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João Miguel Correia Pratas

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Case Study of São Paulo

Dissertação no âmbito do Mestrado em Gestão orientada pela Professora Doutora Susana Maria Palavra Garrido e Professora Doutora Carina Maria Oliveira Pimentel apresentada à Faculdade de Economia da Universidade de Coimbra

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Abstract

The migration to large urban centers has created significant challenges for global authorities. The unbridled advance of climate change has been felt year after year in the most diverse regions of the globe. São Paulo, with its high population density, ranks among the most populous cities in the world and the main artery of circulation in Brazil, has seen the conditions of its urban mobility deteriorate. With an overloaded public transport system and its roads completely congested, residents witness an exponential worsening of their quality of life, due to the long hours lost in buses, trains, or personal vehicles, and all the inherent exposure to polluting gases and noise from the current existing modes of transportation. São Paulo is encircled by rivers that cover a significant portion of its territory, although their current situation is not entirely favorable to navigation in all their stretches, several actions have been carried out to guarantee their navigability.

This dissertation aims to update the body of research on inland navigation and investigate the techniques and strategies used in major cities worldwide that employ waterways as a means of transportation. The study focuses on the city of São Paulo, aiming to analyze the main barriers to the implementation of a waterway and propose a framework for a sustainable waterway transportation mode and its supporting infrastructure. Additionally, the study analyzes existing urban navigation technologies, such as electric or hybrid vessels, and complementary energy-efficient transport modes like bicycles or electric vehicles for last-mile delivery to ensure sustainability across the urban logistics chain. The investigation is a narrative study that analyzes data based on existing literature and identifies possible bottlenecks in execution. The study emphasizes that only a systemic approach involving multiple stakeholders can facilitate an effective energy transition in urban transportation. Urban mobility is a small part of a multidisciplinary ecosystem, and cooperation and alignment are crucial for achieving a greater goal.

Keywords: Inland Waterway Navigation; Urban Waterway Transport; City Logistics

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List of Acronyms

CEMT	Classification of European Inland Waterways
CO_2	Carbon dioxide
COVID-19	Coronavirus Disease 2019
EC	European Comission
EU	European Union
FDC	Floating Distribution Center
ICT	Information and Communication Technologies
IWT	Inland Waterway Transport
MRSP	Metropolitan Region of São Paulo
NOx	Nitrogen oxide
OECD	Organisation for Economic Co-operation and Development
PM10	Particulate Matter 10
PMS	Power Management System
RIS	River Information Services
SMP	Strategic Master Plan
SO	Sulfur oxide
SP	São Paulo
UCCs	Urban consolidation centers
UDC	Urban distribution centers

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1. Introduction

The time has come for the world to rally together in a united effort to combat climate change; world leaders need to act right now on finding alternatives to diminish environmental deterioration.

“Climate change has been defined as a shift in weather parameters and phenomena outside the expected range of climate variability. It includes changes in air temperature, wind patterns, precipitation, and other weather parameters that define the climate of a region “ (Burrel, Beltaos, & Turcotte, 2021, p. 2), resulting on “loss of biodiversity, the spread of invasive species, exhaustion of wild fisheries, and the depletion of freshwater supplies” (Woodcock, Banister, Edwards, Prentice, & Roberts, 2023, p. 6). Natural resources deterioration is being permanently challenged by climate changes with a negative impact on crop yield and food security, consequently, impact hardly on human healthy (Pölzler, 2015).

Over the last decades, climate change has been taken to the top of political and environmental organizations' discussions, working on promoting and creating awareness among worldwide communities, to make needed adaptions to save the future of actual and future generations (Banister, 2011).

Urbanization, considered by many as the main propulsor for climatic changes, “refers to the concentration of the rural population and non-agricultural production factors in cities and the transformation of rural areas to urban areas” (Liu, Dong , Wang, Zhang, & Liu, 2021, p. 4). “Urbanization is a complex process involving population migration, land cover change, an urban agglomeration, economic scale, and other issues “ (Liu, Dong , Wang, Zhang, & Liu, 2021, p. 1).

Massive migration to urban centers will cause even more adverse effects on the environment and increase the already huge demand for resources, as a result, the demand for urban transportation has increased to keep people moving around. By 2025, it is predicted that more than 60% of the world's population will be living in urban areas (Fallahshorshani, André , Bonhomme, & Seigneur, 2012).

Large cities are widely recognized as major contributors to climate change due to their high energy demand and heavy reliance on on-road transportation. As urbanization continues, the climate is facing more pressure due to the influx of people into cities (Hendrickx & Breemersch, 2012).

Urban mobility today brings additional concerns about predicted demands arising from people's necessities of living in cities and their respective needs to travel in different forms, either for personal or professional purposes. Usually, most of these travels are fueled by carbon, which leads to increased carbon emissions affecting the global climate. With the exponential increase in the number of inhabitants in big cities, there is a need for better mobility planning in urban centers, by exploring various methods for maintaining efficient movement of people and goods, competitiveness, and agility in all processes. The current situation is evidently not sustainable, and it is imperative for the transportation sector to make a significant contribution towards achieving carbon reduction targets (Banister, 2011).

As cities form a crucial component of the urban environment, it is imperative to foster a sense of urgency among urban residents to rethink their mobility practices, especially given the urgent need to mitigate climate change impacts. Recent research has shown that climate change risk perception and inaction are closely linked, “with higher levels of climate change risk perception were related to less climate change inaction, and this relation was mediated by enhanced climate change belief and heightened environmental efficacy in a sequential manner” (Wang, Geng, & Rodríguez-Casallas, 2021, p. 1).

Previous research has shown that changes in the behavior of various stakeholders can impact the carbon footprint of large companies throughout their supply chain, including the exploitation of raw materials, transportation, and delivery. As such, companies are increasingly aware of the importance of sustainability and carbon reduction practices in protecting their corporate image.

Urban areas are home to over 50% of the world's population and are responsible for consuming about 75% of the world's energy production. They also play a significant role in greenhouse gas emissions. Transport is a major contributor to these emissions, especially road transport, which is the primary mode of transportation used globally (Zawieska & Pieriegud, 2018).

The use of road transport causes a host of negative impacts on citizens' quality of life, including increased CO_2 emissions, elevated pollution levels, traffic congestion, and accidents (Tarkowski & Puzdrakiewicz, 2021).

Janjevic and Ndiaye (2014) highlighted the potential for significant growth in urban freight transport in the coming years, driven by demographic expansion in cities and an anticipated increase in both the volume and frequency of deliveries per capita.

Lately, consumers have changed behaviors. COVID-19 has had a significant impact on e-commerce worldwide, with some negative effects. Overall, the pandemic has led to a rapid proliferation of e-commerce. As the virus changes consumers' daily habits, the shift towards online shopping is likely to continue in the coming years (Usas, Jasinskas, Zagurska-Antoniuk, Savitskyi, & Fuhelo, 2021). City logistics face a significant challenge due to the expansion of e-commerce, the increasing demand for one-day shipping services, and the high variability in last-mile distribution. These trends have reinforced longstanding patterns of freight transport growth and necessitate the movement of small cargo within urban areas, which predominantly rely on roadway infrastructure.

The cost of the final leg of parcel delivery to its destination, also known as the last mile, can account for a substantial portion of the total costs involved in the entire delivery process, ranging from "13% to 75%, particularly in areas with logistics sprawl", as reported by (Silva, Magalhães, & Medrado, 2019, p. 2).

A pressing need exists to accelerate collaborative efforts for the development of sustainable urban transport policies that address the economic, social, and environmental needs of cities. Failure to implement large-scale measures to mitigate and adapt to climate change risks will result in catastrophic consequences. As Pölzler (2015) suggests, the current situation is merely a precursor to a more severe future, characterized by extreme weather events that threaten the lives of both humans and non-human species.

To achieve sustainable urban transport policies, it is crucial to implement energy-efficient solutions that promote low-carbon initiatives, such as greener and smarter local transport systems. The shift towards zero-carbon transportation modes must be gradual, and existing infrastructures should be leveraged. Road transportation is the most prevalent mode of transport in large cities, and thousands of vehicles use roads every day, contributing to greenhouse gas emissions.

Planned and completed megaprojects form part of the government's strategies to mitigate the negative impacts of roadways. To this end, new infrastructures that incorporate underground and airways modal transportation have been selected as alternatives to terrestrial transport. While these alternatives can significantly reduce traffic congestion within megacities, they are not environmentally friendly, and encourage the use of non-sustainable solutions. As a result, there is a strong need to transition to sustainable transport modes that can reduce the negative externalities associated with transportation. Recent investments in infrastructures such as rail, underground systems, and river waterways have been observed as cities seek alternative modes of transportation (Cardenas, et al., 2017).

We have chosen São Paulo as the city for our study. Firstly, São Paulo is renowned for its high population density, making it one of the most populous cities in the world. However, São Paulo has been grappling with significant challenges in terms of urban mobility. The public transport system is overwhelmed, unable to adequately meet the growing demands of its residents. Furthermore, the city's roads suffer from chronic congestion, resulting in frustratingly long commutes and a negative impact on the quality of life for its inhabitants.

Moreover, the current transportation modes in São Paulo contribute to environmental issues such as increased greenhouse gas emissions and noise pollution. These factors not only harm the environment but also have adverse effects on public health and well-being.

Our study aims to address these challenges and contribute to the reduction of climate change impacts in São Paulo. By examining the city's urban mobility landscape, we seek to identify innovative and sustainable solutions. Our research will explore ways to enhance public transportation, alleviate congestion, and promote low-carbon modes of travel. Additionally, we will investigate strategies to integrate emerging technologies and encourage behavioral changes that support sustainable urban mobility patterns.

By fostering a more efficient and environmentally friendly transportation system, we aim to enhance the overall well-being of the city's residents and contribute to the global efforts in mitigating climate change.

The main objective of this study is to conduct a thorough analysis of the primary barriers associated with implementing a sustainable smart mobility alternative utilizing waterways for the transportation of cargo and passengers in the city of São Paulo. By examining these challenges, we would propose a comprehensive framework that effectively addresses these obstacles and offers a sustainable solution for enhancing the efficiency and environmental friendliness of waterway transportation in São Paulo.

1.1. Objectives

Due to the exponential increase in migration to large urban centers, we have witnessed an overcrowding of public roads to unsustainable levels, which has led to a clear decrease in residents' quality of life and poses a threat to human health due to the side-effects produced by vehicles on city highways. Most of the vehicles travelling on main city roadways are powered by combustion motors, which are totally dependent on fossil fuels.

The main objective of this dissertation is to conduct an in-depth study of the main barriers in implementing a sustainable smart mobility alternative with a waterway for cargo and passengers in the city of São Paulo. It will examine the factors that promote or hinder the adoption of this transportation mode and the advantages it offers. The study will also investigate modern technologies that aim to reduce carbon footprint while ensuring effective implementation. Based on this objective, the main research question was defined:

- **What are the main challenges for implementing sustainable waterway transportation in the city of São Paulo using environmentally friendly vessels?**

To support the research in answering the main question, sub-questions were created to support the study approach:

- What are the main drivers and barriers to the implementation of sustainable smart mobility with waterways?
- What are the advantages of implementing a sustainable transportation matrix with waterways for passengers and small packages?

Lastly, based on literature, a support framework will be proposed to facilitate the successful and appropriate implementation of the inland waterway transport.

1.2. Structure of the Dissertation

After introducing the research objectives and justifying the relevance of the study in Chapter I, the dissertation is divided into four main chapters: research design, inland waterway transport, the state of art of sustainable urban strategies across the world, proposal framework for implementation and conclusions.

Chapter II presents a comprehensive research design that describes key concepts and ideas related to the research topic. The review focuses on the main barriers and advantages of implementing inland navigation in urban environments.

Chapter III presents a comprehensive literature review on inland waterway transport research, with a specific focus on the implementation of waterway sustainable solutions within urban transport networks.

Chapter IV presents strategies and technological solutions used worldwide that enable the effective use of waterways. These solutions aim to reduce energy consumption and pollutant emissions.

Chapter V proposes a framework to support the implementation of the solution based on the literature review and case studies presented in earlier chapters.

2. Research Design

The present research emerged from the necessity to evaluate the applicability of energy-efficient waterway solutions to support decreased emissions and increase the efficiency of existing transport modes, while providing an important tool to reduce traffic from overcrowded roadways.

The research analyzed data regarding the main transport modes currently used in Brazil, the necessary infrastructure to implement IWT, the effect of climate change on water transportation, environmental conditions, and urban river revitalization plans, as well as the main challenges encountered in similar projects.

A narrative research methodology was utilized to conduct this research, with information obtained through a literature review by exploring relevant material from main electronic databases, considering the research problem. This approach facilitated the creation of a clear overview of the analyzed topic through this approach. The narrative review helped identify gaps in the existing literature, the main challenges, and guidelines to overcome obstacles related to the use of the waterway system as a method of transit in urban centers (Snyder, 2019).

The Web of Science database was used to acquire and collect information to support the analysis. This database was chosen because is the most widespread database on different scientific fields which are frequently used for searching the literature (Guz & Rushchitsky, 2009). The literature review primarily focuses on a six-year period, spanning from 2017 to 2023. Although older articles were found to be relevant in the search, it is important to note that significant advancements in technology within this field have been observed during this period. The search was conducted using combinations of the following terms: (“mobility” OR “city logistics” OR “urban logistics”) AND (“smart” OR “sustainab*” OR “green” OR “low carbon” OR “electrical technologies” OR “low emission”) AND ("waterways" OR "Inland" OR "river").

Additional filters were considered to improve the search. Therefore, the sub-areas of "Environmental Sciences", "Green Sustainable Science Technology", "Transportation Science Technology", and "Transportation" were filtered. Similarly, the document type was also considered in the optimization of filtering, with a preference for articles and conference papers. Finally, English and Portuguese were chosen as the languages for the study analysis. Using defined criteria, 140 articles were collected from the online search tool.

After applying the filters, the titles, abstracts, and keywords of each document were analyzed, and in a first stage, those that were not aligned with the research objective were eliminated. In some situations, the introduction or even the conclusion of each document was also read to promote an optimized selection. It is important to mention that during the document collection process for analysis, the Web of Science tool provides information on documents that, despite not being presented in the initial filtering defined by the researcher, may also be of interest for the analysis of the discussed topic. Therefore, additional documents were considered beyond those found in the tool's search engine. Subsequently, by analyzing abstracts, new filters were applied to categorize each document properly according to research questions, reducing the number of articles to fourteen. The remaining articles were not excluded but were used to complement the content.

After selecting and the relevant articles for the discussed topic, a full reading and respective analysis of each document was carried out.

Our research methodology can be visualized in Figure 1, which illustrates the workflow we used to select relevant studies. As previously mentioned, the process began with a search of academic database. We then applied inclusion and exclusion criteria to the search results, which allowed us to narrow down the selection of studies. Finally, we conducted a quality assessment of the selected studies. This workflow allowed us to identify a set of high-quality studies that were relevant to our research objectives.

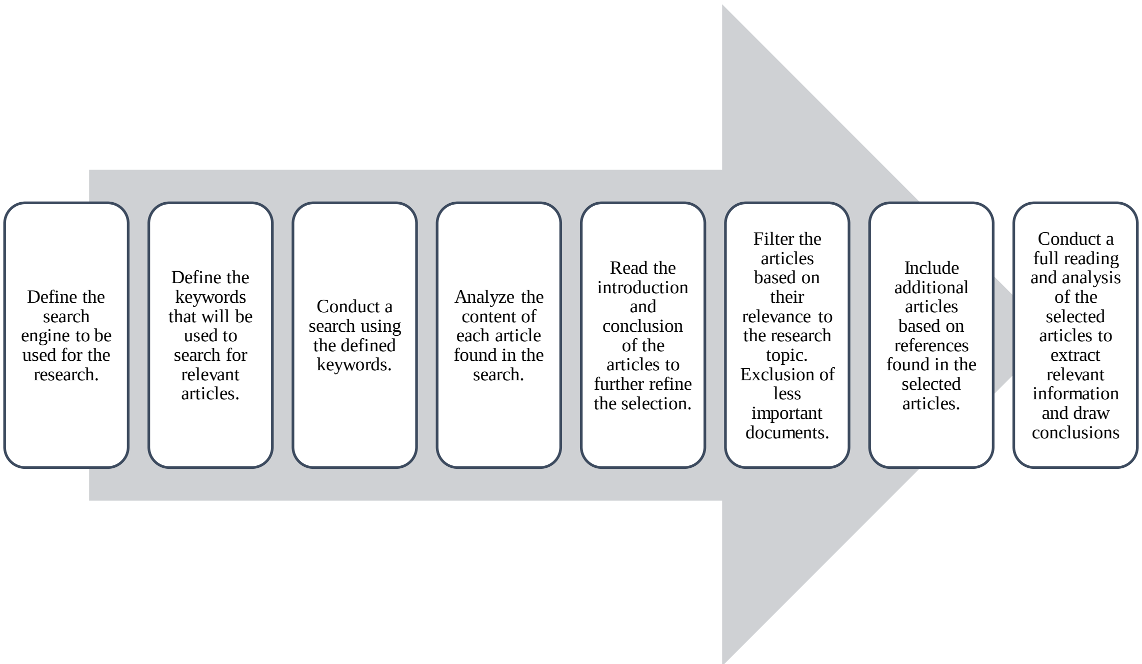

Figure 1 - Research Workflow: From Search to Selection

The information gathered from the articles was carefully documented and organized in a way that would be easily accessible for the final phase, which is the writing of the literature review itself. During this phase, the researcher examined the information extracted from the articles and identified key themes and patterns, which were then synthesized into a cohesive narrative that addressed the research question. This phase also involved critically evaluating the quality and credibility of the sources used, ensuring that the literature review was based on sound and reliable evidence. Overall, the literature review was essential in shaping the final output of the research, ensuring that it was grounded in relevant and reliable literature.

