalena River constitutes Colombia's primary fluvial system, encompassing 25% of the national territory and boasting impressive dimensions, including a length of 1,612 kilometres and a drainage area of 257,400 Km2, its basin includes 724 riverside municipalities, housing 65% of the Colombian population (Restrepo et al., 2005; Silva, 2009). Regrettably, it also holds one of the world's highest sediment transport rates, posing significant challenges for navigation along its course (Higgins et al., 2016), that problem has been exacerbated over time due to human interventions, particularly deforestation and ecosystem alterations (Márquez, 2016). Furthermore, the river sustains diverse ecosystem services critical to the nation's economy, primarily associated with agriculture, livestock, electricity generation, ecosystem regulation, and river transport, the primary focus of this study (Vilardy, 2015).

For centuries, Magdalena River served as the primary communication route linking the interior of the country with the mean seaports in the Caribbean, despite the challenging natural conditions including the formation of sandbanks, significant seasonal variability, and powerful torrents. The establishment of IWT on the Magdalena River dates back to 1824 with the arrival of the first steamboat named "Fidelidad" (Silva, 2009). By 1848, the transportation of exports and imports gained prominence in steam navigation, with key products including leather, tobacco, and coffee. However, in the early 20th century, issues such as low draft levels, inadequate river flow, lack of government concern, and the expansion of rail and roads led to a decline in inland navigation (Márquez, 2016). The introduction of diesel engines and the adoption of tugs and barges, coupled with new regulations, sparked a transformative shift in cargo transportation in the mid-20th century. Furthermore, the consolidation of the three major fluvial companies in the 1980s propelled them to the forefront of river trade, while smaller enterprises continued to operate alongside them, that fleet specialized in transporting liquid bulk, fertilizers, grains, and coal (Silva, 2009).

Throughout Colombian history, Magdalena River has symbolized development, growth, and progress, serving as a vital communication route between the country's interior and the Caribbean Sea (García, 2011; Márquez, 2016) The mouth of the river is located in Barranquilla; however, the river is connected to the Cartagena Bay by a navigational channel called "Canal del Dique", the canal was built in the seventeenth century, and its significance lies in facilitating the transportation of a large majority of oil products from the country's interior to the Caribbean Sea ports (Aguilera-Díaz, 2006). Currently, Cartagena stands as the nation's most crucial port and ranks as the fourth most significant port in Latin

America (CEPAL, 2018). Despite some efforts and investments made by the Colombian government to improve IWT, such as infrastructure projects and action plans, these have been insufficient to improve IWT and strengthen international trade (Zamudio et al., 2019). Consequently, the development of robust physical infrastructure is imperative to facilitate efficient goods transportation to and from the country, satisfying the multimodal trade requirements through the effective utilization of the Magdalena waterways (Otero, 2011).

Nowadays, IWT in the Magdalena River includes cargo, passengers, and a hybrid of both, carried out by two types of vessels according to national regulations. Firstly, there are larger vessels, with the capacity to transport more than 25 tons, and secondly, smaller vessels, with a capacity of less than 25 tons. It is considered important to make this distinction because river transport on the Magdalena River has two main focuses, first the movement of large convoys (larger vessels) propelled by a pusher, especially between the seaports of Barranquilla and Cartagena, and the river ports in Barrancabermeja, with liquid bulk (derived from petroleum) and solid bulk (grains, wood, among others) being the main cargoes transported. On the other hand, smaller vessels provide passenger and cargo transportation services over shorter distances, generally less than 150 km. This type of navigation is crucial in regions where IWT is the only means available, being vital for access to basic services such as education, health, and mobility. Unlike cargo transportation on larger vessels, these shorter routes present different challenges, mainly associated with informality and the lack of basic infrastructure for its development. In this context, the aim of this research, is to understand the main barriers and solutions for the sustainable development of IWT in the Magdalena River.

The article is structured in five sections: an introduction that establishes the context, followed by section 2, which describes the methodology used in the study. Section 3 presents the results obtained, classified into five factors: governance and policies, administration, operations, infrastructure and technology, and human resources. Finally, sections 4 and 5 contain the discussion and results, respectively, offering a detailed analysis of the findings and their relevance for the development of the IWT in the Magdalena River.

2. Methodology

The study employed a qualitative methodology, utilizing semi-structured interviews with a focus on open-ended questions to delve into perceptions related to barriers and potential solutions for the sustainable development of IWT in the

Magdalena River (Bryman, 2016; Patton, 2002). The interviews were conducted individually to uphold participant confidentiality, involving a sample of 20 experts representing various sectors including public institutions, the private sector, and academia. Adhering to Bryman's (2016) guidelines, the researchers meticulously organized and scrutinized the interview topics and question flow, ensuring alignment with the research objectives. Moreover, efforts were made to refine the language used in the questions to enhance participant comprehension and to provide pertinent contextual information (e.g., position within the organization, tenure, and job responsibilities) to facilitate a deeper understanding of the responses.

The data analysis was developed following the steps proposed by Creswel (2014). The process began with conducting and transcribing interviews with participants. Following this, an initial general reading of the transcriptions was undertaken to form an overall impression of the collected data. Subsequently, a thorough reading of all the data was conducted, after which the data was coded to identify patterns and themes. This research utilized content analysis to examine data from interviews, following Bryman´s (2016) approach. Content analysis is a widely used method for qualitative data analysis, notable for its deductive nature. It systematically and objectively identifies specific characteristics within the data, categorized into classes. To ensure an objective process, the researcher established selection criteria prior to analysis (Bryman, 2016; Gray, 2009). Two procedures suggested by Gray (2009) were employed to identify classes and categories. First, common classes were used to pinpoint data fragments related to barriers and solutions, which were then categorized into five pre-identified factors: governance and policy, management, operations, infrastructure and technology, and human resources. Second, special classes described barriers and solutions for each factor, facilitating the identification and categorization of key solutions to overcome barriers to the sustainable development of IWT. The interviews were coded using NVivo, which helped identifying the frequency of recurring criteria. This generated a ranking that could guide decision-makers and policymakers in Colombia. Finally, the interpretation phase in qualitative research was initiated, where deeper visions were drawn from the data analysis process.

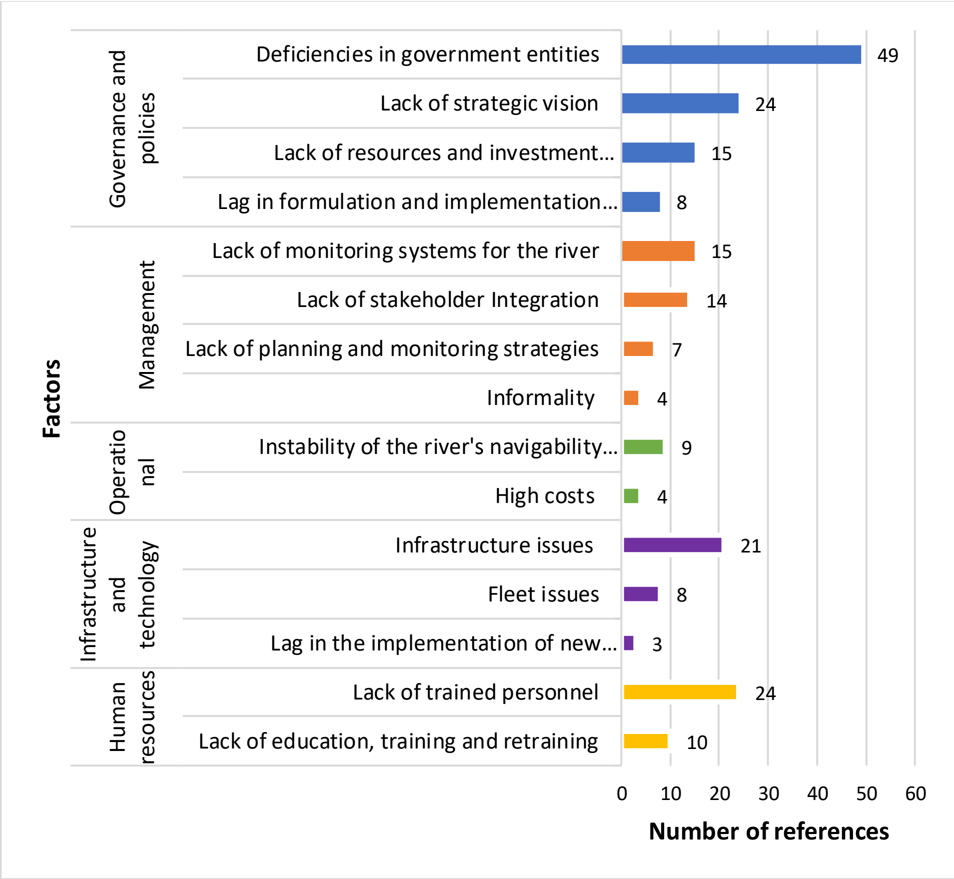
3. Results

3.1. Barriers

The analysis of the barriers exposed by the experts enabled their classification into five factors (governance and policies, management, operations, infrastructure and technology, and human resources) and subsequently a sub-categorization was conducted as shown in Figure 1.

Figure 1

Categorization of barriers for sustainable IWT



3.1.1. Governance and policies

Deficiencies in government entities

Throughout history, inland navigation has consistently lacked priority attention from public administrations, leading to challenges in governing its development. The main barrier mentioned by the experts (49 references) is associated with deficiencies in government entities mainly due to the lack of coordination between public them regarding the sustainable development of both rivers and IWT. In Colombia, there is no centralized entity in charge of managing and regulating activities related to river transportation, the responsibility for its development is distributed among different institutions. Although the effort and commitment of all government entities in their respective functions and in some aspects of the sustainable development of IWT is recognized, their actions are usually independent and lack coordination between them, that is, each ministry carries out its work with scarce collaborating with others. This situation is intensified by the lack of a clear definition of responsibilities and functions between these governmental bodies, which has led to poor governance that affects the exercise of authority in river matters, especially in remote areas where state presence is limited, scarce or non-existent. On the other hand, the lack of specialized technical knowledge public servants generates difficulties in the decision-making process, preventing technical dialogues for infrastructure planning that consider the complexity of river dynamics, such as sedimentation, erosion, and ecosystems protection. This raises concern due to the shortage of technical capacity to evaluate projects with a high degree of technical complexity. While the efforts undertaken by CORMAGDALENA are acknowledged, experts highlight the necessity for this institution to embrace a more holistic vision. This vision should extend beyond solely focusing on the navigability of the Magdalena River to encompass the development of comprehensive strategies addressing a spectrum of issues. These include erosion control, flood management, pollution mitigation, and considerations related to fishing, while also accounting for the cultural and socioeconomic characteristics unique to each region.