3. Inland Waterway Transport

This chapter offers an overview of the literature on IWT, with a focus on studies that examine the implementation of electric vessels in an urban transport matrix. Our analysis aims to identify the key factors that contribute to the success or failure of such implementation. We summarize below the main articles that we have selected for our review.

The research conducted by Diziain, Taniguchi and Dablanc (2014) aimed to compare intermodal freight transport in Japan and France, with a particular focus on the use of waterborne transport in urban areas. Despite being a minor mode of transportation for both people and freight, IWT has exhibited stability among the various modes of transportation in Paris, with a growth rate of 30% between 1997 and 2010. The Japanese government has created the Eco-Ship Mark certification for shippers transitioning from road to sea transportation and has made subsidies available to alleviate traffic congestion in major cities. However, despite an increase in intermodal projects in the last decade, the last-mile delivery has been identified as a significant challenge. The author suggests the need for stringent government policies to promote sustainable transport alternatives within urban areas.

According to Hendrickx and Breemersch (2012), there is a need to adapt IWT to new climate conditions, presenting results of Energy Consumption Networks project (takes into account the complete impact chain of climacteric conditions), integrating the work of different stakeholders from inland navigation."

In a recent paper by Trivedi, Jakhar and Sinha (2021), a case study of India was presented, which analyzed the barriers to implementing IWT using a hybrid Multi Criteria Decision-Making model. The objective of this study was to identify correlations among various variables and provide additional insights to policymakers and decision-makers to address critical points and identify measures to overcome them.

In their paper, Vilarinho, Liboni and Siegler (2019) provide insights on the main challenges and opportunities for using waterways as an alternative to traditional carbon-emitting vehicles for mobility. The authors conducted an extensive review of recent research on river logistics and surveyed various stakeholders to validate their findings. Based on their analysis, the authors suggest several actions that can be taken to overcome the barriers identified in their research.

In the study conducted by Jan and Nepveu (2020), the challenges faced in Amsterdam's historic center were examined. The high flow of tourists and heavy loads pose a threat to the accessibility and quality of life of residents. Despite maintenance and restoration efforts, the deterioration of bridges and canals persists. The author suggests imposing measures to restrict access to heavy load vehicles and implementing sustainable transportation alternatives to address the issue. Success and failure factors have been identified to ensure the effective implementation of these measures.

In their paper, Boudhoum, Oztanriseven and Nachtmann (2021) conducted a comprehensive analysis of the utilization of IWT, taking into account not only its logistics benefits but also its potential impact on other areas such as flood protection, water supply, hydropower generation, recreation, and the environment. The authors presented a valuation analysis to support investment decisions and an optimization model to maximize the benefits associated with the investment.

The study conducted by Tobias, Ramos and Rodrigues (2019) provide an exploratory analysis of the city of Belem, located in the northern region of Brazil. The research is based on a preliminary literature review and on-site observations and aims to identify the critical factors for the development of island areas, with a special focus on the integration of different transport modes. The authors propose four dimensions of integration that promote economic and sustainable development, with a particular emphasis on equity and social inclusion. The study concludes that the physical integration of waterway mode is possible, but additional analysis is required to determine its viability.

In their paper, Mihic, Golušin, and Mihajlovic (2011) examined the utilization of IWT along the Danube River, with the goal of predicting the future development of sustainable transport in the region. The authors analyzed the historical evolution of the waterways over the past half-century and examined how these conditions have impacted the use of IWT for the movement of people and goods in Western Europe. Based on their analysis, the authors concluded that the current state of the Danube as a form of conveyance is unsatisfactory and cannot be sustained in the long term. The paper proposes a set of measures that could be taken to improve and promote long-term sustainable development along the Danube River.

The author Janjevic and Ndiaye (2014), provides a comprehensive analysis of successful IWT in Europe. The study includes a detailed examination of the main barriers to implementation and the measures taken to overcome them. The author suggests that IWT can serve as a viable means for distributing products within urban areas. The author identifies various barriers and proposes corresponding mitigation measures to enhance the effectiveness of IWT. Successful implementation heavily relies on intermodal coordination among different stakeholders, and the provision of last-leg delivery services is highlighted as a crucial factor in improving effectiveness. The importance of local public authorities is emphasized in terms of promoting and providing financial support for cooperation, as these variables play a key role in fostering sustainable inland urban transportation.

Sachs, Azevedo, Dahle, and Henriksen (2021), present a case study of the city and municipality of Stavanger, Norway, in which they describe the implementation of best practices for smart mobility in an urban environment. The authors outline a method for preselecting and evaluating services for a smart mobility hub and provide a clear process for integrating innovative and environmentally friendly vessels into a comprehensive mobility system. The purpose of the study is to share insights into the process of implementing smart mobility practices in an urban context, with a particular focus on the effective integration of new and sustainable transportation modes.

The authors Tarkowski and Puzdrakiewicz, 2021 emphasizes the significance of utilizing small autonomous electric vessels to improve energy efficiency in urban transportation of people and goods, rather than relying on large-scale solutions. The use of autonomous vessels allows for greater integration with existing transportation logistics systems while reducing dependence on them. Small autonomous ferries that emit zero emissions are a flexible solution that can be implemented easily, unlike large-scale solutions. The authors also provide case studies that demonstrate the benefits of including this approach in sustainable urban mobility plans.

In their study, Cardenas et al. (2017) provide a systematic approach to the three dimensions of freight distribution in city logistics: city logistics, urban good distributions, and last delivery. The authors provide definitions and categorizations of each player in the functional scope of urban distribution, as well as list possible obstacles arising from each variable. The study aims to provide a clear understanding of each domain, which can serve as a starting point for future research on the subject.

In his paper, Gołębiowski (2016) examines various modes of transportation, highlighting the advantages of inland navigation in terms of economy, sustainability, direct costs, and external costs. He also discusses the main barriers that can impede the integration of IWT into urban mobility and suggests measures to mitigate these obstacles. One of the key variables he identifies as limiting the implementation of vessels in urban logistics planning is the height between rivers and bridges.

The paper by Ydersbond, Auvinen, Tuominen, Fearnley and Aarhaug (2020) examines the experiences of Norway and Finland in relation to the entry of new and emerging mobility services, the role of government authorities and private sectors in driving the transition towards smart mobility, and the importance of regulation in promoting sustainable and intelligent mobility. The authors identify a range of multidisciplinary challenges that need to be addressed to achieve these objectives. Specifically, they emphasize the need for a change in user mindset to facilitate a socio-technical transition, with a focus on delivering services that promote social inclusion and equity. Overall, the paper provides a valuable contribution to the literature on sustainable and intelligent mobility, highlighting the key factors that must be considered to achieve a successful transition towards more sustainable and equitable mobility systems.

The Table 1 shows the main contributions of each paper.

Table 1 - Main contributions from literature.

Author	Country where the study was developed	Contribution
Mihic, Golušin and Mihajlovic (2011)	Serbia	Policies and promotion of sustainable river transport in Europe. The use of IWT can be increased through government policies that encourage its adoption. Despite the challenges to be overcome, IWT can be a viable and sustainable option to promote urban mobility and trade in the European region.
Hendrickx and Breemersch (2012)	Belgium	IWT relies heavily on dependable water levels, which are being affected by climate change. An increased risk of water levels can lead to reduced cargo capacity and higher transport costs, and damage to water infrastructure. Stakeholders must work together in more climate-resilient infrastructures and finding alternative transportation methods.
Diziain, Taniguchi and Dablanc (2014)	Japan and France	Importance of creating an adequate infrastructure and the required significant investments, concluding that rail and river transport are promising solutions for the countries' urban logistics.
Janjevic and Ndiaye (2014)	Belgium	Experiences reviews of using IWT for city logistics, highlighting benefits and main challenges. Clear need for coordination among different actors, including shippers, carriers, and

		local public authorities. Local public authorities have the responsibility to promote, regulate and align strategic actions, by creating the necessary infrastructure to facilitate the transport process.
Gołębiowski (2016)	Poland	Exploiting the potential of IWT would support reducing roadway congestion and improve the city´s logistic performance. It is mentioned the initiatives realized by local authorities to support and develop IWT, such as the creation of National Program for the development of IWT, and the establishment of dedicated agency to regulate and promoting the sector. Additionally, the authors asked for a strictly cooperation between public and private stakeholders to get the most from this mode of transport.
Cardenas et al. (2017)	Belgium	Challenges and trends in urban goods distribution and the importance of last mile delivery. Importance to involve the various actors involved in city logistics. Furthermore, it is considered relevant considering innovative environmentally solutions.
Vilarinho, Liboni and Siegler (2019)	Brazil	Fluvial logistics offers several advantages, such as cost reduction and lower environmental impact, however it also faces several obstacles, such as the need for investment in infrastructure and awareness of the population (and stakeholders).
Tobias, Ramos and Rodrigues (2019)	Brazil	River transportation integrated with other methods of transit presents itself as a solution for sustainable mobility, reducing the number of cars on the streets, reducing the levels of noise and environmental pollution, and providing social integration for residents in remote regions.
Jan and Nepveu (2020)	Holland	IWT used for the transportation of perishable food products in the regions of Amsterdam, lead to reducing CO_2 emissions and road congestion. There is a need to overcome the lack of infrastructure and the high initial costs for implementation to ensure the success of IWT.
Ydersbond, Auvinen, Tuominen, Fearnley and Aarhaug (2020)	Norway and Finland	Vision of smart mobility services in the Nordic countries, the need to of utilizing new services such as ride-sharing, car-sharing and mobility as a service. Need for collaboration between public and private stakeholders, and the role of local governments in promoting the sector by ensuring safety and security of users. Some risks are addressed, such as the displacement of traditional transportation modes and the potential for data misuse.
Trivedi, Jakhar and Sinha (2021)	India	Lack of infrastructure, lack of regulation and complex policy environment are the main barriers to implement IWT in India. Several measures are proposed to promote this mode of transport, including improving infrastructure and simplifying local policies.
Boudhoum, Oztanriseven and Nachtmann (2021)	United States	Model for decision-making in inland waterway infrastructure investments, focusing on the value extracted from this modal. Many elements are mentioned when considering the investment, cost benefit, transport value, risk and uncertainty

		factors, as well as environmental and social factors. The author supports his study by listing the benefits of sustainable development as an important variable in decision making.
Sachs, Azevedo, Dahle, and Henriksen (2021)	Norway	Initiatives undertaken by local authorities to shape intermodality in Stavanger, including development of Connected Mobility Hub considering integration with cycle and electric vehicles. Some challenges are identified, including lack of coordination between stakeholders and better data sharing and information exchange.
Tarkowski and Puzdrakiewicz (2021)	Poland	Zero-emissions autonomous ferries can provide increased connectivity and accessibility, while also reducing congestion and greenhouse gas emissions. The paper highlights the importance and flexibility of small autonomous ferries, including technical and operational specifications.

4. The state of the art of sustainable urban mobility across the world

4.1. Urban Mobility using Inland Waterway

"IWT refers to the use of ships to transport goods from origin to transit points by the urban waterway network of a city" (Jan & Nepveu, 2020).

After reviewing the literature on the concept of Urban Sustainable Mobility using IWT, it is possible to conclude that there is a consensus that IWT is not a new concept, having been developed in ancient times. For example, in the 25th century BCE, the Nile was used to transport building materials for the construction of the pyramids at Giza (Gołębiowski, 2016). Inland waterways have been used as a mode of transporting freight for thousand years, but they were left behind after the industrial revolution, with interest shifting toward railway transport (Zacharopoulos, El, Supervisor, & Gonzalez-Aregall, 2020).

Throughout history, inland waterways have played a significant role in transporting people and cargo around the world. Merchants have used waterways as a primary means of moving goods to and from cities due to the low pollution levels and high-water densities that make IWT a more efficient and sustainable option (Affairs, 2017).

Jan and Nepveu (2020), Tobias, Ramos, & Rodrigues (2019) and Cabral (2023) agree that urban freight transportation mainly relies on roadways, which are primarily powered by carbon-based fuels. It is widely accepted that carbon emissions have negative and irreversible long-term impacts on the environment. Despite the harmful effects, roadways remain the most practical mode of transportation for moving people and goods within cities. However, this mode of transportation also brings several negative impacts such as traffic congestion, air pollution, and a decline in air quality (Banister, 2011).

Mayors of major cities are seeking "innovative ways to drive economic opportunity, create new public spaces, and find more sustainable uses for aging infrastructure" (Affairs, 2017, p. 5). As a result, there is increasing investment in the redevelopment of IWT. Better utilization of these aged waterways can provide significant benefits to city residents and help address urgent global needs for more sustainable solutions. This can help slow the harm caused by high pollution levels resulting from environmentally unfriendly transportation alternatives (Affairs, 2017).

Over decades, one of the most popular ideas in urban freight transport in cities with a dense water network is the application of water corridors as an alternative (or complementary) to the available transportation options.

Jan and Nepveu (2020), Affairs (2017), Janjevic and Ndiaye (2014) and Boudhoum, Oztanriseven and Nachtmann (2021) have examined projects in various locations that aim to integrate and revitalize the waterway network as a key component of urban planning. By strategically leveraging the waterway matrix, these projects have generated significant benefits across multiple areas, including improved urban mobility, expanded economic activity, and reduced exposure to risk and harmful emissions.

Jan and Nepveu (2020), Janjevic and Ndiaye (2014), Diziain, Taniguchi and Dablanc (2014) presented different cases in which inland navigation has been implemented for the distribution of products across various sectors in urban cargo freight transport. However, each study tends to focus on specific sectors, as it is impractical to cover all suitable types in a single urban logistics analysis (Cardenas, et al., 2017). Janjevic and Ndiaye (2014, p. 3) shared some references to using urban waterways to "transport palletized goods and containerized goods, deliveries to local shops and restaurants, deliveries of parcels, transport of waste and recycled material, and service trips". To go further, Jan and Nepveu (2020) mentioned that IWT has been used for construction projects and waste collection and may also be used to distribute food and beverages.

Based on the finding of Affairs (2017), waterways have historically played an important role in transporting goods and people worldwide, and that redeveloping urban waterways could bring multiple benefits to cities, such as improved mobility, increased economic activity, and reduced exposure to harmful emissions. In particular, inland navigation has been proposed as an alternative or complementary mode of transport to reduce the environmental impact of conventional transportation, which is often fueled by carbon and contributes to climate change.

Janjevic and Ndiaye (2014), as well as Jan and Nepveu (2020), have highlighted specific examples of using urban waterways to transport palletized goods, containerized goods, deliveries to local shops and restaurants, parcels, waste and recycled material, and construction materials. Furthermore, Paris has been used as a benchmark for successful waterway redevelopment projects that can deliver multiple benefits to cities, the municipality's effort to redevelop the banks of the Seine River into a car-free pedestrian zone that will both reduce vehicle traffic and increase economic and recreational opportunities along the river is a prime example of how waterway redevelopment projects can deliver returns on multiple fronts (Affairs, 2017).

Overall, the creativity of different actors, both at the private and public level, has been critical in overcoming barriers and making waterway redevelopment projects a success.

The case of France

Vert Chez Vous is a French logistics company that started a distribution service for small parcels in 2012. The service operates using a multimodal delivery approach, employing two alternative modes of transport. According to Janjevic and Ndiaye (2014), Vert Chez Vous uses 100% environmentally friendly vehicles, such as electric or natural gas vehicles, for its operation. The majority of cargo movement in the urban circuit is carried out by the river, using a Warehouse Barge called Vokoli, which is powered by renewable fuels and navigates the Seine River, stopping at strategic locations.

As stated by Janjevic and Ndiaye (2014), Vokoli performs a round-trip, unloading electric bikes at up to ten stopovers, which serve as the final delivery point for recipients all over Paris. This system guarantees delivery of orders within reduced delivery times, with a seamless transition between the river and the consumer assessment. According to the authors, the "service delivers about 4,000 parcels every day" (Janjevic & Ndiaye, 2014, p. 5).

Figure 2 - Exploring the French Waterways: Vokoli's Warehouse Barge and Electric Bikes (Vous, 2023).

The case of Portugal

As per Shahan (2023), the Portuguese Government plan to increase the capacity of electric passenger boats while reducing emissions. The plan involves the replacement of existent diesel mechanic ferries, by deployment of ten fully electric boats between 2022 and 2024, capable of transporting 540 passengers. The new electric ferries are expected to reduce CO_2 by 6,500 tons per year, equivalent to taking 1,400 gas-powered cars off the road. "The ferries will operate on three routes, connecting Lisbon to Cacilhas, Seixal, and Montijo" (Shahan, 2023, p. 1).

Figure 3 - Exploring Sustainable Transport: Electric and Diesel Ferries in Lisbon (Shahan, 2023).

The case of Germany

A mid-sized hybrid ferry operates within a city public transport system in Germany. This ferry can transport 300 passengers and 40 bicycles between the cities of Bahnhofbrucke (Kiel) and Laboe, covering approximately 20 kilometers. The vessel connects the railway station with several remote regions along the sea. The maximum navigation speed is 11 knots, and the batteries are recharged overnight using fast charging stations, strategically positioned to meet the high-energy requirements of electrified vessels. This project is the result of a partnership between the government, municipal authorities, and private companies, who worked together to develop the technology and share funds to devise the vessel design and basic infrastructure to support navigation Liebreich et al. (2021).

Figure 4 – Unveiling the MS Gaarden Hybrid Vessel (First, 2023): A Sustainable Solution with a Detailed Navigation Profile (Liebreich, et al., 2021).

The case of Holland

DHL, a global leader in the logistics industry, has developed a floating service center (FDC) in Holland that operates in Amsterdam's canals. To address the challenge of narrow, busy streets in Amsterdam's old center, DHL has deployed bicycle couriers as the last leg delivery in an unconventional logistics chain. Known as the Boat-Bike, the DHL multimodal Amsterdam logistics chain specializes in distributing small parcels in the city center, allowing for the avoidance of 10 cars every day, thereby reducing 150,000 car-kilometers and 12,000 liters of diesel per year (Jan & Nepveu, 2020). The Boat-Bike project, which includes both the boat and support infrastructure, was the result of a successful public-private partnership between DHL and the municipality. DHL financed the ship, while the city of Amsterdam provided labor to develop the project (Janjevic & Ndiaye, 2014).

Figure 5 - Revolutionizing Urban Logistics: DHL's Floating Service Center for Cargo Bikes (Kuzeyliden, 2023).

Still in Amsterdam, Mokum Mariteam has also established cooperation with Binnenstadservice (responsible for running urban consolidation centers): “goods are bundled at UCCs at the outskirts of town from where the City Supplier transports them to the city center” (Janjevic & Ndiaye, 2014).

Figure 6 - City Supplier Boat and Electric Bikes for Last Mile Logistics in Utrecht (Mariteam, 2023).

The "Beer Boat" in Utrecht, Holland, is considered by many authors to be one of the earliest examples of an IWT concept. Owned by the municipality, the boat was initially leased to private companies for the distribution of food and drinks to catering establishments along the canals. The diesel-powered version of the boat achieved significant “emissions reductions of particles by 74%, CO_2 by 27%, and NO_x by 85%” (Janjevic & Ndiaye, 2014, p. 4) compared to conventional transportation options of the same capacity. Based on these savings, the municipality decided to invest in a zero-emission version of the boat to deliver a carbon-neutral alternative solution (Janjevic & Ndiaye, 2014). The electric version “reduced CO_2 emissions by over 38 t, NO_x emissions by 31 kg, and PM10 emissions by 6 kg during its lifespan” (de Clerck, 2023, p. 1), contributing to Utrecht's sustainable freight transport initiatives. Recently, local authorities expanded the project to a new area and acquired another electric boat with a greater capacity to transport waste and other products from the city center (Zacharopoulos, El, Supervisor, & Gonzalez-Aregall, 2020).

Figure 7 - Green Delivery Options on Water and Land: The Beer Boat (Noort, 2023) and Solar-Powered Electric Van (Teubner, 2013).

The case of Japan

Coastal shipping has been a significant mode of domestic freight transport in Japan, but its share has declined over time, "representing one-third of ton-km today" (Diziain, Taniguchi, & Dablanc, 2014, p. 5). To promote IWT for general cargo and containers, the Japanese authorities have implemented measures. However, few assessments of the effectiveness of these measures are available, despite the provision of limited public subsidies and incentives. One example of IWT in Japan is the "transportation of gasoline by small tankers from Kawasaki City, Kanagawa Prefecture to Wako City, Saitama Prefecture via the Arakawa River. The tanker capacity is around 500 kiloliters, and it departs from the oil refinery in Kawasaki City at 3 am and arrives at a quay in Wako City at 7-8 am" (Diziain, Taniguchi, & Dablanc, 2014, p. 5). The gasoline is then transported to a terminal from the quay by pipeline and distributed to gas stations by tank lorries to Saitama Prefecture and the northern part of Tokyo (Diziain, Taniguchi, & Dablanc, 2014).

Another example promoted by the Tokyo city government is the transportation of municipal waste at various points along the Arakawa River. However, the high investment required for infrastructure and conditions to implement IWT has made it challenging to encourage shippers to use more sustainable vehicles for mobility in Japan. Thus, the government provides incentives to encourage the transition and reward good sustainability practices. For instance, the Japanese government established an Eco Ship Mark certification label that recognizes and rewards companies that shift their cargo from road to water (Diziain, Taniguchi, & Dablanc, 2014).

The case of Norway

Since 2018, a multidisciplinary consortium consisting of fourteen partners has been working together on a project to develop a zero-emission, fast-speed passenger vessel. The Transport Advanced and Modular (TrAM) project, funded by the European Union's Horizon2020 Research and Innovation program, aims to develop passenger vessels with zero emissions, offering a competitive and environmentally friendly solution (Commision, 2023). Currently, this vessel operates in the fjords of Norway, but the intention is to replicate the same concept in different European cities (see Figure 8)

Figure 8 - Image of the Stavanger Demonstrator and planned TrAM project replication studies for zero-emission, urban waterborne transport (Papanikolaou, 2020)

However, it is important to mention key lessons from this project. The planning of the mobility hub included non-motorized transport, "shared mobility services, eco-friendly transport modes, integrated journey-planning and ticket services, leisure and food services, real-time information systems, accessibility, and proper signaling" (Sachs, Azevedo, Dahle, & Henriksen, 2021, p. 4). To reduce the risk of unsuccessful implementation, the consortium has defined a methodology for the preselection and evaluation of services for a smart mobility hub, as described in Figure 9.

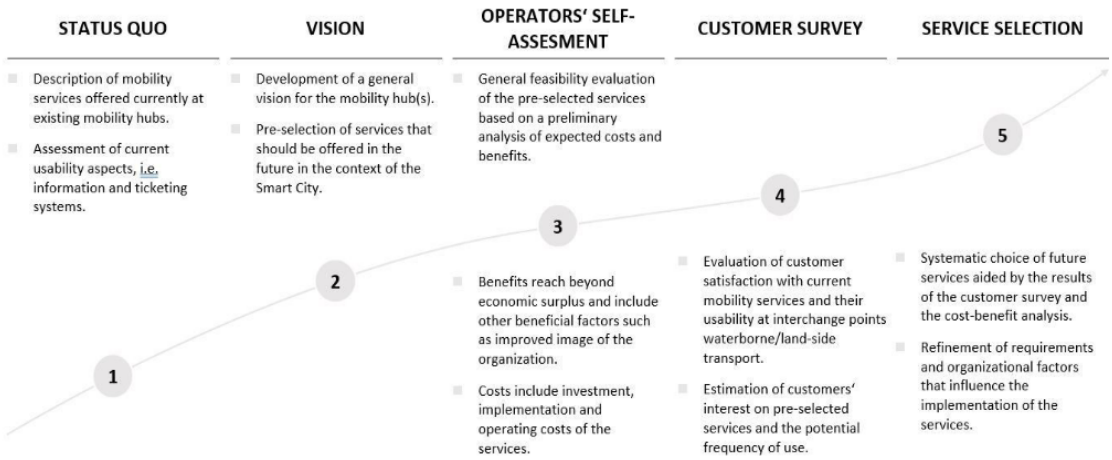

Figure 9 – Pre-selection and evaluation Method for a Smart Mobility hub Services (Sachs, Azevedo, Dahle, & Henriksen, 2021)

The case of Qatar

Lusail, a city located in Qatar, was purposefully constructed to serve as the host for the 2022 FIFA World Cup. As the venue for both the opening and final matches of this global football event, Lusail has been strategically utilized by the Qatari government to symbolize the harmonious convergence of past traditions and a technologically advanced and sustainable future (Natan & Crespo, 2023).

In order to enhance public transportation within Lusail City, the implementation of a hybrid system that combines Personal Rapid Transit (PRT) and water taxis holds immense potential. PRT, an innovative public transportation system, employs small automated electric podcars to provide on-demand, taxi-like services. These podcars offer demand-responsive feeder and shuttle services, seamlessly connecting various facilities such as parking lots and transport terminals with commercial areas. The advantages of the PRT system include its emphasis on safety, reliability, and minimal waiting times, ensuring efficient and convenient transportation for residents and visitors (Tahmasseby, 2022).

Water taxis, on the other hand, provide flexible and adaptable water-based transportation options. Integrating both PRT and water taxis with multimodal journey planning tools, such as mobile applications and real-time information, significantly improves accessibility and convenience for commuters. By incorporating these systems and technologies, Lusail City aligns its efforts with the objectives set by Qatar's Ministry of Transport and Communications, which aims to address mobility challenges and promote digital inclusion (Tahmasseby, 2022).

Overall, the coherent and interconnected implementation of the hybrid transportation system, along with the integration of modern technologies and multimodal journey planning, reinforces Lusail's commitment to sustainable and efficient public transportation. These efforts reflect Qatar's vision for the future, fostering an accessible and environmentally conscious city for residents and visitors alike.

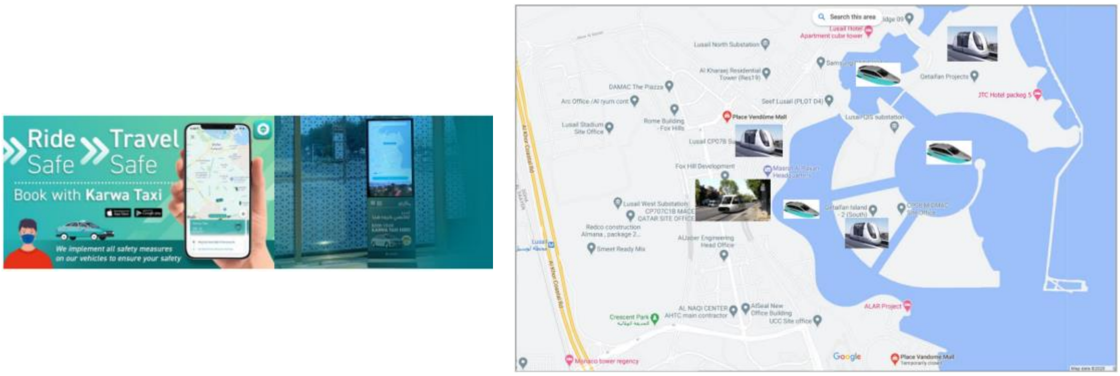

Figure 10 – Hybrid PRT+WaterTaxi Proposal and Multimodal Facilities in Doha (Tahmasseby, 2022)

Smart Mobility by waterways for passengers and urban logistics (parcels)

Ydersbond, Auvinen, Tuominen, Fearnley and Aarhaug (2020), note that a precise and agreed-upon definition of Smart Mobility is yet to be established. However, the authors view Smart Mobility as a crucial factor in supporting the digital transformation of transportation and mobility systems in urban areas. Tahmasseby (2022) concurs with this perspective, but takes it further by describing Smart Mobility as a system that enables access to transportation services through integrated platforms. Ydersbond, Auvinen, Tuominen, Fearnley and Aarhaug (2020, p.2) assert that Smart Mobility has the potential to facilitate “the transition from an automobile society to a multimodal society by using information and communication technologies (ICTs) to integrate and switch between various mobility services”.

Zawieska and Pieriegud (2018) considered Smart Mobility as a concept that facilitates sustainable development by optimizing transport services, and considering technological, societal, economic, and environmental challenges.

Smart Mobility as part of an Ecosystem

“Tackling environmental, social, and economic urban issues with interconnected ‘smart’ approaches can improve livability and equity in cities, in this way, ‘smart’ cities and ‘smart’ mobility are somewhat intertwined” (Sachs, Azevedo, Dahle, & Henriksen, 2021, p. 1). Moreover, Orlowski and Romanowska (2019) argued that Smart Mobility is the area of a Smart City representing mobility, not only representing the existing modes of transportation of people and goods but also the dissemination of information by digital means.

“Smart Cities strive to apply and implement technology, real-time data, and up-to-date information to enhance the quality and functionality of services and infrastructures” Tahmasseby (2022, p. 2), multidisciplinary tasks must be developed looking to creating smart cities (Zawieska & Pieriegud, 2018).

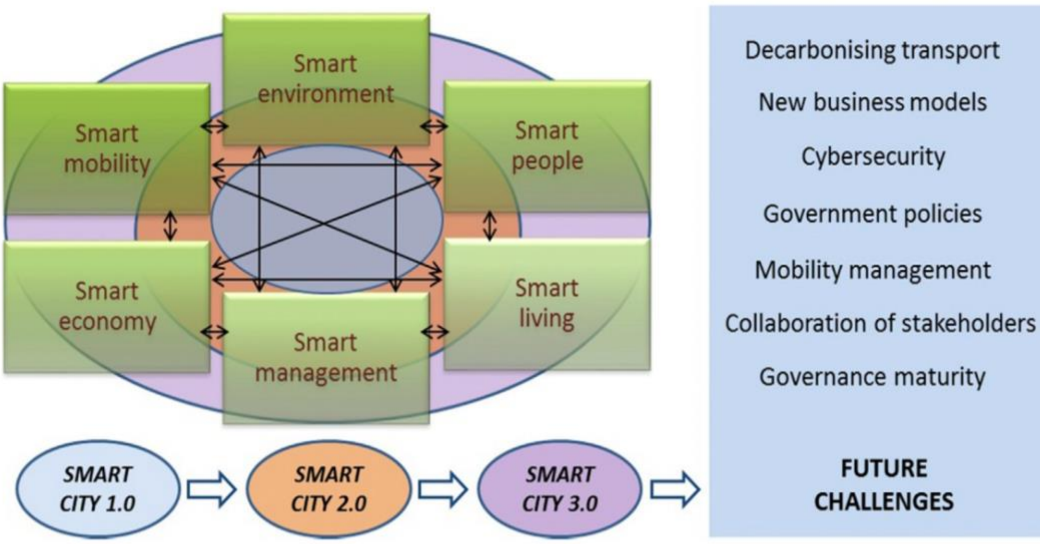

Figure 11 - Smart Cities: An Evolutionary Mode (Zawieska & Pieriegud, 2018).

It is evident that there is a strong connection between "smart" cities and "smart" mobility, as both aim to enhance life quality in urban areas. Smart cities strive to improve services and infrastructure by utilizing technology and real-time data. Therefore, it is crucial to adopt a holistic approach to creating a more efficient mobility system and overcome challenges faced by local governments in ensuring the sustainability of their initiatives to reduce carbon footprints. Figure 11 illustrates the evolutionary mode of smart cities.