Lack of strategic vision and formulation and implementation of policies and regulation

The absence of governmental attention is reflected in the lack of well-defined policies, especially in decentralized institutions, where the deficiency of clear guidelines increases the complexity of the situation. Currently, initiatives to promote this mode of transportation are subject to political cycles, resulting in frequent changes in focus and priorities whenever there is a change of administration. Furthermore, the lack of long-term plans that comprehensively address the development of IWT, and that consider improving the connection between regions and the provision of basic services in remote areas, aggravates the situation. While some riverside communities contemplate the growth and modernization of long-distance freight transportation in long convoys, they do not experience significant improvements in their quality of life or in access to essential services such as potable water, health, and education. Another problematic aspect is the lack of consensus on the concept of sustainability and the absence of clear goals in this regard, which leads to the fragmentation of efforts between public and private entities. Moreover, the projects lack defined guidelines and, in many cases, the possible negative consequences of inadequate development of river are not considered. Furthermore, there are no environmental management plans for the Magdalena River, which should address the understanding of the hydrological characteristics of the basin.

On the other hand, the lag in the formulation of specific public policies for the development of river transport is evident, with the last CONPES dedicated specifically to this issue dating back to the 1990s. Although there are currently other policy documents that address it indirectly, it would be beneficial to have with clear guidelines to drive its development more effectively. Furthermore, the current river regulations are not concrete, are outdated and do not focus on sustainability aspects. The experts interviewed point out that these laws and regulations are often prepared in Bogotá without considering the specific conditions of each area, which makes their updating and effective application difficult. In addition to that, there is poor execution of existing policies and a lack of supervision by the responsible public entities, along with complexity in administrative procedures. These deficiencies contribute to the increase in problems related to illicit activities, such as illegal mining and deforestation, as well as the presence of groups outside the law and cases of corruption. Likewise, that problems promote informality in the provision of river transport services.

Lack of resources and investment strategies

The absence of a strategic vision for the development of the Magdalena River prevents the adequate allocation of financial and human resources. According to what was expressed by the interviewees, approximately 1.5% of the budget assigned to the transportation sector is allocated to river transportation, which directly impacts the execution and financing of projects. On the other hand, the sources of financing for river infrastructure are not clearly defined, and although policies related to the river exist, no specific measures have been taken to develop infrastructure projects. Moreover, respondents point out that this problem is aggravated due to the scarcity of the national budget and the bureaucracy inherent in the execution of works intended to guarantee the navigability of the river. This situation is exacerbated by administrative problems and the existence of monopolies in the contracting of services. Furthermore, the absence of plans or incentives aimed at strengthening the IWT, promote the modal shift or the improvement of port infrastructure and the fleet, adds significant difficulties. In addition, it is necessary to explore incentives that promote the use of river transportation, since the precarious infrastructure, costs and operational logistics represent significant obstacles to its development. On the other hand, when it comes to the transition to cleaner energy sources, communities in remote areas face significant limitations in accessing these technologies. Currently, highly polluting fuels continue to be used together with obsolete technologies, which has adverse repercussions on human health and the environment.

3.1.2. Management

Lack of monitoring systems for the river

The Magdalena River lacks an efficient and reliable monitoring system that allows understanding key variables such as hydro-morphology, water quality and its relationship with tributaries, among others. This lack makes it difficult to understand the general behaviour of the river and hinders the making of informed decisions based on accurate and real-time information. Although some measurements are made, accessing all the data presents significant difficulties. Each government institution carries out measurements in isolation according to its mandate, and inter-institutional collaboration in this regard is limited. Furthermore, the availability of complete information is scarce or difficult to access, and there is no adequate dissemination of existing viewers. This lack of data and information systems directly affects the lack of understanding of the dynamics of the river and, therefore, the development of adequate infrastructure that adapts to the characteristics of the basin. Currently, monitoring and data collection strategies on the river are limited, without addressing all environmental, geomorphological, hydraulic, and hydrological aspects. Which makes it difficult to understand the dynamics of the river, including variations in its alignment, sinuosity, channel formation and abandonment, sedimentation rates, as well as the characteristics of dredged sediments. Although the dredged volume is known, there is no information available on its texture, composition, or the presence of heavy metals, and in what proportion.

Lack of stakeholder Integration

In Colombia, there is a lack of fluid dialogue between private and public actors in the development of collaborative strategies to develop sustainable IWT. Moreover, it is essential to recognize and promote the identification of private sector initiatives through collaborations with universities, non-governmental organizations (NGOs) and the inclusion of the local population in various processes. Currently, a discrepancy between academia and the public sector is evident, which complicates effective coordination and actions aimed at promoting the development of IWT. This situation, together with the lack of intersectoral articulation and the limited participation of private entities, contributes to the complexity of this problem. Additionally, these shortcomings make it difficult to establish a close connection between citizens and bodies of water, transportation, the environment, science, culture, education, and national river interests. On the other hand, divergent interests are observed between the different stakeholders, especially those located in Barranquilla and Cartagena, which are more linked to maritime transport. These actors expect that most of the projects aimed at developing the river will focus on improving access conditions to ports. On the other hand, actors located in the interior of the country seek the development of infrastructure that facilitates the progress of IWT for cargo and passengers along the river.

Lack of planning and monitoring strategies and informality

Currently, public institutions, especially river inspections, face challenges due to the limited number of personnel available to carry out all activities related to the supervision, control, and management of administrative procedures. Furthermore, they lack the necessary resources to carry out effective control in the areas under their responsibility is evident in the public institutions. Some experts also point out the lack of knowledge on the government entities in charge of managing IWT. Consequently, non-compliance with regulations is observed in remote regions, raising safety concerns, particularly regarding the use of life jackets and other essential equipment. Furthermore, there is a high level of informality in the IWT in certain areas of the country, characterized by companies and vessels that offer transportation services without having the authorizations required by law, leads to reduced levels of security, especially in the transportation of passengers and cargo in smaller vessels. However, it is important to recognize that IWT operators face obstacles in obtaining operating licenses, navigation patents, company authorizations, among others, mainly due to staff shortages or lack of knowledge among regulatory entities.

3.1.3. Operations

Instability of the river's navigability conditions and High costs

Currently, cargo vessels that transit mostly between Barrancabermeja and the ports of Barranquilla and Cartagena face difficulties in operating at full capacity due to the reduced depths of the Magdalena River. Some experts argue that the fleet is oversized for depth capabilities of the river, however, they recognize the technical and operational complexities of the river itself, whose conditions are not uniform throughout the year. As a result, convoy splitting is required, and 24-hour navigation restrictions are imposed due to changing river conditions and lack of proper signage. As discussed above, this issue is compounded by the scarcity of data available to inform operational decisions, generating high cost for the users.

3.1.4. Infrastructure and technology

Infrastructure issues

It is essential to address the deficiencies that hinder strategic planning processes for inland navigation infrastructures. For example, the governmental institutions lack an exhaustive inventory of river infrastructure, especially non-concessioned docks, as well as general technical guidelines for their construction. Moreover, infrastructure planning should not be limited only to improvements at the mouth of the river but should also encompass other strategic points along the river. This planning must be innovative and consider the associated risks to support new initiatives, also considering the management of dredged materials and their environmental impacts. On the other hand, other infrastructure linked to IWT, for example the bridges, was not originally conceived for convoy navigation, generating the need to break up the convoy to facilitate its passage through these structures, requiring greater investment of time and resources. On the other hand, connectivity with other modes of transportation, such as road and rail, shows deficiencies, and transportation planning at the national level was not designed to promote the efficient interconnection of different modes of transportation. Furthermore, the transport infrastructure between major cities and production centres with ports, both sea and river, was specifically developed with a focus on road transport. Additionally, in the Magdalena River basin, the lack of signage, navigation aids and vessel traffic control, together with the scarcity or precariousness of port infrastructure in some regions, has led operators to use improvised methods to moor vessels, which represents a risk to the crew and users.

Fleet issues and new technologies

As far as the river fleet is concerned, vessels that carry out cargo transportation using convoys of barges and pushers are often considered oversized for the current conditions of the river, as they cannot operate in their full capacity due to the changing characteristics of the river, especially its variable depth and lack of adequate infrastructure, preventing safe navigation 24 hours a day. On the other hand, smaller vessels used to transport passengers and cargo over shorter distances (up to 150 km) are usually of artisanal and old construction, and lack modern technology, which affects their efficiency and safety. Moreover, it is imperative to develop a specific sector plan for the construction and modernization of vessels, given the technological obsolescence present in the country. These plans must contemplate the training of both the crews and the personnel in charge of technical assistance, thus guaranteeing the sustainability of the technologies over time. Likewise, it is necessary to address the difficulties related to the implementation of new technologies in remote regions.

3.1.5. Human resources

Lack of trained personnel

There is a lack of human resources in public institutions to promote the sustainable development of the IWT. These entities do not have sufficient personnel to apply and supervise current national regulations, which translates into deficiencies in safety and persistent informality, especially in the transport of cargo and passengers on smaller vessels in remote areas. Although some interviewees argue that the country has an adequate number of professionals in this field, both perspectives agree that the high rotation of personnel and the loss of specialized knowledge, particularly in public institutions, are, on certain occasions, due to the lack of transparency in selection processes, budgetary limitations in public entities and the nature of short-term contracts, which are renewed annually and lack benefits such as vacations and social benefits.

Lack of education, training, and retraining

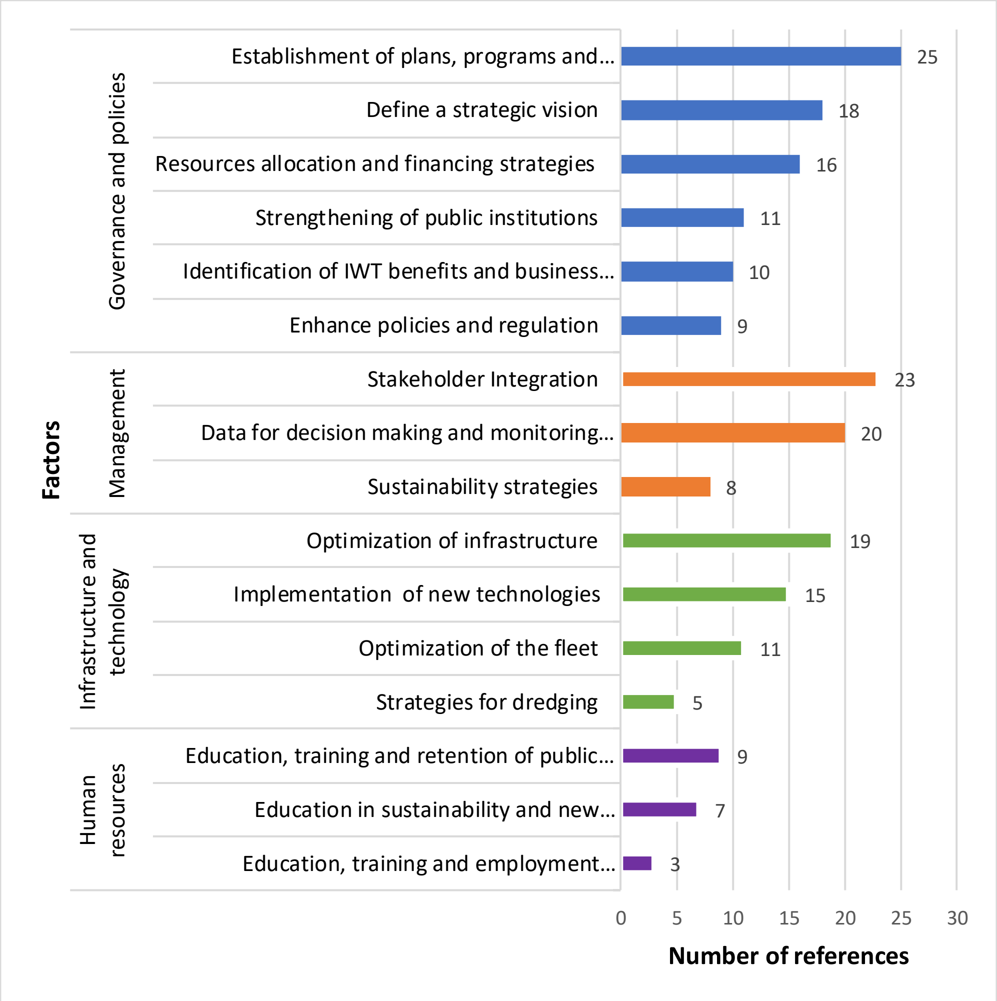
The fleet crews have empirical training, which has been attempted through professionalization courses mainly taught by SENA. However, there is a lack of basic academic training, which results in a lack of awareness and knowledge in crucial aspects such as the management and conservation of natural resources, the safety and regularity of transportation, operating costs, preventive maintenance, as well as the efficient use of equipment and its energy sources. Furthermore, it is noted that, in some remote communities, crew members lack navigation licenses issued by the competent authorities. On the other hand, the level of knowledge and training in new technologies is still incipient, and clear strategies have not yet been outlined to provide the training and updating necessary to address the transition towards the use of cleaner energies.