As per Affairs (2017), cities are facing significant challenges in reducing their carbon footprint, which has resulted in a surge of global projects aimed at supporting the transition towards sustainable energy. These initiatives are interconnected and involve multidisciplinary teams, covering various aspects from mobility to digitalization. It is a complex and time-consuming process that requires the involvement of multiple stakeholders, and it poses a challenge for local governments to ensure the sustainability of their initiatives.

Smart Mobility Goal

According to Banister (2011), cities can greatly benefit from a switch to low-carbon transportation if the right strategy is implemented, considering the combination of economic, planning, and technological innovations. Therefore, Smart Mobility seeks to address transport-related concerns such as expenditure, travel-time, and gas emissions (Butler, Yigitcanlar, Paz, & Areed, 2022).

To minimize greenhouse gas emissions, introducing electric mobility (e-mobility) in cities surrounded by rivers can be an effective solution, also creating opportunities to reduce energy consumption, traffic congestion, and noise. These technologies can be applied in hybrid or purely electric vehicles that run on solar power, batteries, or hydrogen fuel cells, and can be used for both road and waterway transportation (Dutta, Ankan, & Khan, 2020).

In addition, Orlowski and Romanowska (2019) have outlined a range of potential benefits that can be achieved through the adoption of Smart Mobility solutions, as depicted in Figure 12.

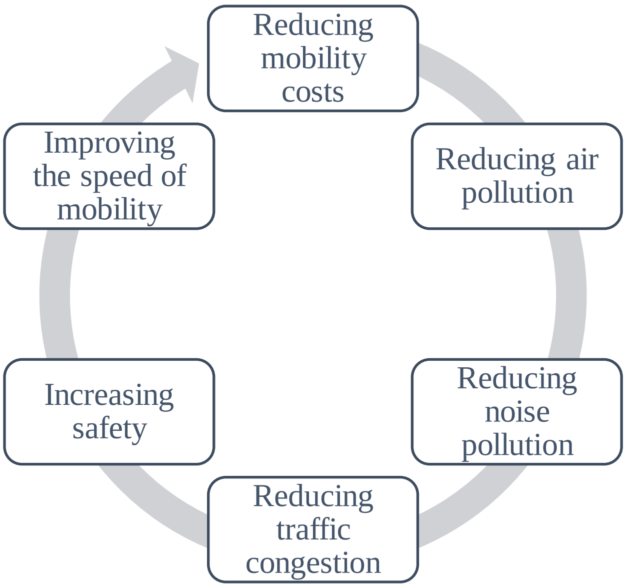

Figure 12 – Benefits of Sustainable Mobility: A Multi-Faceted Approach (Orlowski & Romanowska, 2019).

Smart Mobility Challenges

However, it is essential to plan adequately according to the characteristics and needs of each city. This includes introducing fundamental concepts, core enabling technologies, and necessary infrastructure, and explaining actual solutions in terms of plans, visions, and expected outcomes. The literature highlights several challenges that need to be addressed before implementing Smart Mobility, with a particular focus on user perception and attitude towards the strategy execution of new technologies proposed to improve first/last mile connectivity (Butler, Yigitcanlar, Paz, & Areed, 2022). These challenges include: "a) technology; b) smartphones and apps; c) public transportation; d) sharing rides with strangers; e) private vehicle usage; f) multimodality; g) peer to peer transport; h) environmental consciousness" (Butler, Yigitcanlar, Paz, & Areed, 2022).

Moreover, to achieve a successful transition to Smart Mobility, local communities play an important role in ensuring smooth implementation. Full engagement of both the public and private sectors with transport users is critical in providing the right tools to motivate citizens to utilize smart technologies for urban transportation. Smart Mobility services alone cannot address all elements required for the transition (Ydersbond, Auvinen, Tuominen, Fearnley, & Aarhaug, 2020). Technological improvements and innovations must be pursued as part of a larger context (Tobias, Ramos, & Rodrigues, 2019). Users are an active part of the process, and a clear need to change concepts that have become unchangeable in our daily relationship with available transport options is evident. In their review, Ydersbond, Auvinen, Tuominen, Fearnley and Aarhaug (2020), emphasized the need to move away from ownership to usership, where mobility services deliver access to a mobility network and free users from owning their cars, and highlighted the role of citizens in the transport system, who can have an active role in designing the tailorable mobility service as passengers, drivers, asset providers, or subcontractors. Users' attitudes are likely to influence the uptake of Smart Mobility Services (Butler, Yigitcanlar, Paz, & Areed, 2022).

According to Sachs, Azevedo, Dahle and Henriksen (2021), Smart Mobility is not only about providing additional mechanism travel for the last mile, but it also encompasses the infrastructure of paved streets, railways, and waterways to ensure smart intermodality. In addition, including information systems is crucial to provide real-time intelligence aimed at maximizing the performance of smart integration.

Banister (2011) argued that there is a clear necessity to obtain commitment and leadership from local governments to ensure low-carbon mobility in the future, while regulation and governance are critical in encouraging the transition.

Smart Mobility Implementation

It is crucial to establish a unified approach to the implementation of urban initiatives to achieve optimal results in practice. Decision-makers should be able to define the process and map out actions to implement strategies and solutions that accomplish predetermined goals. Sustainable transportation should be the main criterion for smart mobility, with a focus on promoting solutions from the variables outlined in Figure 13, in line with current research in the field.

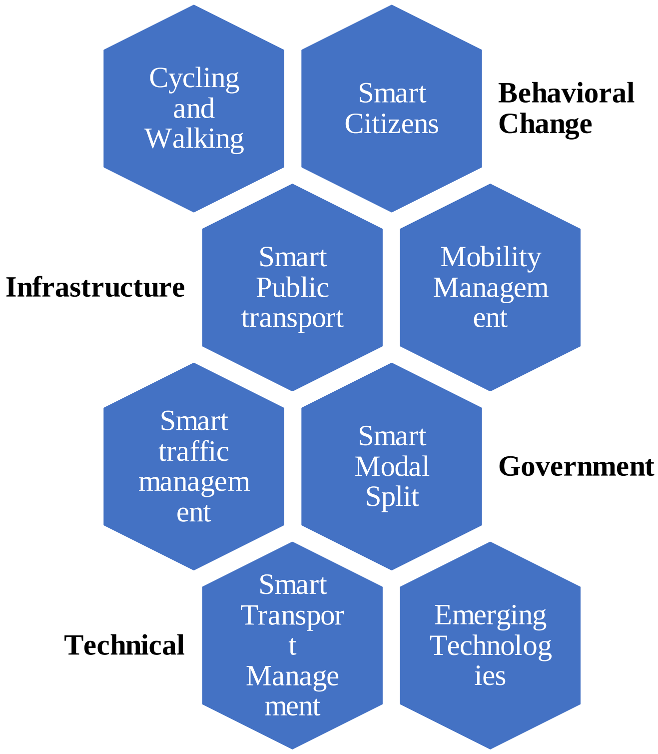

Figure 13 - Elements of a Smart Transportation Ecosystem: Key Aspects sand Strategies (Author's Design).

The efficiency of Smart Mobility implementation heavily relies on ex-ante evaluations. These evaluations enable proper assessments of various cost drivers, horizontal collaborations, technologies, and other factors. To define a Smart Mobility strategy, various research methodologies can be employed, including surveys, mathematical modeling, multicriteria analysis, and a full ecosystem approach to urban logistics. These methodologies aid decision-makers in making informed decisions by providing comprehensive insights into the feasibility, sustainability, and impact of implementing Smart Mobility solutions. Therefore, researchers should prioritize conducting rigorous ex-ante evaluations to ensure that Smart Mobility strategies align with urban transportation goals and objectives.

4.2. Barriers and benefits to the implementation of sustainable smart mobility with waterway concept and consequences

After conducting a thorough review of existing literature, it becomes evident that several barriers hinder the implementation of IWT, with some being more challenging to resolve than others. Nevertheless, various initiatives can be implemented to overcome these barriers and achieve a successful implementation of IWT. There are different factors that may affect the creation of a more sustainable transportation mode in an urban environment. Despite the numerous benefits of IWT, Boudhoum, Oztanriseven and Nachtmann (2021) pointed out that “a failure of the inland waterways would impact more people than anticipated during the conception of the transportation system” (Boudhoum, Oztanriseven, & Nachtmann, 2021, p. 3).

In terms of economic challenges, one primary problem that needs to be addressed to ensure the competitiveness of inland navigation is the cost-effective transport. This issue has been addressed by Hendrickx and Breemersch (2012), who noted that the rise of extreme weather periods could trigger a chain of impacts, leading to changes in navigation conditions for inland vessels, decreased cost advantage, and reduced reliability of IWT.

In addition, extreme weather events can create critical points that inland vessels must navigate, resulting in reduced load for the entire trip. Hendrickx and Breemersch (2012) emphasize that the main element of economic importance for each ship type (by CEMT class) is the maximum load the ship can carry under specific water level conditions. As shown in Table 2, weight reduction can increase the carrying capacity of an IWT vessel. This issue is of particular importance, as inland navigation relies on cost-effective transport to remain competitive.

Table 2 – Impact of Weight Reduction on Carrying Capacity, (Author´s Design). Source: (Hendrickx & Breemersch, 2012).

Weight reduction (tonnes)	**Carrying capacity increase (tonnes)**
0	0
10	2,5
20	5,0
30	7,5
40	10

Jan and Nepveu (2020), and Vilarinho, Liboni and Siegler (2019) have identified transshipment as a critical variable that must be handled carefully, as additional transshipment and related administrative work are challenging to overcome and can become a cost-effective issue .

Moreover, a lack of sufficient transshipment locations along the canals and space for loading and unloading is further complicating implementation, resulting in time and cost increases for various stakeholders (Montwiłł, 2019). In urban centers, commercial shops owners are interested in receiving goods profitably and sustainably, which makes just-in-time deliveries crucial for optimizing inventories and maintaining flexibility while reducing potential costs associated with the negative externalities of freight transport (Cardenas et al., 2017). Therefore, there is a lack of "door-to-door" thinking and awareness among IWT's operators and skills to provide "one-stop-shop" solutions (Hui Lisa & Leung YIP, 2016).

Technical issues have also been identified as an obstacle to the development of IWT. Early studies and current work primarily focus on the underdevelopment of waterways as a critical factor in explaining the underutilization of waterways in major cities. Vilarinho, Liboni and Siegler (2019) suggested that waterways have limitations when compared to roads and railways due mainly to constraints such as infrastructure weaknesses, investment, and institutional weaknesses resulting from governance inefficiencies.

Jan and Nepveu (2020), and Janjevic and Ndiaye (2014), have suggested that intermodal services play an important role, and it is a difficult variable to be mitigated due to their complexity, primarily because of the high investments required. According to Diziain, Taniguchi and Dablanc (2014), in some cases the characteristic of transported goods – high volume flow, last-mile deliveries are not compatible with intermodality, however in the last decade, an increasing number of projects including intermodal services for the "mile before last" have been set up. This trend suggests a growing interest in finding solutions to improve the efficiency and sustainability of urban logistics systems. Despite the challenges of implementing these services, the potential benefits of intermodal transport, such as reduced congestion, improved environmental performance, and increased reliability, make it a promising area of research and innovation in the field of urban logistics.

Inadequate fairway conditions can result in suboptimal load factors, which can lead to increased fuel consumption and emissions per tonne, as well as pose safety risks to navigation and decrease reliability. Moreover, an insufficient network of inland ports and suboptimal spatial planning of logistics and industrial sites may require pre- and end-haulage by trucks, resulting in higher external costs (EC, 2011).

The slow speed of inland navigation presents a significant barrier that may hinder its competitiveness compared to other modes of transport such as road, rail, or air transport. This is particularly relevant when quick delivery of goods is required, as inland navigation may not be able to meet such demand (Gołębiowski, 2016).

The European Commission (2011) has demonstrated that shippers and freight forwarders tend to favor a comprehensive 'door-to-door' solution, rather than engaging in complex intermodal transport chains involving multiple stakeholders and cargo consolidation. Additionally, the EC (2011) and Jan and Nepveu (2011) have identified challenges such as the willingness of shippers to entrust their goods to different carriers and the lack of cooperation and organization between carriers and shippers.

It has been reported that the "long lifetime of vessels and engines results in the slow implementation of innovations" (EC, 2011, p. 33). This limitation presents a challenge to "push and pull factors for ship-owners and/or IWT operators to provide a sense of urgency to improve the environmental performance of existing vessels" (EC, 2011, p. 33). Therefore, it is important for policy makers to consider implementing incentives to encourage the adoption of sustainable practices in the IWT's industry.

The EC (2011) have emphasized that the underdevelopment of RIS would cause several limitations in route planning, resulting in more fuel consumption and emissions, a lack of integration with logistics, and sub-optimal efficiency of transport (leading to higher costs).

According to Hui Lisa and Leung YIP (2016), a lack of skilled labor force has been reported, leading to higher labor costs, and a shortage of knowledge in transport logistics education, especially in IWT courses. Gołębiowski (2016) has also noted a shortage of specialized ships and a lack of loading and unloading facilities in river ports. These factors can negatively impact the efficiency and competitiveness of inland navigation.

Low clearances under bridges can pose a challenge to transporting stacked containers on vessels, as mentioned by Gołębiowski (2016).

Tarkowski and Puzdrakiewicz (2021) discussed the challenges associated with introducing large waterbus solutions in Gdansk, Poland, citing the unsuccessful efforts to reinvigorate tourist waterbuses. They attributed the project's failure primarily to the unavailability of modern ships, infrequent operating schedules, high operating expenses, and the impact of the COVID-19 pandemic. The pandemic have made passengers more skeptical about using public transportation, particularly due to concerns about crowded spaces and the risk of infection (Butler, Yigitcanlar, Paz, & Areed, 2022).

In response, the municipality modified the project's design to incorporate small self-sufficient vessels with either pure electric or hybrid diesel-electric propulsion.

When considering the effectiveness of utilizing waterways as a reliable solution in urban environments, climate conditions have been identified as a primary challenge in the literature. The past few decades have seen rapid and significant changes in global climate conditions, and combined with unplanned urban growth in many major cities, this can lead to collateral effects such as urban flooding in low-lying areas (Bedla & Halecki, 2021).

Adaptation to low water levels is a critical concern for the IWT sector, as it has been shown to be the most influential factor for the industry. Effective strategies must be developed to address this issue, as water scarcity and droughts can have severe impacts on various sectors, including agriculture, energy, and industry. According to Hendrickx and Breemersch (2012), while high water levels pose mainly short-term problems for navigation, low water conditions can involve problems for the passage of larger freight ships for longer periods. Additionally, the movement of vessels over water generates pressure differences that can create waves, which, depending on their intensity, can cause shoreline changes (Mcconchie, 2003). Therefore, wave wash is an essential factor to consider when imposing ship speed restrictions and selecting a speed for any shallow and narrow waterway. Strategies must be developed to minimize the potential damage caused by wave wash, which can lead to shoreline erosion and other environmental impacts (Saha, Abdullah, & Ashrafuzzaman, 2017).

According to Wang, Geng and Rodríguez-Casallas (2021), higher climate change risk perception can lead to climate change inaction and negatively affect sustainable initiatives aimed at improving the quality of life. Inaction related to incorrect risk perception of the global community towards climate change has caused natural disasters that have affected nations worldwide.

Porto, Alencar and Theodoro (2019) have focused on the challenges of rehabilitating polluted rivers in major cities due to increasing urbanization and population density. They have noted that over time, it has become more challenging to prevent and rehabilitate polluted rivers in urban areas due to mass migration to big cities resulting in densely populated urban areas.

In terms of governance issues, previous research has identified various stakeholders in IWT. Cooperation among these stakeholders is extremely critical to ensure the effective implementation of the correct strategy for IWT. Environmental agencies, cargo shippers/carriers, port authorities/terminal owners, departments of parks and tourism, utility companies, and local communities (Boudhoum, Oztanriseven, & Nachtmann, 2021), should act together to overcome the main barriers. Given its complexity, there is a clear need for a regulatory authority that can create rules to promote and incentivize synergies between all actors. The regulatory authority would be responsible for overseeing and enforcing regulations related to navigation on inland waterways. Regulation should require stakeholders, such as retailers located in urban centers, to address the lack of interest in urban distribution centers (UDCs), as argue that the limited space in the cities' centers, may make UDC operation economically unviable (De Oliveira, et al., 2019). Nonetheless, the same study found that who assess UFT negatively also strongly support city logistics measures and evaluate UDC positively as a city logistics measure. Also, the lack of confidence among stakeholders (in this case, carriers and retailers) makes it necessary to inspect all goods delivered in commercial establishments.