3.2. Solutions

Following the same structure as proposed for the barrier classification, Figure 2 shows the solutions towards the sustainable development of inland navigation on the Magdalena River. However, there were no responses associated with the operational factor itself, which may be associated with the need to improve other aspects that have a direct impact on operational issues.

Figure 2

Categorization of solutions for sustainable IWT



3.2.1. Governance and policies

Establishment of plans, programs and projects and defining a strategic vision

Interviewees suggest that the government should establish a clear vision for the sustainable development of IWT, including a comprehensive basin management strategy in which both public and private actors have a clear understanding of national goals. This vision must address both environmental concerns and the improvement of river conditions and navigation infrastructure, always considering the impact and interrelationship between society, the environment, and the economy. Furthermore, progressive plans are essential for the modernization and renovation of both the fleet and the supporting IWT infrastructure, with allocated budget to attain all proposed objectives and ensuring connectivity with other transportation modes. In accordance with the above, it is relevant to understand the advantages associated with the advancement of IWT for both passenger and cargo transportation within the country. Moreover, conducting studies to delineate suitable business models for short or long-distance navigation is essential. These studies should consider the infrastructure, personnel, and investments required to ensure the efficient operation of such models.

Resources allocation and financing strategies
The interviewees recommend securing resources to conduct studies that aid the public sector in policy development, offering technical and coordination support. Experts suggest various approaches, including crafting a progressive plan for fleet renewal, modernization, and technological advancement, alongside initiatives for constructing river terminals. Additionally, they emphasize the significance of technical cooperation and project financing to devise strategies for the sustainable development of the IWT. They also underscore the utilization of royalty funds and the necessity of proposing incentive plans to encourage the adoption of IWT.

Enhance policies and regulations
Various experts advocate the establishment of an intersectoral body to lead the IWT in the country, alongside a clear definition of government functions to enhance coordination and planning. They also propose reinforcing ministerial teams responsible for IWT matters and increasing institutional presence in remote river areas to bolster security and foster sustainable transportation practices. Moreover, they highlight the necessity of strengthening state presence, particularly in remote regions, to oversee and regulate river transportation, thereby enhancing security conditions and administrative efficiency. On the other hand, they stress the importance of enhancing administrative and transparency capacities to combat corruption and ensure the proper implementation and monitoring of regulations, acknowledging the need to streamline redundant procedures and processes. Finally, authorities are urged to collaborate, identify priorities, and work collectively to address key issues within the river basin.

Enhance policies and regulation
To promote the sustainable development of IWT, it is necessary to establish an updated regulatory framework and an institutional strengthening program. This implies the implementation of long-term public policies, as well as the constant

review and updating of existing regulations to guarantee their relevance to national needs. Additionally, it is essential to create a river legislation that considers the geographical, environmental, and cultural conditions of the basin. To achieve this, a firm political will is required to execute existing policies and implement concrete institutional actions, such as promoting the modernization of river infrastructure and the inclusion of the river component in planning instruments. Additionally, strategies must be developed to formalize river transportation companies and ensure their compliance with safety regulations. On the other hand, regulations must be included to address pollution and discharges into rivers.

3.2.2. Management

Stakeholder Integration

The relevance of greater integration between the different sectors involved in IWT is highlighted. Specifically, public entities are urged to develop institutional strengthening and technical training plans that contribute to the formalization of the transportation service. This could be achieved through campaigns that promote the authorization of companies and the registration of vessels, accompanied by advice on security issues and financial aspects. Furthermore, the participation of the private sector is suggested for the development of strategies, incentives and analysis of the industry and its production centres, with emphasis on the active participation of communities, entrepreneurs, and investors to move towards sustainable IWT. On the other hand, interviewees propose the implementation of strategies for understanding and application of the multimodally policy, as well as the infrastructure conditions and human talent necessary to reduce logistics costs and enhance the capacity of rivers. Highlighting the advantages of IWT is relevant not only in terms of cost reduction, but also in its positive impact on social aspects, such as improving the quality of life of populations, and in environmental aspects, such as reducing pollution. Moreover, regarding port terminals, the need for collaboration is emphasized to establish commercial strategies that promote the sustainable development of both ports and their interaction with the IWT. Moreover, it is essential to coordinate all sectors engaged in the sustainable development of the IWT to collectively tackle the challenges associated with river management, fostering collaboration among diverse authorities and stakeholders. This entails establishing and sustaining working groups to discuss and devise strategies for the IWT, engaging not only public entities but also all stakeholders. By working together and actively involving private enterprises, academia, NGOs, and local communities in the planning and implementation of river initiatives, a comprehensive and sustainable approach to river transport development and conservation can be ensured.

Data for decision making and monitoring systems

The establishment of continuous monitoring programs of the hydrological conditions of the river and its main tributaries and the implementation information systems can facilitate more effective planning and informed decision making. Although various tools such as viewers, forecasts, models, and databases are in use in different public and private entities, there is still a lack of a comprehensive system that integrates them and allows broader public access, along with strategies to guarantee the accessibility of data and promote the socialization of information. In that regard, the establishment of agreements between the public and private sectors and academia is suggested not only to improve data collection but also to take advantage of hydraulics laboratories in universities, which can strengthen knowledge management on river issues, and improve decision making processes. On the other hand, it is crucial to understand the impact of operations and the construction of new infrastructure both on the hydro-morphological conditions of the river and on the local communities that reside on its banks. Likewise, the implementation of a dredging monitoring system is proposed, since the dredged volume is currently quantified, but detailed information is not available on its textural characteristics, composition, or the presence of heavy metals, and in what proportion. Regarding water quality, a preventive approach to pollution is advocated instead of simply treating already contaminated water, collaborating closely with the companies responsible for discharges into the river and the river fleet.

Sustainability strategies

Some strategies associated with IWT sustainability were described by the experts as possible solutions for the Magdalena River, among them are policies of maintenance and efficient use of vessels, classification and certification as green ports, reuse and recycling and other strategies being implemented by the private sector that can be generalized and become best practices, especially for ports and the fleet.

3.2.3. Operations

The solutions proposed to address the operational challenges of the IWT in the Magdalena River focus mainly on the strategies outlined in the management (Section 3.2.2) and infrastructure and technology section (Section 3.2.4). These solutions focus on the establishment of river monitoring systems, the implementation of programs aimed at formalizing the IWT and the improvement of infrastructure both on in land and onboard vessels.

3.2.4. Infrastructure and technology

Optimization of infrastructure

Colombia, particularly along the Magdalena River, needs enhancing its port infrastructure to facilitate the loading and unloading of passengers and cargo. While it's acknowledged that the transportation of liquid and solid bulk in large convoys benefits from more advanced infrastructure, there's a necessity to bolster connectivity and access between ports and roadways to support river operations. In the realm of smaller vessel transportation, the construction of docks would play a pivotal role in formalizing IWT and enhancing safety conditions for users. Furthermore, there's a recommendation for a comprehensive plan aimed at technological modernization and updating, with long-term projections. This initiative could commence with the transition from two-stroke to four-stroke engines, recognized for their heightened efficiency and reduced environmental impact. Such a shift holds promise as an initial step toward curbing greenhouse gas emissions in the sector. For larger vessels, it is noted that some barges used for transporting hazardous materials lack double hulls, necessitating strategies for modernization and mitigation of pollution risks. Overall, emphasis is placed on the significance of equipment maintenance both on land and aboard vessels, alongside promoting the efficient utilization of fuel to enhance operational efficiency and mitigate the environmental footprint of IWT.

Implementation of new technologies and optimization of the fleet

One crucial aspect for the sustainable development of IWT is the digitalization of ports, vessels, and governmental bodies. Currently, there is a need to implement software to digitize information from port terminals, fleets, cargo, and data managed by state entities. This initiative would enhance operational efficiencies and foster smoother integration with the highway mode. Moreover, it would streamline the management of information essential for decision-making and the formulation of short, medium, and long-term plans by public institutions. However, it's worth noting that while traffic control and navigation aids are deemed vital projects for ensuring safety and oversight of IWT activities, their feasibility largely hinges on the development level of river transport itself. As per the interviewees, without clear guidelines and a vision for IWT in the country, it's unlikely that substantial investments in such initiatives will be justified.

Regarding the planning and implementation of new technologies, interviewees underscore the importance of adhering to high standards and methodologies in structuring river transportation projects. These projects should be based on rigorous technical and conceptual foundations, with established progressive goals and plans for modernizing both land facilities, such as ports and shipyards, and the fleet, encompassing all vessel categories (both larger and smaller vessels for cargo and passenger transport). A transition towards cleaner technologies like electricity or hydrogen is imperative, considering geographical conditions, energy availability, personnel training, and the economic and social benefits in the areas of implementation. In terms of ports and shipyards, proposed strategies include the utilization of cleaner and more efficient energies, such as solar power, leveraging the geographical location of the Magdalena River and the abundant availability of this resource in the region. Additionally, it's suggested to acquire technologies used in other countries to reduce CO_2 emissions, along with equipment to safeguard personnel health against harmful loads like coal and coke. Finally, there's a proposal to develop a strategy for constructing a dredge exclusively for servicing the Magdalena River, utilizing Colombian shipyards, considering the challenges in equipment procurement for dredging and its availability.

3.2.5. Human resources

Education, training, and retraining

In general terms, dissemination and training on best practices or sustainable practices for the development of IWT is considered essential at all levels of education and is recognized as a key strategy for water management. Likewise, the importance of promoting the social appropriation of the knowledge generated from research and results related to the river in all its dimensions is highlighted, especially regarding ports, navigation, and the fleet. In this context, the academy plays a crucial training role that must be complemented with the action of public institutions to raise awareness in society about the importance of sustainable development of the IWT and promote safe transportation, with properly trained crews aware of the positive impacts of environmental preservation and the reduction of pollutants.

Those interviewed suggest intensifying the training of human talent involved in river activities, both in public institutions and in the personnel who operate the fleet and in ports and shipyards. This training must adopt a sustainability approach that guarantees the provision of basic services for riverine communities, understands the environmental impact of activities, and establishes economically viable business models, but with comprehensive mitigation, recovery, and compensation plans for their repercussions on the environment and the society.

Specialized and trained professionals

Government entities must establish solid strategies for the retention of specialized personnel in the transportation sector, with special emphasis on the IWT. These selection processes must be carried out in a transparent manner, considering both the training and experience of the candidates, and avoiding any political influence in the appointment of positions. It is crucial to open vacancies for those experienced employees who are not currently on the payroll of public entities, but who provide services independently. In this way, it is guaranteed that the training and technological updating of these professionals are kept up to date, and that the strategies developed from their experience fully understand the needs and conditions of the IWT sector and are completely traceable over time. In this sense, it is essential to strengthen territorial entities where the state presence is limited and there are significant difficulties in the formalization of river transport services.

4. Discussion

4.1. Governance and policies

Colombia has a national development plan that undergoes review every four years to align with the approach of each successive government. From this plan, sectoral strategies are developed through CONPES (from Spanish: National Council of Economic and Social Policy) documents. However, the lack of prioritization of IWT in those policies has led to significant delays on its development compared to the road mode. While there are some policy documents aimed at strengthening the IWT, interviewees point to the lack of vision and poor execution of these policies as the main challenges. Additionally, given the high investments required for IWT to be competitive, as well as the absence of long-term policies and incentives for its development, Colombian rivers continue to face challenges related to insufficient investment and prioritization of the IWT. It is evident that, considering the challenging navigability conditions on the Magdalena River, the transportation of high-value goods would not attain the efficiency currently offered by road transport. Therefore, it is urgent to establish a clear state vision that guides the planning and investment of both public and private entities.

Although the particular conditions of each waterway are recognized, various countries in the European Union, China and Vietnam have recognized the importance of developing strategies to promote IWT, considering it a key factor for mitigating the externalities generated by the transportation sector (e.g., NAIADES II and NAIADES III, PLATINA “Room for the River” “Window of Opportunity”) (Bu & Nachtmann, 2021; Havinga et al., 2006; Mihic et al., 2011; Nguyen & Nguyen, 2020; Zoran Radmilović & Maraš, 2011). Although these plans do not fully adjust to the socioeconomic and geographic reality of the Magdalena River, understanding global strategies to optimize activities towards sustainable development of the IWT can influence the evaluation and implementation of new policies.

On the other hand, as in the case of Lithuania and India, the lack of political interest in the IWT directly affects the measures aimed at their IWT development (Malkus et al., 2020; Trivedi et al., 2021). Additionally, the data obtained confirm the assertions made by Jaimurzina and Wilmsmeier (2017) regarding weak regulatory frameworks in Latin America and the Caribbean hindering the strengthening of the IWT. Currently, Colombia moves around 3 million tons of cargo per year, which represents less than 2% of the total cargo transported in the country. However, despite its lower environmental and social impact compared to other means of transport, the lack of business models, incentive plans, and modal change policies, together with deficiencies in connectivity with the road mode, discourage private investors to allocate resources to an unstable market lacking clear state policies for its development. On the other hand, in many riverside towns, basic needs are not satisfied and there are various social problems, such as illegal mining, the presence of groups outside the law, dumping and deforestation, due to little or no state presence. Therefore, it is imperative to develop transportation sector strategies to improve the quality of life in these areas.

4.2. Management

Considering the diverse functions of rivers, including their role in providing drinking water and supporting industrial, agricultural, and tourism activities (Konings & Weigmans, 2016), the development of IWT should adhere to principles of comprehensive natural resource management. These principles should encompass inclusive spatial planning, as emphasized in the research by Maksin et al. (2017) for the Rhine-Danube corridor, which prioritizes understanding and mitigating irreversible environmental impacts and their societal consequences. Additionally, various authors have underscored the importance of integrating stakeholders with shared interests (Ilchenko et al., 2021; Roso et al., 2020). In Colombia, their involvement is crucial for harmonizing the vision and functions of the public sector and aligning the actions of the private sector. This fosters collaboration toward achieving more efficient and inclusive development in the realm of IWT. It is worth noting that, while some private entities express interest in pursuing IWT-related initiatives, the lack of guarantees to develop new business models often hinders their implementation.

4.3. Infrastructure and technology

Several authors emphasize the importance of having a robust infrastructure, which includes navigable canals with adequate depths, bridges, locks, among other elements, as well as comprehensive maintenance and adaptation plans to guarantee their effective connection with other modes of transport (Bu & Nachtmann, 2021; Havinga, 2020; Mihic et al., 2011; Nguyen & Nguyen, 2020;

Sommerauerová et al., 2018). For this case, experts recognize the infrastructure limitations faced by the Magdalena River, as well as the difficulties for its development, considering its dynamic nature and relatively little intervention compared to other large international waterways, such as those in Europe, China, and USA. This situation poses significant challenges for both the engineering and economic viability of investments. Furthermore, the lack of infrastructure for the interconnection of river transport with other modes of transport, together with the distance between the main cities and the river, contributes to hindering the efficiency of river transport in the region.
On the other hand, there is an urgent need to modernize the fleet and incorporate new technologies to enhance the efficiency of operations and minimize their environmental impact. This requirement has not only been highlighted by the experts consulted in the context of the Magdalena River but has also been observed in the fleet of European waterways, many of which are between 20 and 50 years old (Koralova, 2017; Maternová et al., 2022; Oulfarsi, 2016). Furthermore, the development and strengthening of information systems that support river transport is crucial, highlighting three fundamental aspects in this area: firstly, the need to understand the hydrodynamic and meteorological conditions of the river, as well as its possible variations, to facilitate operational planning and informed decision making; secondly, the importance of establishing fluid connections between terminal activities and vessel operations; and thirdly, improving safety for crews, passengers and cargo (Maternová et al., 2022; Niedzielski et al., 2021).

4.4. Human Resources

Some of the barriers associated with human talent, as outlined by experts, have been well-documented in the literature, particularly concerning the shortage of qualified personnel to operate vessels (Koralova, 2017; Vilarinho et al., 2019), and the lack of training facilities (Pfoser et al., 2018). In the Colombian context, it is essential not only to encourage the recruitment of professionals in fields related to inland water transportation (IWT) but also to prioritize the retraining of crew members and other workers to adapt to the evolving demands of the sector. These demands entail the modernization, renewal, and technological upgrading of both port infrastructure and vessels, with a notable emphasis on transitioning towards the use of more efficient and environmentally friendly fuels.

5. Conclusions

During the interviews, barriers were primarily associated with the absence of governance and policies guiding the development of IWT in Colombia overall, as well as specific strategies for the Magdalena River. Experts agree that overcoming these obstacles should commence with a clear vision from the State regarding the allocation of resources and efforts to foster sustainable IWT development. Furthermore, they underscore the significance of comprehending the roles and responsibilities of various public entities, along with the necessity for an entity to provide cross-cutting leadership, ensuring alignment of actions towards a shared objective rather than isolated and disjointed goals. It is imperative to enhance data collection and processing to gain a deeper understanding of river dynamics. The resultant information should be publicly accessible in real-time, facilitating decision-making processes in the formulation of public policies, infrastructure investments, and the planning of cargo and passenger transport operations. Furthermore, updating databases related to port infrastructure (docks) and fleet characterization is essential, as it will contribute positively to the formulation of modernization, renewal, and technological advancement plans for IWT infrastructure. The training and retraining of personnel are equally vital in state institutions responsible for formulating regulations, plans, and projects in the sector, as well as overseeing project approvals, licensing, and transportation activity supervision. This training is also crucial for personnel operating the fleet and engaged in activities within ports and shipyards, ensuring their adaptation to new technologies and more efficient processes to reduce emissions and optimize resources.

Although experts advocate for the sustainable development of IWT, they stress the necessity for this transport mode to be reinforced by clear business models that incorporate all stakeholders, including riverside communities, academia, and the private sector. Additionally, there is unanimous agreement among stakeholders regarding the importance of aligning this development with policies aimed at preserving the environment and natural resources in the area. Furthermore, there is a shortage of academic literature on IWT in Latin America, especially in Colombia. Future research could explore the prioritization of solutions proposed in this document and the role of stakeholders in their development.

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Paper IV

Analysing sustainable development of inland waterway transport in Colombia: The Magdalena River case

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Abstract

In Colombia, although road transport predominates as the primary mode of hinterland transportation, inland waterway transport (IWT) plays significant roles both in the movement of bulk cargo, mainly oil products, and in the transport of passengers, especially in regions where road infrastructure is limited and access to basic services depends exclusively on small boats that navigate the rivers. Despite the socioeconomic and environmental benefits associated with IWT, its development is closely linked to factors such as the availability of infrastructure and the policies or strategies that support it, which are in an incipient stage in Colombia. In this context, this research, through a mixed methods approach that includes interviews and questionnaires directed to experts from the public, private and academic sectors, analyses the data and defines the concept of sustainable development of IWT and its main elements (fleet, waterway, and inland river ports). Furthermore, the analysis of the opinions of respondents revealed the current state of Magdalena River in relation to characteristics of sustainable IWT system, the country's primary navigable waterway that facilitates the transport of over 50% of the total cargo via water routes, while also facilitating the movement of a significant number of passengers.

Key words: Inland waterway transport, sustainable development, Magdalena River.

1. Introduction

River transportation is recognized for its various environmental benefits associated with the reduction of polluting gases, its low noise levels and high economic efficiencies, especially for the transportation of bulk goods (Barros et al., 2022; Kotowska et al., 2018; Mihic et al., 2011). Likewise, its use is considered as a strategy to reduce externalities generated by road transport.

Among the countries with the longest length of navigable waterways, Colombia, with 18,000 km, ranks sixth worldwide and second in Latin America (Konings & Weigmans, 2016). However, despite its extensive water resources, the development of river transport has been framed by a lack of concrete actions or a strategic vision that encourages modal change, added to the deficient or non-existent infrastructure that supports the cargo transport service. and passengers. Additionally, Colombian navigable rivers lack classification, posing challenges in understanding their characteristics and making challenging the formulation of goals and plans aligned with their development (Jaimurzina et al., 2016).

There is also no validated and operational definition of sustainable development of IWT in the country and although some plans and projects are currently being developed, they are inconsistent in their implementation, without a short, medium, and long-term vision. For example, the last river master plan published in 2022 shows little progress in the execution of projects proposed in the 2015 plan for strengthening infrastructure and lacks a concrete evaluation of the activities proposed there (Ministerio de Transporte, 2015, 2022), which does not allow the understanding of the reality of compliance with said documents, generating a repetition of the actions proposed for each period, without having clear goals and concrete actions to advance towards the sustainable development of IWT in the country.

On the other hand, most of the academic literature is oriented to IWT located in Europe, China and the United States, with very little research carried out in developing countries especially in South America (Hunt et al., 2022). Additionally, recent academics does not propose definitions of the sustainable IWT service, nor does it define the elements that compose it (fleet, waterway, and inland river ports).