Social challenges have also been identified in the literature. One of the key social challenges is the lack of access and mobility, which hinders individuals from breaking out of the cycle of social exclusion (Tobias, Ramos, & Rodrigues, 2019). Transport plays a crucial role in providing access to various activities and services, and its absence or limitations can impede individuals' ability to meet their needs and participate fully in society. It is essential to ensure that people can access key services in a timely, affordable, and convenient manner.

The social dimension of transport is supported by three fundamental values and principles: equity, accessibility, and mobility (Tobias, Ramos, & Rodrigues, 2019). Equity ensures fair distribution of transport resources and opportunities, promoting equal access for disadvantaged groups. Accessibility focuses on providing convenient transportation options to individuals regardless of location or circumstances. An intermodal network integrating urban, and IWT can improve accessibility to remote areas, promoting social inclusion (Tobias, Ramos, & Rodrigues, 2019). Mobility facilitates efficient movement, enabling people to reach destinations and participate in social and economic activities.

However, the transition to more sustainable modes of transportation requires significant investments in infrastructure and convincing local governments to provide the necessary funding. Obtaining these funds can be challenging, as several standards must be obeyed to make them available (Vilarinho, Liboni, & Siegler, 2019).

Table 3 provides an overview of the main barriers identified previously in the literature.

Table 3 - Challenges for implementing IWT (Author's Design)

Economic	Technical	Environmental	Governance	Social
City Logisitics	Transshipment Locations	Water Conditions	Regulatory constraints	Social Inclusion
Integration on urban transportation	Intermodal Implementation	Pollution	Flood Protection	Equity on accesing information
Logistical Costs	Low Speed	Climate Change	Policies, local regulations	Fair Prices
Leadtime	Inland Traffic Mangement	Energy Intensive Transport	Government Incentives	
High Initial Invesment	Logistics Information systems	Fauna	Public and Private sectors cooperation	
Transshipment Costs	Infrastructure	Flood Protection		
	Waterways Maintenance	Rehabilition of polluted Rivers		
	Skilled Labour Force			
	Electrical Equipments to support logistic			
	River Fleet			
	Solar Power Charging			

4.3. Benefits through implementation of a sustainable transport mode with a waterway for passengers and small packages

In recent years, a growing number of studies have suggested that alternatives must be explored in order to promote the transition of existing transportation systems in large cities. Among these alternatives, the better utilization of inland waterways has been highlighted, especially in cities surrounded by rivers. The benefits of waterway urban development projects have been widely studied, with outcomes ranging from well-governed, efficient, and safe transport modes to the creation of high-quality jobs for a skilled workforce adhering to high environmental standards.

Intermodal transport supply chain involves several authors, such as “shippers, road haulers, terminal operators, barge operators, waterway operators and consignees” (Caris, Limbourg, Macharis, van Lier, & Cools, 2014, p. 2). In this context, (Diziain, Taniguchi, & Dablanc, 2014, p. 2), define intermodal as “the use of at least two different modes of transport integrated in a door-to-door transport chain”. Although intermodal services have traditionally been challenging to implement for last-mile deliveries due to their focus on high-volume flows, a growing number of recent projects have focused on intermodal services for the "mile before last" (Diziain, Taniguchi, & Dablanc, 2014). The main benefits found in literature are identified next.

Environmental Benefits - Protect the Environment

The demand for mobility of both people and goods requires energy, and the amount of energy consumed varies greatly between different transport modes. As the consumption of fossil fuels has a significant impact on the environment, sustainable development aims to fulfill the demand for mobility with transportation systems that are clean and low energy-consuming.

The development of inland waterways has the potential to “redevelop brownfield sites, restore systems, maximize public and private reclamation resources, improve resilience, and decrease the carbon footprint of cities” (Affairs, 2017, p. 9). According to Tobias, Ramos and Rodrigues (2019), investments in the urban regeneration of waterfronts can be seen as experiments that test the creativity and resilience of cities to change under global pressures and their ability to transform themselves by restoring identity.

The literature recognizes that existing waterway systems offer a large and untapped potential “to manage increasing transport flows and decrease congestion of roads and railways” (Lybeck, 2019, p. 19). The European Commission also emphasizes the important role that waterways can play, by promoting its utilization, sustainable transportation systems can be established to reduce the carbon footprint of cities and improve their resilience to future challenges (EC, 2011).

As per the European Commission (EC), there is a target to “shift 30% of road freight over 300 km to other modes of transportation, such as rail or waterborne transport, by 2030, and more than 50% by 2050” (EC, 2011, p. 6), with the help of efficient and eco-friendly freight corridors.

Prior research supports the idea that a shift to IWT could reduce the number of freight vehicles needed to meet demand, and would also relieve pressure on road infrastructure, which is currently facing deteriorating conditions (Jan & Nepveu, 2020). In addition, research suggests that inland waterways is the most economical, and, emit the least amount of CO_2 and have a significant, though modest, performance level compared to other transport sectors within the European transport system (Grzelakowski, 2019), as reported in Table 4.

Table 4 - Comparing Transportation Options in terms of Efficiency, Economy and Environmentally Friendly aspects (Gołębiowski, 2016).

Aspect	Inland Water Transport	Road Transport	Rail Transport
Efficiency (tonne-km/L)	36.2	2.5	6.8
Economy (PLN/tonne-km)	0.029	0.045	0.052
Environmentally Friendly	Low emissions, low noise, low accidents	High emissions, high noise, high accidents	Moderate emissions, low noise, low accidents

In terms of reducing CO_2 emissions, it has been observed that the use of IWT is still more environmentally friendly than road transport. For instance, according to a study by the European Commission (EC), the difference in CO_2 emissions between an intermodal chain that includes waterway transport and one that only relies on road transport is approximately 50% in favor of the former in a door-to-door container transport between Rotterdam and Duisburg.

Based on the literature review, Janjevic and Ndiaye (2014, p. 2) described “inland waterways as the most energy and carbon-efficient mode as a ship uses 1 to 2 times less fuel than a train and 2 to 5 times less fuel than a truck and can be economically competitive". Additionally, the authors suggest that inland waterways offer significant advantages for urban logistics, such as reduced congestion and emissions in cities, cost savings, and increased efficiency in freight transport. However, they also note that the development of inland waterways for urban logistics requires the involvement of local public authorities to ensure efficient organization and management of transport and handling facilities.

According to Mihic, Golušin and Mihajlovic (2011), IWT is considered ecologically most acceptable for several reasons. Above all, to carry out IWT, natural waterways (rivers, canals, seas, and oceans) are used, with the use of some waterways whose purpose is to shorten the distance during a certain trip. The author argued that while conducting IWT, many modern high capacities mean of transport are used and they allow heavy-load transport nowadays.

"Apart from all of this, IWT can use ecologically acceptable fuels, especially biodiesel, and its blends" (Mihic, Golušin, & Mihajlovic, 2011, p. 2). Besides, enhancing existent modal transportation chains, by including modals that can provide better usage of environmentally sustainable solutions instead of fossil-based modals, could potentiate even more the efficiency of those alternative transports. In that sense, lately, has been seen newly built or retrofitted ferries equipped with pure electric or diesel–electric hybrid propulsion has been placed into operation (Tarkowski & Puzdrakiewicz, 2021)

The author Mihic, Golušin and Mihajlovic (2011, p.2), have considered that if IWT is conducted properly, it has the capability to "do not jeopardize the environment that much" as the other methods of transit, mainly because IWT does not create waste, not that much pollution and keeps the landscape with original characteristics more appreciable for residents and visitors.

According to Tobias, Ramos and Rodrigues (2019), IWT can contribute significantly to sustainable urban mobility, particularly in terms of reducing greenhouse gas emissions. The authors argued that IWT can be an alternative to road and rail transport, particularly for low-density and bulky goods. Additionally, inland waterways can be integrated into urban mobility plans as an alternative for passenger transport, particularly for tourism and leisure activities. Overall, IWT has the potential to be an integral part of sustainable urban mobility plans in many countries.

The author Grzelakowski (2019) analyzed capacity of different modes of transportation, it was considered that a vessel with a capacity of 2000 tons would be the equivalent of 50 train carriages with a capacity of 40 tons each, or 80 trucks with a capacity of 25 tons each.

According to Bedla and Halecki (2021), revitalizing waterway channels can bring numerous benefits, such as improving water quality, reducing the risk of flooding with infrastructure costs, and increasing space for the community and wildlife.

Boudhoum, Oztanriseven and Nachtmann (2021) conducted a systemic analysis of the benefits arising from the use of IWT, where flood protection is considered one of the main pillars. Reservoirs provide flood protection and water supply benefits by using flood control pool storages. Additionally, dams and reservoirs are used to regulate river levels and downstream flooding by holding excess water temporarily and releasing it later. The authors present ten groups of benefits that can help demonstrate the benefits of IWT: navigation, recreation, flood protection, hydropower generation, irrigation, water supply, sewage assimilation, strong property values, congestion reduction, and positive environmental impacts (Boudhoum, Oztanriseven, & Nachtmann, 2021). These benefits are summarized in Figure 14.

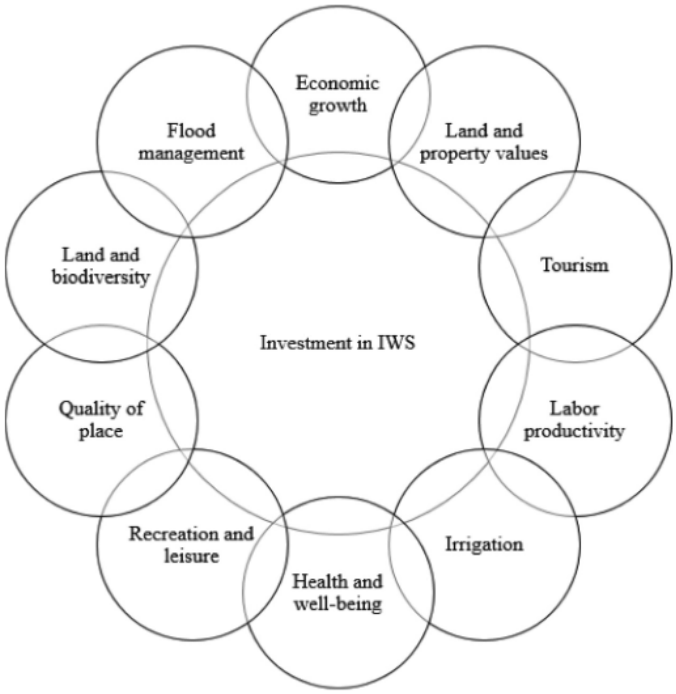

Figure 14 - Exploring the Benefits of Inland Waterway Transport (Boudhoum, Oztanriseven, & Nachtmann, 2021).

Moreover, Boudhoum, Oztanriseven and Nachtmann (2021) mentioned that the energy produced by various hydropower plants located along the rivers, are a result of the revitalization process implement for IWT.

The concept of Green Logistics and the search for more sustainable transportation of goods have given rise to an increased interest in IWT in recent years (Felea, Yankov, Mărunţelu, & Vasiliu, 2010). Inland waterways are seen as a means of contributing to economic development through private investments, property tax benefits, increased consumer spending, new job creation, and increased visibility and competitiveness for cities (Affairs, 2017, p. 8).

Krčum, Plazibat and Mrčelić (2015) state that the cost of logistics in inland waterways is 17% of the cost of road transport and 50% of rail transport. Additionally, transport by rivers is seven times more sustainable than other forms of transport (Felea, Yankov, Mărunţelu, & Vasiliu, 2010). Similarly, Boudhoum, Oztanriseven and Nachtmann (2021), drawing on studies from different authors, assert that IWT is considered the cheapest mode of transportation and can help to avoid millions of truck trips on roads every year.

To better analyze the competitiveness of each transport mode, it is important to evaluate the inherent external costs associated with them. An external cost arises when "the social or economic activities of one group have an impact on another group, and the impact is not fully accounted for or compensated by the first group" (Caris, Limbourg, Macharis, van Lier, & Cools, 2014, p. 7). For example, the calculated external costs in different areas can be observed in Table 5, which compares the external costs based on factors such as fuel efficiency, operational costs, and environmental impact of various forms of transport. Inland waterways transportation has lower environmental impact compared to rail and road transport.

Table 5 - Costs by mode of transport (Gołębiowski, 2016).

Mode of Transport	**Air Pollution Costs**	**Noise Costs**	**Accident Costs**	**External Cost 1000 tonne-km**
Inland waterway transport	Baseline (1)	Baseline (1)	Baseline (1)	< 5 euro
Rail transport	7 times more	70 times more	178 times more	24.12 euro
Road transport	no data	87 times more	12 times more	12.35 euro

In evaluating the competitiveness of different transport modes, it is crucial to take into account the inherent external costs associated with them. These external costs arise when the social or economic activities of one group have an impact on another group, and the impact is not fully accounted for or compensated by the first group. In this context, it is important to note that external costs related to transshipments in terminals should also be included since they're an integral part of the intermodal supply chain process. This idea is discussed in detail in a study by (Caris, Limbourg, Macharis, van Lier, & Cools, 2014).

Social sustainability - Improve public health and recreation

Boudhoum, Oztanriseven, and Nachtmann (2021) have shown that revitalizing urban waterways can have various positive impacts, such as creating open spaces, improving public health, and promoting recreational activities. Furthermore, they have argued that IWT can improve the quality of life in urban areas by reducing pollutant gas emissions, traffic congestion, and road accidents associated with land-based transportation.

Moreover, inland waterways can "offer a range of recreational opportunities, such as fishing, boating, swimming, cycling, and hiking", contributing to the well-being and health of urban residents (Boudhoum, Oztanriseven, & Nachtmann, 2021, p. 2). For instance, the McClellan-Kerr Arkansas Navigation System has created important lakes used for recreational purposes, including picnicking and camping (Boudhoum, Oztanriseven, & Nachtmann, 2021).

In addition, the implementation of waterways can promote sustainable transport and active mobility, thereby improving the public health and recreation of cities (Tarkowski & Puzdrakiewicz, 2021).

According to Janjevic and Ndiaye (2014), inland waterways are the only land infrastructure that offers free capacity and is not subject to congestion problems, making it an attractive option for city logistics.

Previous research showed that redeveloping urban waterways "can create open spaces, improve public health, and promote recreation, such as sporting events and active lifestyles" (Affairs, 2017).

According to Affairs (2017, p. 9), "redeveloped urban waterways can create open spaces, improve public health, and promote recreational activities". Furthermore, implementing IWT can reduce pollutant gas emissions, road accidents, and traffic congestion, all of which are detrimental side effects of traditional urban transportation (Boudhoum, Oztanriseven, & Nachtmann, 2021).

Additionally, creating barriers to road access to city centers could shift transportation infrastructure to recreational activities and promote low-carbon energy means of transportation such as walking or cycling, resulting in improved public health and recreational activities (Tarkowski & Puzdrakiewicz, 2021). Finally, (Janjevic & Ndiaye, 2014) emphasize that inland waterways are not subject to congestion problems, making them an excellent option for city logistics.

Therefore, it can be concluded that revitalizing urban waterways and promoting IWT can have significant positive impacts on public health, recreation, and city logistics, thereby contributing to the sustainable development of cities.

Promote equity and social inclusion

IWT are key enabler to "promote inclusion through neighborhood reinvestment, equitable access, and social interaction and cohesion" (Affairs, 2017, p. 9).

Distance and lack of terrestrial access to large cities often lead to the creation of underdeveloped and isolated regions, contributing to a low index of human development in many countries. According to Tobias, Ramos and Rodrigues (2019), IWT is an essential means to promote social and economic inclusion of island populations. River channels can serve as a unique way to create bridges between isolated areas. In some situations, regions surrounded by river channels are the only possible connection route to the cities, either for people or goods transportation. This can lead to the inclusion of unfavored populations in the metropolis, giving them access to jobs, schools, and other opportunities, as well as making these regions accessible for tourism from the mainland. This could be used as complementary, integrated, and, therefore, a factor of social inclusion and promotion of sustainable mobility.

The integration of IWT into the urban transport system can be a complementary and sustainable solution for promoting social inclusion and sustainable mobility. As highlighted by De Oliveira et al. (2019), this could also contribute to protecting historic city centers from the negative impacts of traffic, especially in areas with narrow streets. Furthermore, Caris, Limbourg, Macharis, van Lier and Cools (2014, p. 9) underscore the importance of analyzing the "link between transport geography and logistics" activities to enhance the competitiveness of IWT. Neglecting this connection could lead to economically unsustainable solutions when compared to traditional transportation modes such as railways or roadways.