In that regard, this study aims to define, from the point of view of sustainability, the river transport service, and its elements. Moreover, by delineating the characteristics of a sustainable or desired state and contrasting them with the present realities of IWT on the Magdalena River, this research seeks to answer the following question: What are the distances in characteristics to transition an inland waterway system from its current state towards a sustainable one? Through this enquiry, the study seeks to present recommendations aimed at guiding policy makers and other stakeholders towards more sustainable practices, thus adding to the wider discussion on sustainable development of IWT within developing countries.

1.1. IWT in the Madalena River

Madalena as a Navigable River

The Magdalena River, extends over 1612 km in length and stands as Colombia's largest river system (Higgins et al., 2016). Originally flowing naturally into Barranquilla, however, since the 1920s, a 114 km canal was constructed under the auspices of the national government, linking the river from Calamar to the bay of Cartagena (Juan D. Restrepo et al., 2018). Covering 24% of the national territory, the Magdalena River and its primary tributary, the Cauca River, play an integral role in the socio-economic activities of 11 departments, where over 79% of the country's population resides (Cabarcas & Peñaranda, 2023). However, the Magdalena River, as well as other rivers in South America, have strong seasonal variations associated with the El Niño Southern Oscillation-ENSO or El Niño-LaNiña cycle generating variations in sediment discharges (Juan D. Restrepo et al., 2018).Moreover, the river has one of the highest sediment rates in the world (Higgins et al., 2016), which has increased during the last two decades in which the Magdalena basin has suffered various changes associated with the reduction of forests, expansion of areas for agriculture and increase in mining exploitation (Higgins et al., 2016; Restrepo et al., 2015), the most representative examples being anthropogenic activities such as deforestation, water contamination by extraction of hydrocarbons and other materials, extensive crops for the generation of palm oil and the construction of dams for the generation of hydroelectric energy since the Magdalena River supplies 50% of the electric energy demand in the country (Salgado et al., 2022).

In this context, some authors argue that inadequate environmental planning in the infrastructure projects along the Magdalena River exacerbates sediment production which triggers serious effects not only for the IWT but also for the coastal-marine ecosystems. Thus, it is imperative to develop to mitigate the stressors both to minimize the impacts on the mouth areas and adjacent marine areas (Restrepo et al., 2018). Moreover, a comprehensive understanding of the different variables of river sediment loads and their influence on the management of areas prone to sedimentation is essential (Restrepo et al., 2006). These fluctuations in sedimentation rates directly impact activities associated with IWT, as variations in channel depths affect vessel navigation possibilities, leading to increased transportation costs (Fernández et al., 2010). Additionally, Torres-Marchena et al. (2023) maintain that the river's navigability is susceptible to seasonal changes, requiring ongoing dredging efforts to maintain optimal conditions for vessel berthing and departure. Furthermore, the authors argue that the rigid infrastructure projects implemented at the river mouth have inadequately addressed the sedimentation issue and advocate for the adoption of soft, nature-based strategies, along with the implementation of optimal dredging techniques. Moreover, various authors advocate for the necessity of quantifying and monitoring the hydro-morphological, environmental, and socio-economic conditions of the river to ensure navigability and facilitate informed decision-making processes (Avila et al., 2019). Furthermore, Fernández et al. (2010) emphasize the critical need for data and forecasts to inform decision-making across three key aspects: water usage planning for hydroelectric plants, navigation, and agricultural water use; disaster prevention from high or low water flows; and pollution prevention. Likewise, the importance of cooperation between academia and public and private actors is highlighted for the development of the IWT in the Magdalena River (Avila et al., 2019).

In addition, harmonizing the classification of waterways or navigable rivers offers several benefits. Firstly, it enhances control over river infrastructure to better meet the needs of navigation, thereby improving the quality of navigation experiences. This harmonization also facilitates more effective planning, monitoring, identification of missing links, and prioritization of necessary improvements. Additionally, it leads to improvements in available information and transparency, which not only benefits the construction of river infrastructure but also enhances the operations of the fleet providing navigation services (Jaimurzina & Wilmsmeier, 2017; PIANC, 2020). However, the classification of waterways or navigable rivers in Latin America, unlike Europe, there is not a consistent organization and there exists a variety of classification systems with different names and standards in each country.
In Colombia, for instance, there is a classification system that designates routes for major and minor navigation. Major navigation routes are those suitable for vessels exceeding 25 tons or those transporting over 50,000 tons annually, such as the Magdalena River. Furthermore, a distinction is made between "long-distance cargo transportation," which primarily serves export-import activities or commercial exchanges between regions, and "goods and passenger transportation," which focuses on connecting isolated regions, fulfilling essential service needs that cannot typically be met by other modes of transportation (Jaimurzina & Wilmsmeier, 2017). Although this classification has been used within regulations and policy documents, it does not provide sufficient information for the decision-making process at all levels, making a better classification necessary for Colombian rivers, especially the Magdalena River.

Magdalena River Fleet

In Colombian law, river fleet is broadly classified into two categories based on the presence or absence of a propulsion system. River vessels are defined as "main or independent constructions capable of navigating regardless of their propulsion system, intended for travel on the nation's waterways" (Congreso de Colombia, 2008, art. 4). In contrast, river artifacts are described as "floating structures lacking their own propulsion, operating in river environments as navigation auxiliaries but not intended for navigation, and not included in the definition of river vessels" (Congreso de Colombia, 2008, art. 4). Furthermore, river vessels can be classified into two primary groups: larger vessels, which have a transport capacity exceeding 25 tons, and smaller vessels, with a transport capacity of less than 25 tons. In addition to that, all vessels registered as tugboats are considered larger vessels under the law. Larger vessels typically adhere to long-range navigation routes, commonly traversing between the river port of Barrancabermeja and the seaports in Barranquilla and Cartagena. The primary cargo consists of hydrocarbons (91%) along with some solid bulk (Kafarov et al., 2017), utilizing a fleet of six barges propelled by a pusher (TB+2B+2B+2B), with each barge boasting a capacity of 1200 tons (Avila et al., 2019).

On the other hand, smaller vessels engage in passenger or mixed transportation over shorter distances. This type of transportation is sometimes informal and is characterized by poor maintenance of both the vessels and the docks (Atencio-Molinares et al., 2023). Similarly, companies providing inter-municipal transportation services lack basic knowledge about business models, unaware of breakeven points and the minimum number of passengers required to operate the service (Atencio-Molinares et al., 2023). Additionally, service frequency in some regions varies, emphasizing the importance of having accessible schedules and visualization means for users to reduce uncertainty levels and enhance service quality. Moreover, there is a shortage of studies focused on understanding passenger transportation in Colombia, along with a lack of data for policy-making and decision-making purposes (Berrio et al., 2019). Finally, another major weakness of IWT in Colombia, applicable to both larger and smaller vessels, is technological obsolescence and the lack of modernization or fleet renewal to support IWT (Atencio-Molinares et al., 2023; Melgarejo, 2014).

Inland river ports in the Magdalena River

River transport along the Magdalena River is linked with maritime transport, facilitated by ports within the initial 38 km stretch of the river and those situated in the Bay of Cartagena. These ports predominantly handle hydrocarbons, bulk cargo, and containers (Ramirez et al., 2019). As shown in Figure 1, port facilities located in the maritime area have more formal structures and concessions granted by the competent authorities. On the other hand, inland river ports in Colombia are underdeveloped, lacking proper docks, storage yards, warehouses, and essential complementary services. Moreover, the equipment used in these ports often lacks advanced technologies for cargo handling and, in some instances, fails to meet industrial safety standards (Zamudio et al., 2019). Specifically, along the Magdalena River, the concessioned infrastructure is situated in Magangue, Puerto Salgar, and Barrancabermeja, with the latter serving as a focal point for significant cargo movements, particularly in liquid bulk derived from hydrocarbons. However, as illustrated in the Figure 1, most of the infrastructure remains outside the formal concession system, directly impeding the advancement of IWT sector. However, addressing this challenge requires government intervention and capital investment from both public and private sectors.

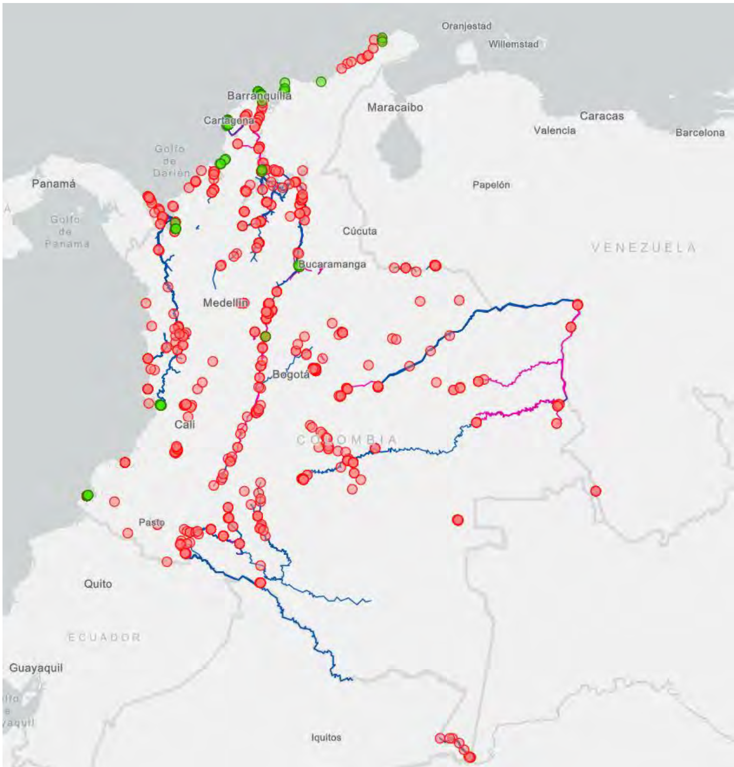


Figure 1. Concessioned and Non-Concessioned Maritime and River Infrastructure
Source: Superintendence of ports and transportation viewer

In the case of passenger transportation along the Magdalena River, approximately 90% of all river journeys originate from or terminate at seven primary ports situated along, such as Calamar, Magangué, El Banco, Gamarra, Barrancabermeja, Puerto Berrío, and Puerto Boyacá/Puerto Salgar. Ports with the presence of authorities, such as river inspections, experience higher demand due to the association with more organized companies offering superior customer service and better infrastructure for service provision (Berrio et al., 2019). Atencio-Molinares et al. (2023) highlight that the main shortcomings for passenger transportation are the delays in dispatch time, the precarious infrastructure of the piers and vessels, coupled with the lack of safety standards and the costs of the service.