Corporate Governance

To reduce the carbon footprint of cities, it is necessary to involve product manufacturers in the development of strategies that take into account the entire life cycle of products. This includes not only the production and sourcing of materials but also the transportation of goods. Manufacturers must take responsibility for the environmental impact of their products and ensure that transportation is conducted using environmentally sustainable solutions.

4.4. The Urban Mobility in São Paulo

4.4.1. Background

Transportation in Brazil

The historical context has had a significant impact on the evolution of the transport system in Brazil. The country's railway infrastructure was first established in 1854 by Emperor Dom Pedro II for the purpose of transporting ore between Rio de Janeiro and Petrópolis. Throughout the 19th century, additional railways were built to transport cargo, such as the coffee line between Jundiaí and Porto do Santos. These developments were further expanded in the 20th century, resulting in a railway network that spans approximately 30,000 kilometers in total length (Estadão, 2022).

In 1930, the government of Getúlio Vargas made the decision to nationalize the existing railways, which were previously controlled by foreign capital. This led to disinvestment and the creation of precarious conditions within the railway system. The scenario of investment in the rail network suffered from strong pressure to expand Brazilian roadways, the development of the automobile industry, and the location of main industrial centers near large urban areas. These variables all contributed to the decline of the railway system and the exponential growth and predominance of road transportation.

However, after decades of total responsibility of the railways under the aegis of the State, the Brazilian Federal Government signed a document in 2021 that foresees the de-statization of railway lines and their control by third parties, as was the case in the late 19th and early 20th centuries. This move is expected to generate a new wave of investment and greater representativeness of the rail system in the national panorama.

On the other hand, while IWT historically presented itself as a practical mode of transportation for moving loads and people through river channels, initially using trunks and later small boats, it has never been a primary option for users. Despite having more than 4,000 kilometers of navigable Atlantic coastline, the lack of investment by state and federal governments has limited the potential of this transportation mode (Estadão, 2022).

According to a study by the Logistics Infrastructure Platform unit from Fundação Dom Cabral, as reported by Cabral (2023), two scenarios for the Brazilian transportation matrix are currently being drawn: one with and one without ore transportation. Disregarding ore transportation, 77.3% of Brazilian production is transported by roadways, 12.9% by waterways, 6.4% by railways, and 1.0% by pipelines (Estadão, 2022). However, when ore transportation is taken into account, the following distribution emerges: 61.4% of Brazilian production is transported by roadways, 13.2% by waterways, 23.7% by railways, and 1.7% by pipelines. Fundação Dom Cabral projects changes in the transportation matrix by 2035.

Strategic investments made by federal and state authorities are expected to significantly influence and promote the use of alternative transportation modes, foreseeing a reduction in dependence on the predominant roadway matrix and replacement mainly by railways and waterways, with an eye toward environmental sustainability. Thus, Fundação Dom Cabral foresees the following distribution scenario until 2035: without ore transportation, 69.1% of Brazilian production is transported by roadways, 12.9% by waterways, 17.0% by railways, and 1.0% by pipelines. However, when ore cargo is considered, the transportation matrix could have the following configuration: 54.0% of Brazilian production is transported by roadways, 13.6% by waterways, 30.3% by railways, and 2.1% by pipelines (Cabral, 2023).

Current situation and main barriers

Roadway transportation is the predominant mode of transportation in Brazil, accounting for over 65% of cargo and passenger transport in the country. This is due to its ease of access and use, which leads to an overlap with other modes of transportation.

Despite the COVID-19 pandemic's influence, the Brazilian road transport fleet has grown more than 50% in the last decade (Estadão, 2022), like presented in Figure 15.

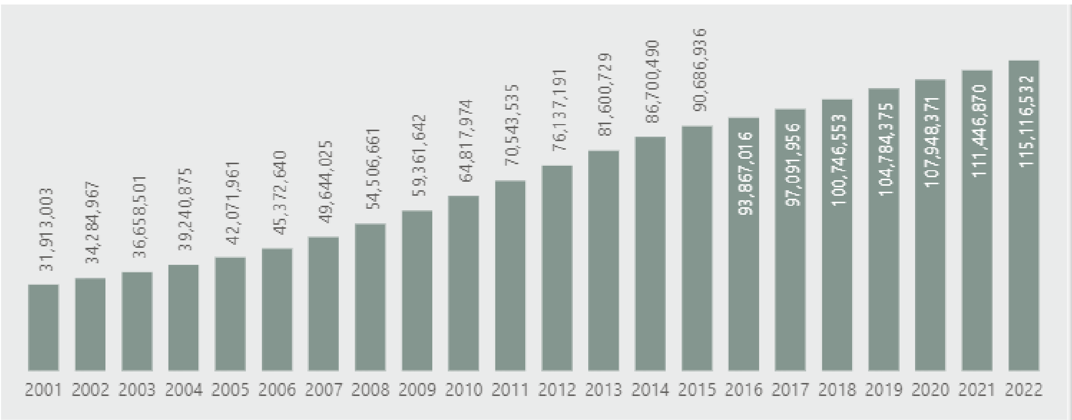

Figure 15 - Analyzing the Changes in a Vehicle Fleet from 2001 to 2022 (Transporte C. N., 2023).

On the other hand, IWT has a small share of responsibility for transport among the most diverse modes, with approximately 14% of the country's goods movements, of which only 0.7% are for cargo transport. Maritime transport represents 9.4% of this percentage, responsible for a considerable amount of the country's trade, and passenger transport accounts for 3% (Estadão, 2022). Although Brazil has an extensive hydrographic network, with 63 thousand km of rivers, only about 30.9% of this network is used commercially by inland navigation, and only 5% of the cargo movement in the country is carried out by this mode of transport (Transporte C. N., 2019).

Regarding inland navigation in the metropolitan region of São Paulo, it is currently almost non-existent, except for small vessels used by the municipality to support dredging and cleaning processes (which will be addressed later). In 2022, São Paulo was responsible for 28.1% of all vehicles licensed in the country, with over 30 million vehicles registered within the state itself. Since São Paulo is the country's main hub and center of commerce, it is common for most of the vehicles produced to travel on the busy streets of the city (Transporte C. N., 2023).

Use of the waterway network as an alternative to roadways

Unfortunately, due to the lack of attention to the development of inland navigation in the metropolitan region of SP, the potential of city’s river channels as an alternative mode of transportation has not been fully explored. The lack of investments in infrastructure, such as ports, terminals, and waterways, has made it difficult for this mode to compete with the dominant road transport system, leading to an overburdening of the road network, which results in traffic congestion, air pollution, and accidents.

However, in recent years, some initiatives have emerged to promote the use of waterways in the region, such as the creation of the Tietê-Paraná Waterway, which connects the metropolitan region of SP to the south of the country, as well as the construction of the São Lourenço Terminal, which enables the transport of cargo by barge to the port of Santos, reducing the dependence on road transport.

Despite these initiatives, much remains to be done to increase the competitiveness of inland navigation and its integration into the urban mobility system of the metropolitan region of SP, such as the improvement of the navigability of rivers, the construction of new terminals, the integration of waterway transport with other modes of transport, and the development of regulations and incentives to promote the use of this mode.

Metropolitan waterway ring

In light of the deteriorating state of the rivers surrounding the city of SP, the state government commissioned a study to develop a plan to reintegrate the urban waterways into the city's daily life. The resulting plan was presented in 2011 and aimed to restore the canals by implementing a series of measures. The goal was to reverse the damage to the ecosystem and reintroduce the rivers into the city's routines. The plan recognized the importance of territorial strategic planning, basic sanitation care, and green space protection. By undertaking these efforts, the government hoped to reduce the high cost of externalities resulting from the migration to urban centers and the movement of people and goods Source: (metropolefluvial.fau.usp.br, 2011).

The Metropolitan Waterway Ring (Hidroanel Metropolitano de São Paulo) plan, aims to recover the urban waters by reintegrating the city's canals into daily life, improve urban mobility by integrating the main rivers into the city transport network, foster inland navigation dynamics and attract external, federal, and state investments (Metropolitan Waterway Ring of São Paulo, 2011)

“The Metropolitan Waterway Ring of SP is a network of navigable canals composed of the rivers Tietê and Pinheiros, the reservoirs Billings and Taiaçupeba, and an artificial canal connecting these reservoirs, adding up to 170km of urban waterways” (Metropolitan Waterway Ring of São Paulo, 2011, p. 1).

The Metropolitan Waterway Ring not only aimed to improve navigation conditions in the city but also to address environmental concerns such as reducing pollutant gas emissions, car traffic, and road accidents. By revitalizing the rivers, the government also hoped to improve the quality of life for residents by reducing exposure to health risks caused by pollution. The plan included a set of steps and projects scheduled to be implemented until 2040, which involved creating infrastructure for navigability and identifying the types of urban cargo vessels suitable for transporting public and commercial cargo (metropolefluvial.fau.usp.br, 2011).

4.4.2 The city of São Paulo

São Paulo, the capital of the state of SP, is the most populous city in Brazil and one of the most populous in the world, with an estimated population of over 12 million inhabitants in the metropolitan area and responsible for approximately 10% of the Brazil´s Gross Domestic Product (GDP) in 2020.

São Paulo and the relationship with City´s Rivers

The origin of the city dates to the creation of the "Vila de São Paulo de Piratininga", in 1532, by the Jesuits and Indigenous who coexisted there. Thus, the Village of São Paulo de Piratininga was in a strategic and safe position between the flat spot that existed between the Tamanduateí and Anhangabaú Rivers, the former flowing into the Anhembi River, later known as Tietê River (Borges, 2023).

The Tietê River, which is approximately 1,100 kilometers long and rises in the Serra do Mar, at an altitude of 840m, and unlike most rivers in Brazil, does not flow into the Atlantic Ocean, but rather towards the country's continent. This characteristic made it a route for the Bandeirantes, a group of Paulista men who explored the interior lands of Brazil between the 16^{th} and 17^{th} centuries, leaving the town of São Paulo towards Mato Grosso in search for riches and founding cities (Borges, 2023).

In the middle of the 19^{th} century, with the expansion of coffee throughout the countryside of the state, investments were attracted to SP, and in 1867, the first railway "São Paulo Railway" was inaugurated, being the only railway connecting the city to the sea, to transport the coffee production and using the valley of Tamanduateí River, which at the time was the commercial center of the city (Pinheiros, 2023).

With the railway the distances ended up "decreasing", but the rivers that were the reason for the city's existence ended up becoming obstacles to the city's growth, bridges and viaducts were built to connect the neighborhoods, as well as the channeling of the tributaries (which were many) of the Tamanduateí and Pinheiros Rivers (Ferraz, Abreu, & Scarpelini, 2023).

Thus, in 1878, the Companhia de Águas e Esgoto was created, and it was responsible for taking piped water to the coffee-growing elite and urban workers who were settling in the city. The sewage was poured into the rivers, causing a sanitary problem, which led to diseases and epidemics (Ferraz, Abreu, & Scarpelini, 2023).

To solve the sanitary problem, the Tamanduateí and Anhangabaú rivers' floodplains were filled up, the areas were sold into lots, and parks were built, following the example of the great European cities. The Parque do Anhangabaú and Parque Dom

Pedro Segundo were created, after rivers canalization (Ferraz, Abreu, & Scarpelini, 2023) (Mancuso, 2023).

Thus, as SP was growing due to the increase in its population, two other rivers became obstacles to the city's growth. They would be the Rivers Tietê and Pinheiros, which also flows into the Tietê River (Ferraz, Abreu, & Scarpelini, 2023).

In the early twentieth century, the landscape around the Tietê River and Pinheiros River began to change due to the new waves of immigrants, mainly Italians, and Japanese, who came to settle along the banks of the river. From the 1920s onwards, the capital of SP began to face structural problems such as urban disorder, traffic congestion, difficulty in parking vehicles, irregular housing, and periodic flooding of the Tietê and Pinheiros Rivers (Ferraz, Abreu, & Scarpelini, 2023).

It should be noted that the Rivers Tietê and Pinheiros are plain rivers, and their characteristics are that they form many meanders, and in times of flooding the flooded area was very large.

Thus, pursuing a solution to the problems of the time and through a mercantilist vision, due to capitalism and especially the automobile industry being spread throughout the world, Francisco Prestes Maia and João Florence Ulhôa Cintra created the Plan of Concentric Radial Avenues mirrored in the great European metropolises, with the main objective of expanding the Center and decentralizing trade, while the radial avenues established traffic flow that linked the neighborhoods to the central region (Oda, 2023), described in Figure 16. The two main structuring elements of the Avenues plan were the transfer of the railways to the marginal roads and the parkways circuit in which the most important avenue was the Tietê (Custódio, 2004).

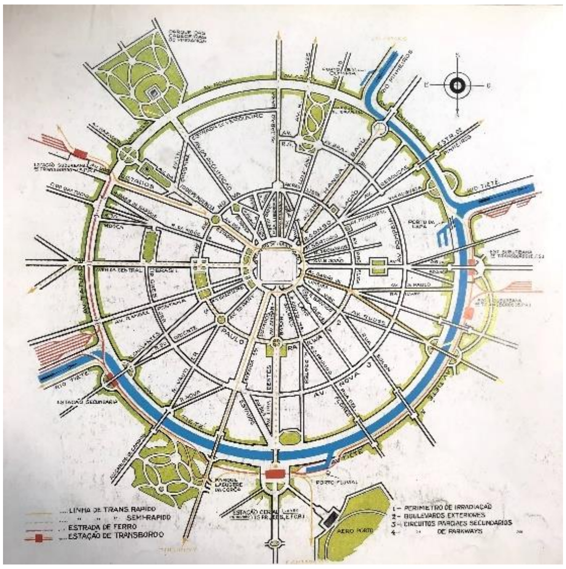

Figure 16 - Theoretical diagram of the São Paulo Avenue Plan (Oda, 2023)

By reading the plan, anyone can notice the total mercantilist nature and the lack of concern with sanitation, there was the intention to the urbanization of the riverside areas to take the railway tracks to the banks of the Tietê River, as well as the implementation of a parkway circuit formed by the Tietê and Pinheiros riversides, interconnecting the city parks, the canalization of the Tietê River - to make use of it for road, railway, navigation, and leisure circulation -, the destination of its margins on one side for the railroads and on the other for residences and pavements and also for industrial areas were based on canalization of its main rivers - Pinheiros and Tamanduateí (Custódio, 2004).

From 1938 to 1945, Prestes Maia put the Avenues Plan into practice when he was mayor of the City of SP. Most of the avenues were built but the railways were no longer transferred to the riverbanks, but his successors built the riverside roads of the Tietê and Pinheiros in the 1960s (Custódio, 2004)

In parallel to the Avenues Plan, as of 1940, the Pinheiros River was straightened to stop flooding, channel the waters and direct them to the Billings Dam. Thus, with the initial goal of generating energy, Light Company expropriated 20 million square meters for the works, which included the execution of dams, pumping stations, and the reversion of Pinheiros River water courses which would receive the waters of Tietê River, of which it was a tributary, to feed the Henry Borden Plant on the slopes of Serra do Mar.

Pinheiros and Tiete Rivers: The main rivers of the Metropolitan Region of São Paulo (MRSP), together with the Billings and Taiaçupeba reservoirs, form a 170 km navigable circle around 15 municipalities of the Metropolitan Region of São Paulo, described in Figure 17 (metropolefluvial.fau.usp.br, 2011).

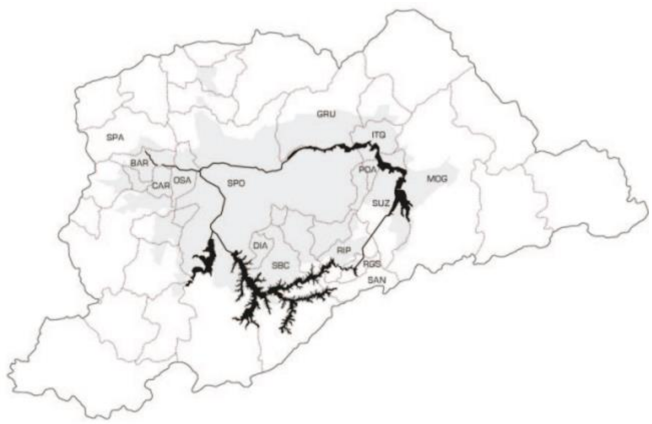

Figure 17 - The Course of Rivers in São Paulo (metropolefluvial.fau.usp.br, 2011).

Until the mid-1970s, the city's main rivers were used for commercial and leisure practices, citizens lived around the rivers for various purposes, whether for commercial use or leisure activities such as swimming, fishing, and recreation (Pinheiros, 2023).

The rivers, once appreciated and overused by the residents, no longer fit in the desires of the Paulistas, which mirrored in the references of the great European capitals started to consider the rivers as obstacles to the growth of the city, the trails of the rivers would then serve as a reference for the growth of a new reality of the city (Pinheiros, 2023).

Beginning of the 20^{th} century, the two main rivers that served the city began their transformation process, through the straightening of their natural course and the sinking of their innumerable tributaries (Pinheiros, 2023).

Several factors have contributed to the degradation of the Pinheiros and Tietê Rivers, however, the generation of electrical energy at the beginning of the 20^{th} century is considered one of the main drivers of it. The high demand for electric power, together with the operationality of the riverbeds, led to the alteration and rectification of the original characteristics of their courses, through the elimination of natural curves (they simply disappeared, creating a straight course) and the inversion of the course of the free waters in the direction of the hydroelectric plants of Billings and Cubatão. Thus, the progress of the city took a heavy toll on the condition of the rivers in practically all their length, exposing their waters to decades of diffuse discharges of waste from industry and communities, which directly connected sanitary drains into the rivers' streams, which in turn were discharged into the once-crystalline waters of the Tiete and Pinheiros Rivers. In the Pinheiros River alone, more than 500,000 households dumped waste directly into the river (Pinheiros, 2023).

Urbanization of the city was so fast and violent that the banks and adjacent areas of the rivers were stages for the growth of housing complexes in a disorderly manner. The lack of strategic planning for the construction of the new city led to the non-creation of the basic structure to support the minimum sanitary conditions for the protection of the inhabitants and their rivers, exposing the latter to constant discharges of sanitary residues and diffuse loads, essentially the result of the urbanization process. Accelerated alteration of the natural course of rivers, combined with the birth of residential areas previously occupied by riverbeds, have caused their waters to become more volatile to constant flooding. Unfortunately, the rivers have paid dearly for the territorial disorder, the decades of continuous exposure to untreated water and urban waste have destroyed the city's rivers. In 1989, the rivers reached such a high level of pollution, that the state government prohibited the sending of its waters to the Billings dam, reversing its course to the hydroelectric plant (only reversed in case of emergencies, e.g. flood prevention) (Pinheiros, 2023).

Paulo P. d. (1976), have established a scale for classifying the river water conditions as follows:

> *Class 1 - waters intended for domestic supply, without prior treatment or with simple disinfection.*
> *Class 2 - waters intended for domestic supply, after conventional treatment, for irrigation of vegetables or fruit plants and for primary contact recreation (swimming, water skiing and diving).*
> *Class 3 - waters destined for domestic supply, after conventional treatment, for the preservation of fish in general and other elements of the fauna and flora.*
> *Class 4 - waters destined for domestic supply, after advanced treatment, or for navigation, landscape harmony, industrial supply, irrigation and less demanding uses,* (Paulo P. d., 2023, p. 3).

The rivers of the City of São Paulo are Class 4, considering that the waters that flow throughout the urban perimeter are used for restricted use.

As described, due to the high degree of degradation of the waters surrounding the metropolitan region, in the last three decades we have witnessed several initiatives aimed at recovering the urban ecosystem and healthy integration in the services provided by the waters to the main city of the country (leisure, water supply, transportation, landscape, etc.). With this, several programs, mostly from public-private partnerships, involving several entities (Federal Government, State Government, Ministry of Environment, State Secretariat of Environment, Universities, non-governmental organizations, investment banks, and private and public sanitation companies) were launched, such as Projeto de Despoluição do Tietê; Programa Novo Rio Pinheiros; Projeto POMAR. These programs aimed to rescue the urban rivers and return them to the city's ecosystem, guarantee the city's survival, and create engagement with the citizen (Caldana, 2023).

Complex plans with multidisciplinary scope, which included the implementation of basic sanitary system connection of industry and low-income housing complexes, treatment of sanitary waste in treatment plants located at strategic points, creation of bicycle paths, and construction of spaces around riverbanks to encourage leisure activities (Caldana, 2023).

In 2014, due to the exhaustion of the urban mobility strategical planning model and the respective threat to the life quality of residents, the State Government presented the Strategic Master Plan (SMP) of the City of São Paulo, with the clear intention of reinforcing the need to accelerate the ongoing processes and create effective actions to conclude the de-pollution process of the waterways (and surrounding areas) (Paulo P. d., 2014).

The focus of the initiatives stated on SMP was finalizing 2022 with a clean Pinheiros River, certainly not intended to make its waters drinkable, nor available for swimming, but to make it available at least for irrigation purposes. In the same way, although in the first phase, its navigability will be limited to tourism and leisure purposes, there is an expressed need (according to the SMP), to implement a waterway matrix capable of integrating with conventional public transportation and support basic city services, to decongest the hyper congested marginal roads of the city (Paulo P. d., 2014).

Thus, at the end of the year 2022, although much work still needs to be done, great milestones have been reached, showing that despite of complexity it is possible to rescue the rivers. Two indicators were used to monitor the effectiveness of the actions, a) biochemical oxygen demand: a parameter used to measure the level of water pollution, b) Decree 8,468, a scale that classifies the condition of river waters (Caldana, 2023).

After the implementation of the measures, at the end of 2022, the performance indicators showed the following results: 1) Biochemical Oxygen Demand, a parameter to measure pollution, measures the amount of oxygen needed to stabilize organic matter: < 30mg/ml, means a river with low fluidity and aquatic life condition (visible in the appearance of animals such as fish and ducks); 2) Class 4: waters destined for domestic supply, after advanced treatment, or for navigation, landscape harmony, industrial supply, irrigation, and less demanding uses. Certainly, there is still hard work ahead, but the registered evidence indicates actions are being executed in a correct way (Caldana, 2023).

The current evaluation of rivers opens a new perspective for better use and integration in everyday activities (see Figure 18). As example, the current state of rivers is similar to what is currently possible to find in the Thames River in England, and the Seine River in Paris, which despite providing multi-use, it is not possible to swim or drink in its waters (Jornalismo, 2022).

Figure 18 – Comparison of the Pinheiros River before (left) (Cavalcanti, 2023) and after (right) the revitalization process (Vivo, 2023)

São Paulo Strategic Master Plan

In 2014, São Paulo's Government launched a Strategic Master Plan (SMP) containing a set of regulations and guidelines aimed at the sustainable development of the city. The SMP outlined projects and plans for the development of the city that not only emphasized the revitalization process of floodplain areas but also created opportunities for new urban fronts, such as the construction of new urban riverfront and public space system associated with the urban mobility network. These actions were closely aligned with the Metropolitan Waterway Ring project, which emphasized the importance of revitalizing the city's rivers to restore healthy waterways to São Paulo (Paulo P. d., 2014).

The urban mobility plan described in the SMP aimed integration and articulation between different transportation modes, by establishing minimum and permanent resources to expand the network and qualification of non-motorized public transportation.

The SMP also recognized new components of the urban mobility system, such as the logistics system, waterway, and car sharing, to structure a more comprehensive, efficient, and environmentally balanced commuting matrix (Paulo P. d., 2014).

From the SMP, some excerpts highlight the importance of revitalization, conservation, and maintenance of hybrid resources, in the most different modalities, aiming at economic, social, and environmental sustainability of Greater SP. The SMP for the MRSP presents clear guidance toward essential efforts to recover symbiosis between the city and natural environment by recovering green areas and rivers and integrating them with the urban systems, providing the necessary conditions for drainage and basic sanitation to mitigate the latent pollution currently existing (Paulo P. d., 2014).

Urban Mobility strategic planning has been considered a top priority among many other projects, whereas local authorities are looking to improve and articulate the local mobility system to the Collective Transport System, prioritizing non-motorized modes of transport. Different projects should be working together aiming to get the most from a well-planned Mobility System, considering the organization and between various transport modes, services, equipment, infrastructure, and operational facilities necessary for the broad mobility of people and displacement of cargo through the municipal territory, to ensure the quality of services, safety and health protection for all users, especially those in socially vulnerable conditions, in addition to contributing to mitigate climate change (Paulo P. d., 2014).

An increased share of collective and non-motorized public transport in the modal split is a must-have, and the promotion of more sustainable transportation options alternatively to conventional roadway transports was also included in SMP. It was visible on defined contributors of urban mobility to be improved (Paulo P. d., 2014):

a) Roadways;

b) Pedestrians circulation system;

c) Public collective transportation system;

d) Private collective transportation system;

e) Cycling system;

f) Waterway system;

g) Logistic and load freight transportation;

h) Airway system.

Thus, the State of SP´s Government addressed some programs towards promoting integration between collective public transport systems and non-motorized transport systems and between these and routine private collective passenger transport; incentive public and private operators to replace existent fleets by more modern, preferably fueled by non-carbon fossils (batteries, hydrogen, electric, solar), consequently less pollutant. Lastly, promote the transport of passengers and cargo by utilizing the waterway system (Paulo P. d., 2014).The theme of the waterway gains principal prominence because it is reinforced in various parts of the SMP (Paulo P. d., 2014), mentioned prominently in SMP points 245, 255, and 256. From 245, the strategic actions are focused on Public Collective Transport System, whereas the state´s government has mentioned the need for implementing terminals, transfer stations, and connections, preferably, in the locations that make the connection of the collective IWT system with the infrastructure system for the circulation of the collective transport of the Municipality. Furthermore, it has also been cited need to implement the Collective Waterway Transport System (Paulo P. d., 2014, p. 119). From 255 and 256, SMP defined the Waterway System variables and needed components to achieve the best performance of the cargo and passenger transportation service by waterways, such as rivers and dams; navigable channels and lakes; movable dams and locks; fluvial and lacustrine ports and integration and transshipment terminals; the edge of the channels; vessels; installations and buildings of support to the system, all of them extremely essential to implement an effective waterway system (Paulo P. d., 2014, p. 221).

Lastly, Paulo P. d. (2014) described strategic actions to ensure effectiveness when implementing a Waterway system:

> *a) adapt existing interferences in navigable channels, lakes and dams to guarantee navigability conditions, as well as to guarantee that new works do not cause interference with river navigation; b) encourage the expansion of the waterway network, especially in the Railway and Riverfront Zone of the Metropolitan Structuring Macro-area, through articulation with other modes of transport; c)*

collaborate with the development and implementation of cargo and passenger transportation; d) implement passenger transportation, especially lake crossings, integrating it with the electronic ticketing system; e) develop waterway projects in an integrated way with the requalification of the canals' edge, dams and navigable lakes, transforming them into coexistence and embarkation spaces for passengers and/or cargo ports; f) incorporate the Waterway System into the Municipal Urban Mobility Plans, the Integrated Environmental Sanitation Plan, the Drainage Master Plan and the Integrated Solid Waste Management Plan (Paulo P. d., 2014, p. 221).

River's situation and layout after revitalization

The actions considered in the implementation plan of the waterway ring, consider that at the end of its implementation, the configuration of the waterway will have within its 170 km length several urban ports to facilitate cargo transportation: 20 locks (allow vessels to go up and down rivers in places where there are unevenness such as dams, waterfalls, and rapids), 3 tri-ports (separation, processing, and final disposal), 14 trans-ports (receive waste, dredging earth and unsorted solid waste), 60 eco-ports (receive separated material coming from the selective collection, eco-points and large generators of solid waste), 36 dredge-ports (dredges have the function of permanent maintenance of the waterway, removing sediments that are accumulated in the river beds), 4 mud-ports (port of origin of the mud, residue from the process of water or sewage treatment) and 24 passenger ports (metropolefluvial.fau.usp.br, 2011).

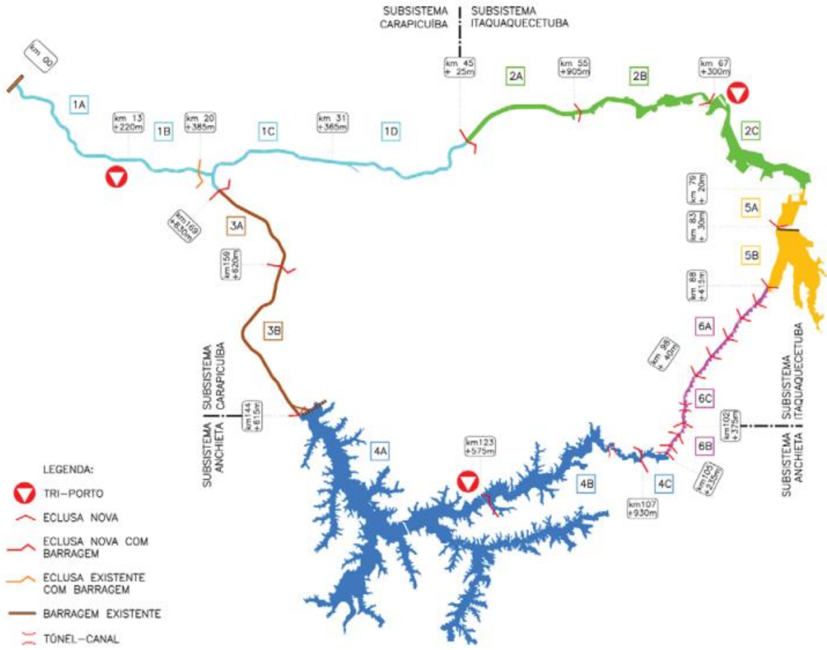

Figure 19 – Map of São Paulo's Metropolitan Water Ring (source: (metropolefluvial.fau.usp.br, 2011)).

In the conceptualization of the waterway ring, bridges were also part of the study, having concluded that the existing bridges do not have the minimum conditions to ensure navigability in all sections of the urban perimeter. With this, bridges will have to undergo deep engineering intervention to make the project feasible. From the study conducted by the University of São Paulo, it is possible to identify proposals to eliminate this potential barrier, defining a scope the modernization and implementation of three types of bridges: a) movable bridges, b) equipment bridges, c) pedestrian bridges. Movable bridges, especially those located next to railroad bridges, can make the passage of vessels more flexible by allowing them to open and close at every moment. Equipment bridges, mark the addresses of public transportation line stations. And finally, pedestrian bridges allow connection between the two banks of the canal and access to public and private leisure and service areas (Paulo F. d., 2012).

From the report "Articulação arquitetônica e urbanística dos estudo de pré-viabilidade técnica, econômica e ambiental do hidroanel metropolitano de São Paulo" (Paulo F. d., 2012, p. 42), it is possible to extract information about the limitations of vessels due to the project's characteristics, marked by "narrow and shallow channels (minimum depth of 2.5 meters), the dimensions of the locks (9x60 meters) and the amount of cargo to be transported".

Barriers and challenges to make the waterway navigable

From the literature review, we were able to identify several barriers that must be overcome to guarantee the minimum conditions of navigability of the rivers of SP. The state government continues to do hard work to make the rivers as operational as possible, but there are some other complementary barriers that need to be observed to mitigate exposure to risk (Table 6).

Table 6 - Key barriers Hindering Progress (Author' elaboration)

Dimensions	***Barriers***
Technical	Transshipment locations
	Ports, Citadine Hubs
	Terminal construction and Operation
	Maintenance operations, including dredging and lock and dam maintenance/repair
	Conditions of navigation and water levels (water density, security and depth)
	Navigational infrastructure, night navigational and RIS
	Charging infrastructure systems for small to medium-sized electric boats
	Logistics Information systems, Inland traffic management
	Ownership of infrastructure
	Skilled labour force
	Electrical equipment to support logistic
	Vessel construction designed based on specific characteristics (Hidroanel Project)
	Special Vessel designs to meet navigation conditions
	Lack of passenger terminals
Economical	Initial Investment
	Transhipment Costs
	Delivery time
	Electrical equipment to support logistic
Governance	Public Authorities
	Bureaucracy
Environmental	Climate change
	Bank Erosion due to vessels speed

	Fauna, Fish and wildlife
	Flooding
	High level of polluted rivers
Social	Social Inclusion
	Behavioural Changes
	Easy access to technology (mobile apps)
	Tickets at fair price
Legal	Regulatory constraints
	Flood protection
	Policies, local regulations.