2. Methodology

This research contemplates a mixed methods approach that seeks to define the elements of a sustainable IWT system, as well as the characteristics that differentiate the sustainable ones. Drawing upon the case of the Magdalena River, this study will identify the distances between the current state of IWT and the desired state of sustainability. For this purpose, the methodology was divided into two phases, beginning with semi-structured interviews carried out with experts in public, private and academic entities. The collected data together with a literature review, allowed the development of the definitions and initial characteristics of a sustainable IWT, as well as the understanding of the particularities and challenges of IWT in developing countries such as Colombia, which are underrepresented in academic literature. The interviews were conducted and the data analysis performed in accordance with the guidelines proposed by Creswel (2014), starting with conducting and transcribing participant interviews, followed by an initial broad review of the transcriptions to understand the general ideas and broad themes. Next, a complete examination of all data was developed, employing coding techniques within NVivo to identify recurring patterns and themes, followed by a discussion of the identified themes and their relationships. Finally, the interpretation phase inherent in qualitative research was conducted. The second phase contemplates a quantitative approach through the application of a survey to experts in different waterways or navigable rivers in the world. This stage allowed validation of the definitions obtained in the first phase and understanding the distances between the desired or sustainable state of IWT and the current state of the Magdalena River. The development of the survey followed the framework proposed by Grønmo (2020) adapted for the context of the research. The questionnaire utilized a variety of question types to gather comprehensive data. Filter or contingency questions with binary responses

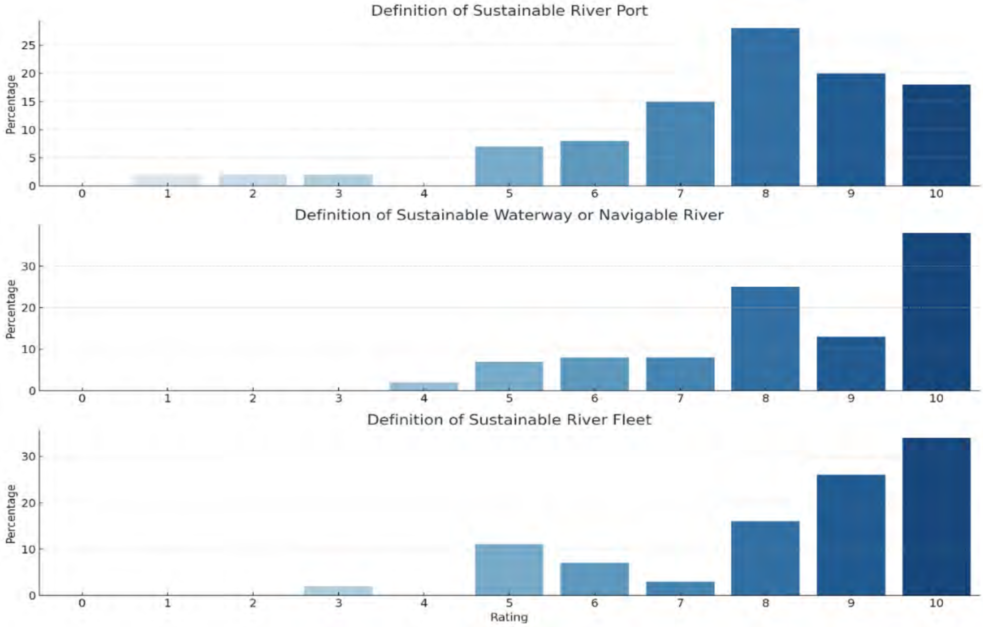
(Yes or No) directed respondents to follow-up questions based on their initial answers. Participants ranked the significance of information related to IWT services using ordinal responses, and interval level response formats were used to assess perceived distances between current and desired states. Questions were carefully worded to minimize misunderstandings and researcher bias, with revisions for clarity, neutrality, and avoidance of ambiguity (Trochim et al., 2016). The questionnaire was divided into five sections, starting with the validation of definitions and ranking of characteristics, followed by segments on transversal, environmental, social, and economic aspects of sustainable ITW development. The questionnaire was validated by two academics with expertise in IWT on waterways and navigable rivers in Latin America and Europe by pilot testing and providing feedback for improvement. Survey results were analysed and presented using descriptive statistics. Nominal data were collected to understand geographic location, participant experience, and opinions or knowledge on specific topics, such as new technologies. Ordinal data were collected to rank items related to sustainable IWT characteristics. The survey aimed to understand the implementation degree of sustainable development characteristics in the Magdalena River and to validate these definitions in other waterways or navigable rivers globally.

3. Results

3.1. Defining sustainable IWT

Based on the data gathered from interviews and literature sources, the authors proposed some characteristics of IWT service, as well as the definitions of the three elements of an IWT system. Those definitions were validated by 63 experts in IWT with experience in rivers such as the Amazon, Danube, Magdalena, Mississippi, Paraguay-Paraná-De la Plata, Rhine, among others.

As per the definition, first, a *sustainable river port* is defined as an "infrastructure on the edge of a body of water that facilitates the safe transfer of passengers or cargo, on which zero or low emissions technologies operate and possess social responsibility and environmental protection standards". Second, a *sustainable waterway* is a "body of water that is naturally navigable or intervened, that possesses a navigation classification system (PIANC, 2020) and environmental and social regulatory frameworks implemented. Third, a *sustainable river fleet* is "a set of vessels that comply with national or international safety and social protection regulations and standards, generate zero or low emissions, and the stakeholders jointly seek the optimization and resilience of the services".



	River port	*Waterway*	*Fleet*
Mean	8,77	9,38	9,35
Standard Dev	1,93	1,66	1,80

Figure 2. Level of agreement of the proposed definitions

On the other hand, the characteristics of IWT service from a sustainable perspective were identified and the ranking was obtained by the calculation of the total frequency sum and weighted average, for both cases the result provided the same order as shown in Figure 3.

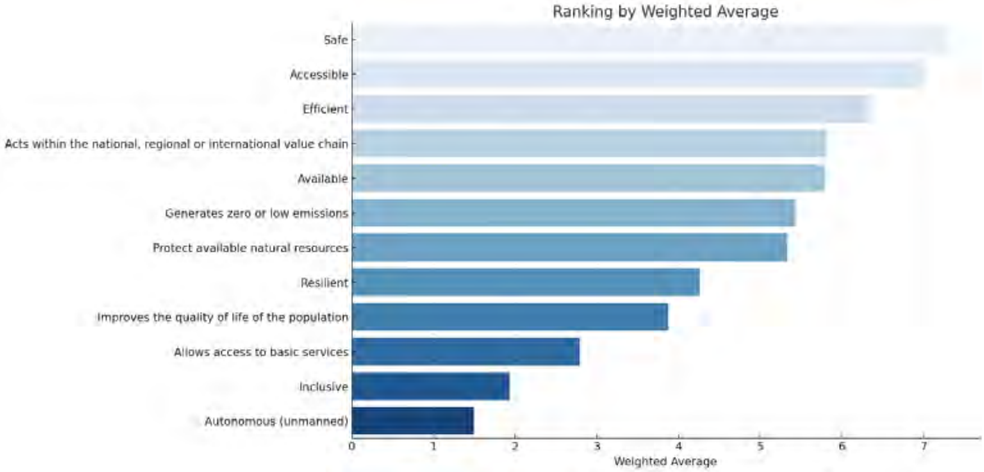


Figure 3. Ranking of sustainable IWT characteristics

3.2. Sustainable development of IWT in the Magdalena River context

To assess the desired and current state of IWT, the characteristics were divided into four aspects: transversal, social, environmental, and economic. The transversal issues must be led by the public administration and encompass strategic aspects, plans, and regulations, among others, considering the three pillars of sustainability. On the other hand, some social, environmental, and economic issues that usually go beyond those matters were included in que questionnaire to understand the fulfilment of those characteristics. This part of the research used responses IWT experts in Colombia only, in order to provide the sustainable development perspective of the Magdalena River case. The results were obtained through the opinions of 18 people, who belong to the public and private entities and academia.

Transversal aspects

Some transversal aspects were assessed, considering that the public administration of the country must address those general aspects to support the sustainable development of IWT, the answers reflect the opinion about the presence or absence of four main instruments: vision, strategy, sustainability report, and RIS (Figure 4).

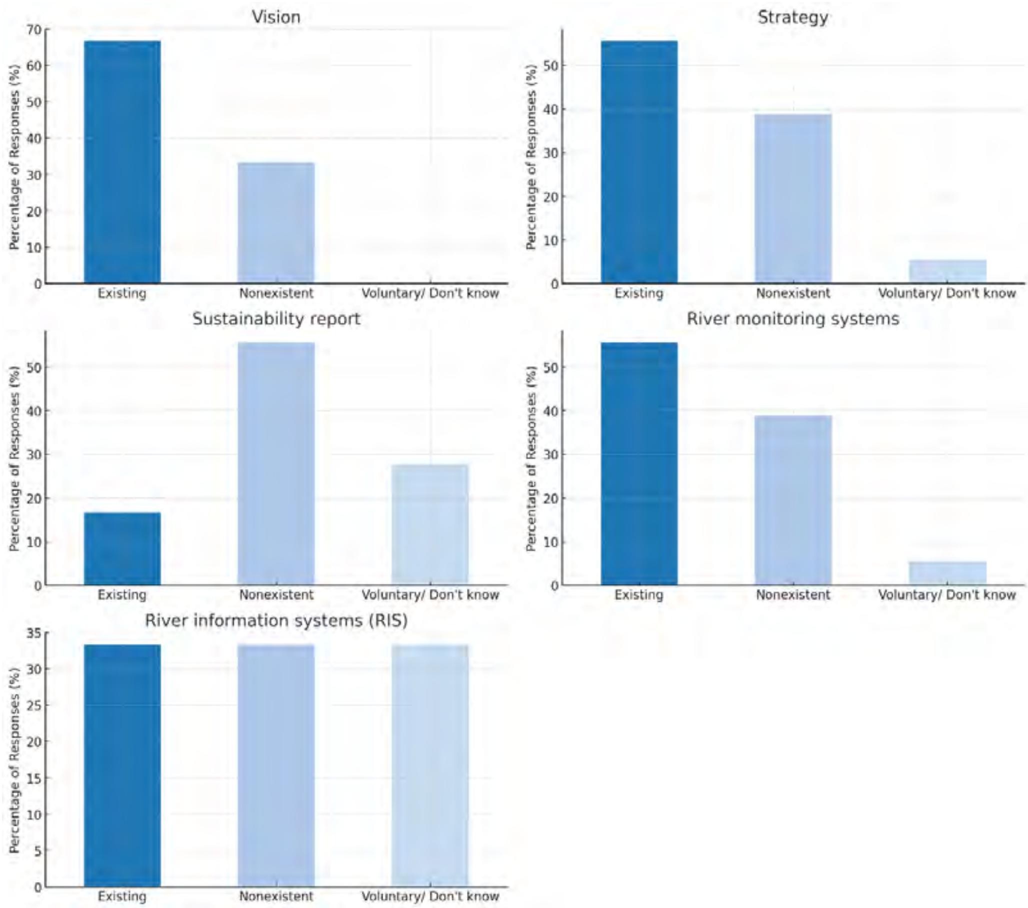


Figure 4. Percentage of implementation of instruments for sustainable development of the IWT}

The data shows that most respondents consider that there is a vision (67%), strategy (56%) and river monitoring systems (56%) for the development of the IWT. However, 65% of respondents argue that there is currently no sustainability reporting, while the river information systems present more variable data suggesting uncertainty or diversity of opinion in their implementation. Considering that the interview results revealed that one of the barriers to the sustainable development of IWT is associated with illicit activities and in some cases corruption, the survey showed that 50% of the experts consider that there are no anti-corruption policies in place although the same number argue that there are mechanisms for reporting irregularities, as for data protection laws the opinions are fragmented showing a lack of awareness and indecision in the implementation of data protection mechanisms. (Figure 23).

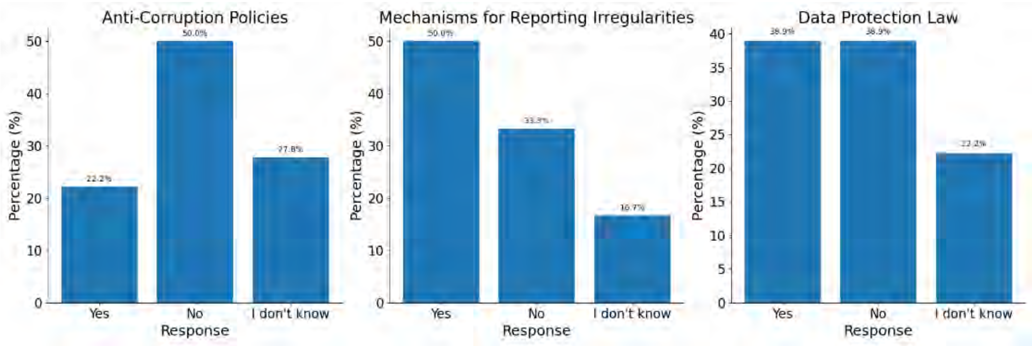
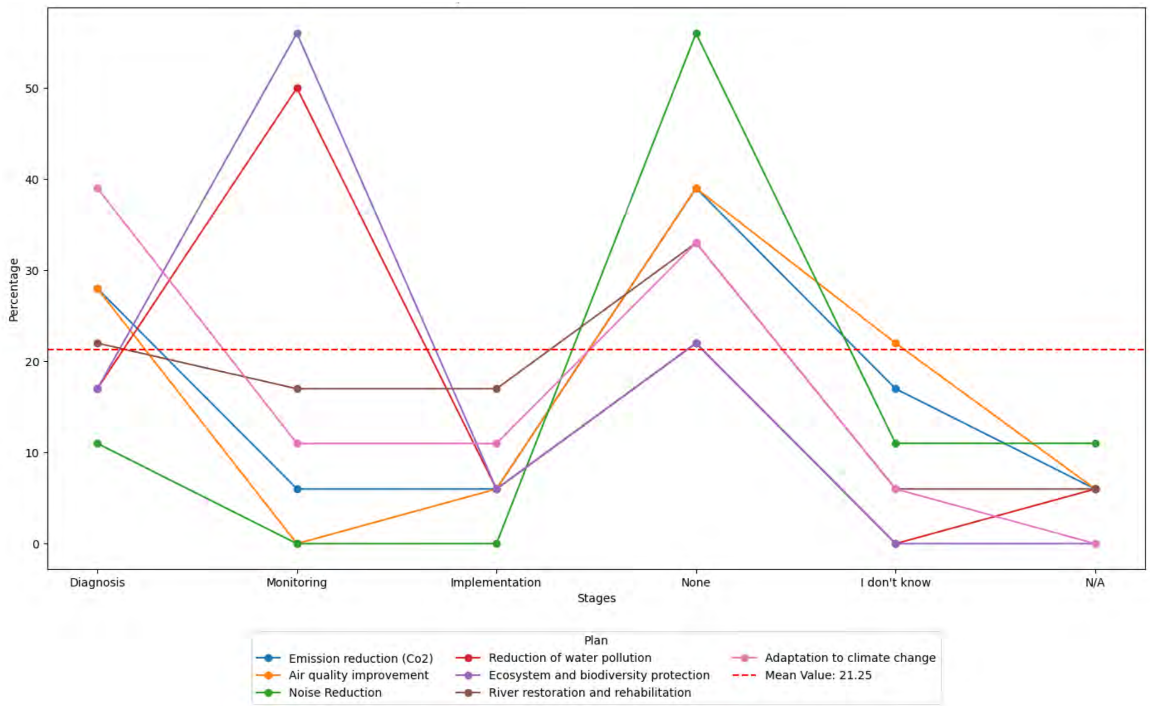


Figure 5. Percentage of implementation of other transversal mechanisms

Environmental aspects

Figure 6 shows that most of the environmental plans have a high percentage in the "None" category with only two exceptions (Reduction of water pollution and Ecosystem and biodiversity protection), indicating little progress in the implementation of these plans associated with the IWT. However, some experts state that many plans are in the “Diagnosis” phase, especially the “Adaptation to climate change” plan with 39%. On the other hand, high values in the "Monitoring" phase stand out for the “Reduction of water pollution” and “Ecosystem and biodiversity protection” plans (50% and 56%, respectively). However, the categories "I don't know" and "N/A" have significant percentages in several plans, indicating a lack of knowledge or relevance of certain plans from some respondent’s perspectives. The average line (21.25) obtained from the average between the diagnosis, monitoring and implementation phases added to the graph indicates an average reference value to compare the different levels of progress of the plans. Most of the implementation levels are below this average, which is evidence of a general trend of low implementation of such plans in the IWT sector. Moreover, only 39% of the respondents argue that IWT uses or facilitates the implementation of new technologies, and listed items such as Satellite Navigation Systems, Cartographic digitization, GPS, some pilot schemes for the use of cleaner fuels, autonomous barge operation, and artificial intelligence in barge loading and unloading operations. Although a majority of respondents (61%) report the absence of such technologies. On the other hand, the level of implementation of those technologies associated with low or zero emissions is low in general as most of the responses (79%) are below five on the scale proposed in Figure 7, in addition the experts only mentioned the realization of consultancy works for the implementation of new technologies and some pilot projects, demonstrating that few actions have been carried out in this area.



Environmental policies	*Mean*	*Mode*	*Standard Deviation*
Diagnosis	23	17	9
Monitoring	20	0	23
Implementation	7	6	5
None	35	22	12
I don't know	9	0	8
N/A	5	6	4

Figure 6. Presence and the level of progress of environmental plans

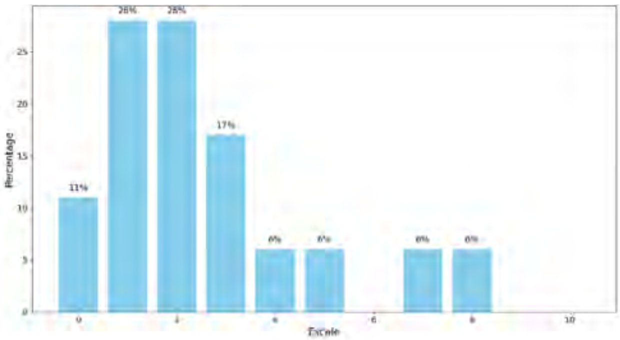
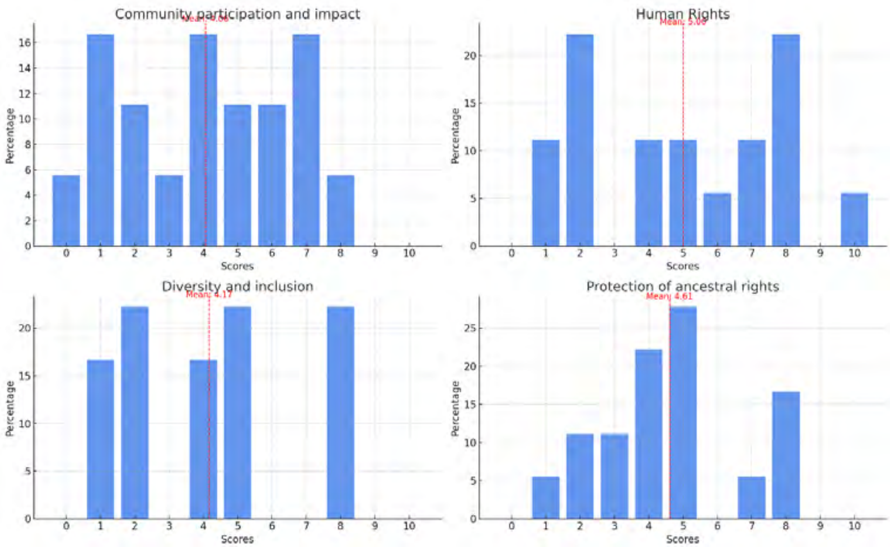


Figure 7. Level of implementation of low or zero emissions technologies

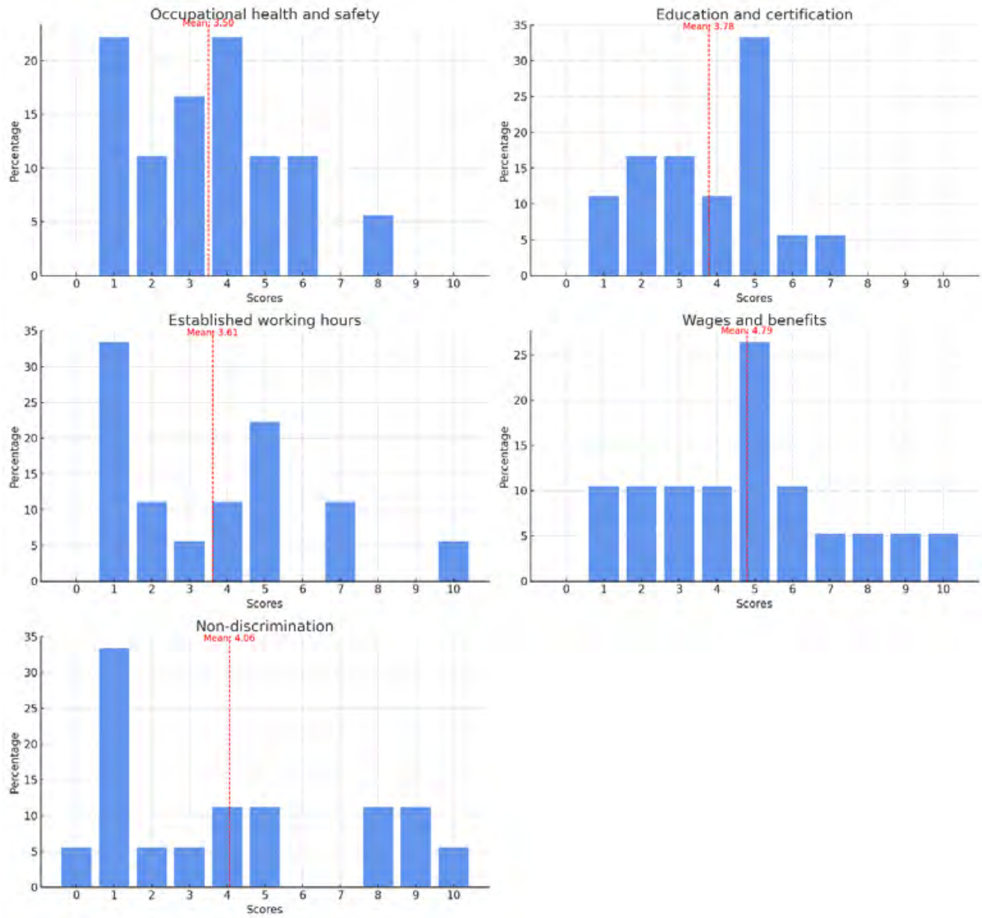
Social Aspects

The third section of the survey covers the social aspects that surround the IWT. The first question sought to understand whether there are stretches of the river where the only form of access to basic services such as mobility, health, or education, among others, is the use of IWT, for which 100% of respondents answered "yes" demonstrating the significance of the sustainable development of the IWT in the country. In addition, four aspects of social responsibility programmes and five labour standards were assessed, revealing low and medium compliance averages for both aspects as shown in Figures 8 and 9.



	Mean	Mode	Standard Deviation
Community participation and impact	4,56	1	2,54
Human Rights	5,06	2	2,83
Diversity and inclusion	4,17	2	2,22
Protection of ancestral rights	4,61	5	2,44

Figure 8. Level of implementation of social responsibility programmes

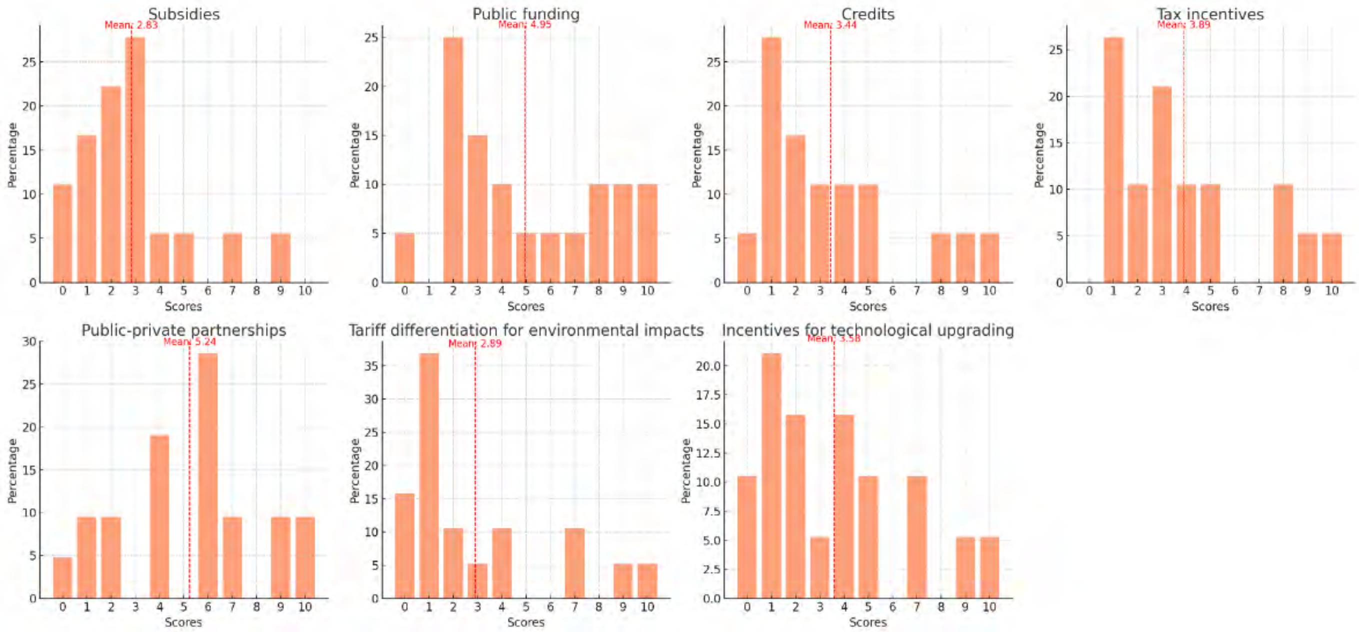


	Mean	Mode	Standard Deviation
Occupational health and safety	3,5	0	1,6
Education and certification	3,8	0	1,9
Established working hours	3,6	0	1,9
Wages and benefits	4,8	2	1,3
Non-discrimination	4,1	1	1,6

Figure 9. Level of implementation of labour standards

Economic Aspects

Finally, from an economic perspective, it was examined whether there is a higher cost-benefit of using inland waterway transport compared to other transport modes for both freight and passenger movement. Although most opinions (61% for freight and 56% for passengers) affirm that there is such a benefit, further research is required considering the high variability among the answers corresponding to "No", "Not calculated" or "I don't know". On the other hand, Figure 10 illustrates the accessibility of various financing strategies for IWT, revealing significant variability in the implementation levels of different economic approaches. However, most of the averages range between 2.83 and 5.24 with a maximum standard deviation of 2, demonstrating low levels of implementation of such strategies for the IWT in Colombia. Public-private partnerships show the highest mean score (5.24), indicating the strongest implementation of all. In contrast, tariff differentiation for environmental impacts has the lowest mode and significant variability, suggesting lower levels of implementation. Although this kind of economic incentives have been described in the literature as possible solutions for the sustainable development of the IWT, the Magdalena River and in general the rivers of Colombia show little effort to incentivize its development and implement new technologies to support it.



	Mean	*Mode*	*Standard Deviation*
Subsidies	2,83	1	1,69
Public funding	4,95	1	1,33
Credits	3,44	1	1,43
Tax incentives	3,89	2	1,62
Public-private partnerships	5,24	2	1,81
Tariff differentiation for environmental impacts	2,89	0	2
Incentives for technological upgrading	3,58	1	1,27

Figure 10. Accessibility to financing strategies

4. Discussion

The Magdalena River played an important role in the development of passenger and freight transport because it connected production centres located in the interior of the country with the main ports in the Caribbean. However, since the development of road transport and the poor prioritization of the river mode during the 20th century, the IWT of both freight and passengers decreased substantially. (Berrio et al., 2019; Zambrano, 2019). In the evaluation of the current situation, the results show that although a high percentage of respondents consider that in Colombia the IWT possess a vision and strategy for its sustainable development, the data reveal that the environmental plans are implemented in 21.25%, social plans 42% percent and economic plans in 38%. Demonstrating a high necessity to re-evaluate the actions that are being carried out both in the establishment of public policies and in their implementation. Likewise, despite several attempts to establish plans to incentivize or develop the IWT in Colombia, including two fluvial master plans and two unsuccessful attempts at public-private partnerships, it is evident that these strategies have not been sufficient to propose clear goals and define the functions that each public entity should carry out to guarantee a sustainable IWT.

From an environmental perspective, some of the solutions proposed by Salgado et al. (2022) coincide with the understanding of mitigation measures such as reforestation, the development of modelling tools and the understanding of the consequences of extreme events and their interaction with other anthropogenic stressors for both the social and ecological integrity of the areas under their influence. However, although the *Reduction of Water Pollution* and *Ecosystem and Biodiversity Protection* were the environmental plans that received the highest values in the Monitoring item, nevertheless, most of the environmental plans proposed in the survey are either not implemented or are in the diagnostic phase, with *Emission Reduction*, *Air Quality Improvement* and *Noise Reduction* plans standing out as those with the lowest levels of implementation. This in turn is associated with the scarcity of implementation or facilitation of new technologies for the IWT in general as well as those associated with low or zero emissions, which are scarce in the sector.

On the other hand, this study confirms the findings argued by Berrio et al. (2019) who state that in some regions in Colombia the IWT is still the only transport alternative mainly due to the poor development of road infrastructure and the complicated geographical conditions of some regions. However, despite the relevance of this mode of transport in some regions, the social standards evaluated in this survey show low values in the implementation of social responsibility programmes and implementation of labour standards. In addition, the use of the IWT for the use of the IWT for small boats and short journeys has decreased, and the role of tourism in the use and exploitation of the IWT in Colombia is not clear (Atencio-Molinares et al., 2023).

In relation to the economic issues, several authors suggest the implementation of economic incentives as a solution to boost the sustainable development of the WT, both in developed and developing countries (Calderón-Rivera et al., 2024). However, the data reveal that in the Magdalena River, these financing strategies are accessible on average only 38% in Colombia, coupled with the lack of business models and an unclear vision of waterway transport in the country, generating difficulties in understanding and prioritizing the IWT as well as actions that positively impact society, environmental protection and economic stability at local, regional and national levels. On the other hand, the demand for IWT service in terms of cargo on larger vessels is determined by fares, journey times and reliability (Zambrano, 2019). However, Berrio et al. (2019) argue that in Colombia there are no policies that motivate the use of the IWT or modal shift or any type of incentive, and the authors argue that in the case of the Magdalena River, the cost of transport is more influential than the travel time, and for this reason, the implementation of subsidies would significantly stimulate its use. However, the data obtained in the survey show a limited scope for the implementation of such practices and future studies could evaluate the feasibility of each of the strategies and their applications in different business models for both long and short-range navigation in different types of vessels. Additionally, for passenger transport, although cost reduction is important, waiting time and travel time is also considered a fundamental variable for choosing the IWT, for which improving timetables and frequencies and optimizing the multimodal service would have a positive impact on its development, generating benefits for passengers and making it more attractive to the public (Berrio et al., 2019).

Moreover, the development and application of business models play a key role in informed decision-making for modal shifts, high quality data and information strengthen their application and facilitate informed decision-making by transport users (Zambrano, 2019). However, river monitoring systems and river information systems still require further development for the Magdalena River as there is high variability in the answers provided by experts, with high values associated with their non-existence or lack of awareness of them.
Finally, although Zamudio et al. (2019) argue that functional models applied in other parts of the world should be replicated, the authors consider that these approaches should be done in a cautious manner, as the characteristics of each waterway or navigable river and the mechanisms to be implemented should be adjusted to the current conditions, barriers, risks and definitions of the vision and strategy of each case, since even if some models are functional in other regions, they may not be appropriate for the particular conditions of the Magdalena River. On the other hand, investments must be based on realistic scenarios, as the absence of forecasts or understanding of the applicable business models for freight or passenger movement may result in inappropriate decisions for the region, which requires caution in the development of infrastructure and prioritization of actions that lead to the sustainable development of the IWT. Furthermore, even if the infrastructure and policies associated with the IWT are strengthened, for it to become feasible, other investments are needed to strengthen multimodal connections between production centres and river ports (Zambrano, 2019).

5. Conclusion

This research proposes and validate the definitions of the elements of an IWT system and rank the characteristics associated with sustainable IWT service. On the other hand, the research provides the distances between a sustainable IWT systema and the current state of some transversal, environmental, social and economic aspects, for the Magdalena River case, showing low levels of compliance of the elements proposed in the survey. Although this study provides insight into the current state of Magdalena River, Colombia's most significant navigable river concerning sustainable IWT, the findings not only offer valuable insights for prioritizing actions to enhance IWT but also hold broader implications, and some results can potentially be generalized and utilized as a reference point for decision-making processes, evaluations, and policy formulation within IWT systems across various waterways. Further research can focus on the prioritization of actions that seek the implementation of the plans proposed in this article, as well as the evaluation of business models applicable not only to the Magdalena River, but also to other navigable rivers in the country. On the other hand, it is necessary to understand the needs for the implementation of new technologies and some social standards such as the education required for IWT development. Finally, this research presents some limitations associated with the participation of experts in Colombia with experience in the Magdalena River, as they are scarce and their engagement in academic activities is often limited, making it challenging to achieve a high number of participants.

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