As mentioned, throughout their history, urban rivers have undergone several transformations in their basic structure, they have been confined in narrow, shallow and restricted channels, with reduced dimensions and restricted between dams that at certain points affect possible navigation courses. In addition to direct transformations to the free water course, their banks and hydrological regimes have also felt the changes made by human hand, thus forcing the design of specific channels and vessels to use the watersheds for urban river navigation [1].

[1] (metropolefluvial.fau.usp.br, 2011)

5. Proposal for waterway implementation

5.1.Background

From the literature review, it is possible to observe several successful cases implemented globally that can serve as benchmarks for the city of SP, to ensure efficiency in the implementation and reduction of variables that can cause failure in the implementation of the IWT. Certainly, several barriers will be encountered during the implementation process of the waterway project, but greater care and selection of the most appropriate technologies will help in the correct execution.

Based on the theoretical description previously made, several cases refer us to the situation of initiating the integration process in a phased and careful way, pursuing an implementation in gradual steps aiming at the final execution. Although the waterway has multiple applications in enhancing urban transportation, it is important to consider certain precautions. During the literature review, we encountered cautionary notes regarding the implementation analysis and the necessity to concentrate on specific sectors to facilitate the approach and its subsequent implementation.

As we can infer from several examples, the large-scale integration of waterway transportation options with other modes of transportation is a process that involves great complexity, and multidisciplinary projects that go far beyond ensuring the navigability and operability of vessels on waterways (Sachs, Azevedo, Dahle, & Henriksen, 2021).

Public and private companies must be involved to ensure implementation and to overcome obstacles arising from intermodality, which presents itself as one of the main challenges for implementation (Janjevic & Ndiaye, 2014).

The type of vessels can be divided according to their purpose, depending on the strategy of the of the waterway system and the different stages of the revitalization of the rivers.

Type of vessels

Due to the characteristics of the urban rivers of the MRSP, the conceptual report and technical pre-feasibility study conducted by the University of São Paulo suggest different vessel configurations (and complementary means of transportation) suitable for navigation on urban waterways. It is essential to note that vessels designed for urban mobility purposes, whether for cargo or passengers, must comply with minimum standards and respective requirements and norms of state, federal, and international waterway safety to ensure navigability conditions on the waterway (Paulo F. d., 2012).

Urban Cargo Vessels

The use of vessels for transporting urban cargo, whether polluting or non-polluting, must adhere to international regulations and safety standards. The Metropolitan Hidroanel project has identified Urban Cargo Vessels as a means to reduce the presence of large vehicles within the urban perimeter, including mobile floating dredges used in the de-pollution of the Pinheiros and Tiete rivers (Paulo F. d., 2012).

Successful cases from the literature review have highlighted the importance of energy-efficient urban cargo vessels, typically resulting from public-private partnerships.

Certainly, the case of Amsterdam's Mokum Mariteam can serve as a reference for the city of SP, as it shows a successful implementation of electric urban cargo vessels. Basically, this vessel is used for material or construction waste transportation, urban waste collection, and reverse logistics. Urban Eletric Cargo Vessel can support reducing greenhouse gas emissions, noise pollution, and traffic congestion in urban areas, contributing to the overall well-being of city residents (Zacharopoulos, El, Supervisor, & Gonzalez-Aregall, 2020). The fully electric barge equipped with electrical cranes for the collection of urban waste is a good example of how reverse logistics can be made more sustainable and efficient.

This case demonstrates how public-private partnerships can result in successful and innovative solutions for urban logistics, contributing to the sustainability and livability of the city (Zacharopoulos, El, Supervisor, & Gonzalez-Aregall, 2020).

Figure 20 - The Mokuem Mariteam Barge Loading Construction Waste with Its Own Crane (Zacharopoulos, El, Supervisor, & Gonzalez-Aregall, 2020).

To support urban freight logistics, it is crucial to create the necessary infrastructure, which includes defining the proper location for collection and dumping points of urban waste and providing appropriate equipment to ensure easy access for boats.

Cargo ships focused small deliveries (floating service centers)

Cargo ships, also known as floating platforms, are designed for parcel deliveries within the urban environment. They sail over a predefined route, distributing goods along the way and help to reduce the number of trucks on the streets that are used to distribute small parcels within the city center. According to Jan and Nepveu (2020), these platforms are revolutionizing urban services and supporting the mobility of products from different industries and destinations in cities. Jan and Nepveu (2020) have also highlighted the use of similar concepts to transport palletized goods and containerized goods, deliveries to local shops and restaurants, parcels, waste, recycled material, and service trips.

Private companies have been developing concepts and technologies to improve waterway transport sustainability, supported by the municipalities responsible for driving and supporting the development of basic infrastructure to ensure functionality and operability. However, transport operators have indicated a lack of loading and unloading infrastructure to improve operationality (Jan & Nepveu, 2020).

Figure 21 - DHL Floating Service center for cargo bikes (Kuzeyliden, 2023), Beer Boat (Noort, 2023) and City supplier Boat in Utrecht (Mariteam, 2023)

The capacity of floating service centers can vary significantly depending on the solution. For example:

- The DHL floating service which is a 17-meter-long, can replace about five delivery trucks (Stevenson, 2023) and is equipped with 21 bicycle couriers who can deliver to approximately 250 addresses (Lawler, 2023);
- The Beer Boat has a capacity of 18 tonnes or 40 to 48 rolling containers, which is equivalent to six vans or two truckloads (Jan & Nepveu, 2020);
- The City Supplier, an electrical vessel, has a capacity of 185 square meters, which corresponds to four compact trucks" (Jan & Nepveu, 2020).

Passenger ships

Vessels designed for passenger transportation have different operation profiles, such as ferries, public transportation, and tourism.

Figure 22 – Cruise Boat in Paris (Bureau, 2023).

The capacity of these vessels can vary greatly depending on the seaworthiness conditions of their intended operation location. Pure electric vessels can be classified into the following categories based on their capacity (Liebreich, et al., 2021):

- Large Ferries – 1000 passengers, 150 cars, operating short routes (up to 5km);
- Medium-sized ferries – 300 passengers, 50 cars, operating short and medium routes (up to 40km);
- Fast Camaran ferries – 250 passengers, no cars, operating commuter or tourist routes (up to 90km);
- Large Ferries – 1000 passengers, 150 cars, undertaking longer routes (over 60km);
- Commuter ferries undertaking chained routes, electric, or switching to electric in city centers for air quality reasons.

Service and Dredgers ships

Service and dredger ships have various uses and play a fundamental role in the cleaning process to speed up the revitalization process of channels. These vessels also have basic support characteristics for other vessel profiles and users of the waterway modal, such as navigational aid and first aid (Paulo F. d., 2012).

Since 2020, the City of São Paulo's government has put into operation service vessels with the functionality of collecting floating solid waste and disposing of it to duly licensed receptors. These boats are part of the Novo Rio Pinheiros project and are known as Ecoboats (Ambiental, 2023).

Figure 23 - The Ecoboats (Ambiental, 2023) and Waste Collection Eco-Boats Contributing to Cleaner Waterways (Logística, 2023).

Ecoboat vessels are 7 metres long by 3 metres wide, with a capacity to carry up to 3.5m^3 of waste volume (Ambiental, 2023).

Autonomy of Inland Waterway Vessels

Numerous factors can affect the autonomy of electric vessels, with the navigation profile being a crucial determinant in assessing the feasibility of each project and selecting the most appropriate topology. Variables such as navigation speed, cargo weight, vessel size, number of stops, and operational requirements can all impact energy consumption and demand.

It is evident that selecting electric or hybrid systems for vessels that require short-duration trips, moderate loads, and reduced propulsion power with frequent stops is a feasible solution. This navigation profile is typically associated with passenger vessels, specifically ferries, that have a specific profile with a trip duration of less than an hour and frequent stops. Such profiles allow for batteries to be recharged frequently within short intervals, thus making electric or hybrid systems suitable for the intended applications (Perčić, Vladimir, & Koričan, 2021).

The application of electric or hybrid systems is well-suited for cargo distribution vessels operating in urban areas with clearly defined stopping points for loading and unloading, such as floating distribution centers. At these locations, shore-supply (shoreside electricity) could be strategically implemented to provide shore power (preferably from renewable energy sources) for vessel operations and hotel loads, while simultaneously feeding the battery banks installed in the vessels. Such an approach allows for sustainable goods movement within the city, while reducing greenhouse gas emissions and improving air quality (Perčić, Vladimir, & Koričan, 2021).

In the case of service vessels, such as eco-boats and dredgers, autonomy may be a barrier to the implementation of fully electric (or even hybrid) systems, since their navigation profile requires a high number of hours of uninterrupted operation. A hybrid solution, combined with stop programming, could be a technically and economically viable option for implementation. Also, in the case of service vessels, a proper study of their operating radius may add variables that allow the use of shore-supply to ensure service execution, delivering power for propulsion drive and possible additional demands of energy peaks (to be supported by the network) (Perčić, Vladimir, & Koričan, 2021).

Vessel propulsion systems

The propulsion system is responsible for powering and directing vessels in the desired direction. Depending on the type of vessel, the propulsion system may consist of a range of components, including diesel engines, gas engines, dual fuel engines, nuclear-powered engines, gas turbines, gearboxes, generators, electric motors, and propellers. To steer the vessel, the angle of the rudders or propellers may be adjusted.

Mechanical Propulsion (Diesel Engine)

Traditionally, inland waterway vessels have employed conventional propulsion systems that rely on fossil fuel-powered engines, specifically diesel engines. Diesel engines are internal combustion engines that rely on compression heat to ignite and burn fuel that has been injected into the combustion chamber. Despite the practicality and widespread use of these technologies, combustion engines are increasingly regarded as a significant threat to human health and the environment. Indeed, the high levels of CO_2, NO_x, SO_x, and other harmful gases that are emitted from diesel combustion systems can lead to serious respiratory and cardiovascular diseases (Bernardes, 2016).

Hybrid-Electric or Eletric Power System for vessels

The feasibility of electric or hybrid systems for vessels depends on various factors, with the navigation profile being a crucial determinant. Variables such as navigation speed, cargo weight, vessel size, number of stops, and operational requirements can all impact energy consumption and demand.

According to Perčić, Vladimir and Koričan (2021), hybrid (Figure 24) or electric power systems (Figure 25) are well-suited for vessels that require short-duration trips, moderate loads, and reduced propulsion power with frequent stops. Such profiles are typically associated with passenger vessels, specifically ferries, that have a trip duration of less than an hour and frequent stops. These profiles allow for batteries to be recharged frequently within short intervals, making electric or hybrid systems suitable for the intended applications. The authors also suggest that electric or hybrid systems are feasible for cargo distribution vessels operating in urban areas with clearly defined stopping points for loading and unloading, such as FDC. In such cases, shore-supply from renewable energy sources could provide power for vessel operations and hotel loads while feeding the battery banks installed in the vessels.

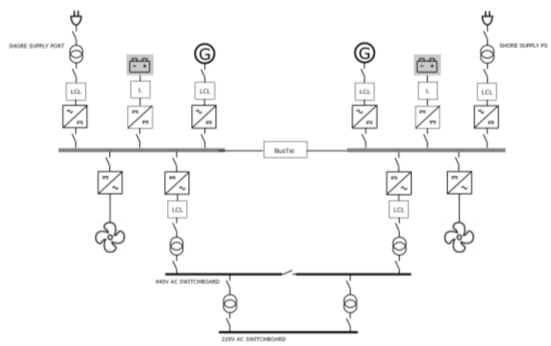

Figure 24 – Schematic of Hybrid Electric Power System for Marine Vessels (Author's Design).

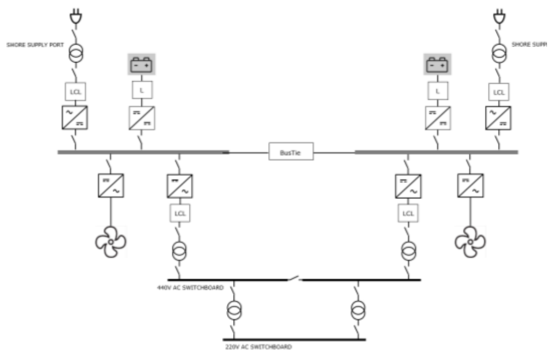

Figure 25 – Schematic of Electric Power System for Marine Vessels (Author's Design).

As the shipping industry aims to reduce its carbon footprint, there is a growing interest in exploring alternative power solutions, with hybrid-electric systems being a potential option. Compared to fully electric systems, hybrid-electric systems require less investment and may be better suited to certain vessel navigation profiles. A proposed vessel design incorporating a hybrid shipboard power system with a Common DC Bus distribution is presented in Figure 24. This system allows for the recharging of battery packs and the supply of power to electrical propulsion motors. The inclusion of a shore connection plug and low-voltage shore supply technology integrated into the ship grid can further reduce the vessel's operational impact and eliminate polluting emissions from diesel engines (Bucci et al., 2017).

Shore side infrastructure for supporting inland vessels

Regarding shore side infrastructure for supporting inland vessels, Liebreich et al. (2021) proposed a possible layout of an electrical ecosystem that aims to perform electrical power transfer from land to vessel, as shown in Figure 26. The infrastructure on the shoreside consists of various electrical elements that allow the port to supply shore power, also known as shore connection, shore-supply, shore side, shore to ship power, cold ironing, or shore side electricity. This system performs the transfer of power from shore to ship when the ship is docked in an urban port, keeping the onboard functionalities operational. By shutting down the main engine completely, the system reduces the emission of pollutant gases such as CO_2 and NO_X, while eliminating harmful noise and vibration from conventional power generation technologies such as diesel generators.

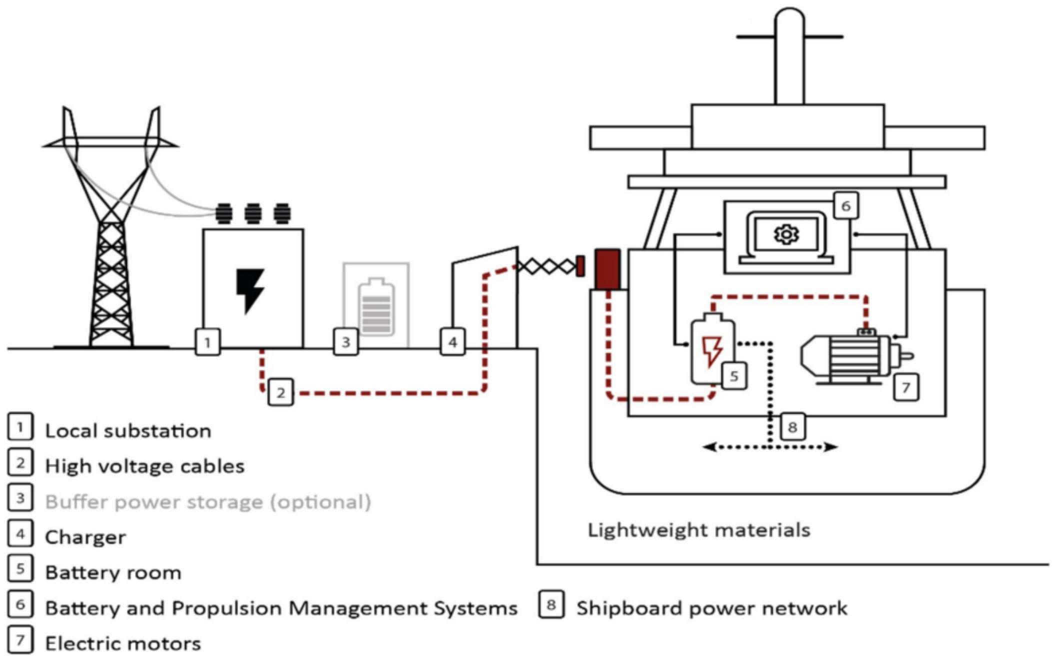

Figure 26 – Schematic of an onshore infrastructure to power up vessel Liebreich et al. (2021)

The ship grid consists of four essential points, the Power Management System, shipboard power network, batteries installed in the ship, and electric motor installed in the vessel. The PMS, is the ship's intelligence and is responsible for managing the energy flow throughout the ship, ensuring the correct power flow to the different loads, and preserving the battery´s lifetime. It also performs the synchronism of multiple sources connected to the ship grid, whether they are intrinsic or ship or external sources. The main objective of this system is to ensure that the necessary electrical power is provided to the electric motor installed in the vessel to perform its operations, regardless of vessel´s type (Drives, 2015).

In the context of promoting sustainable practices in the shipping sector, it is important to consider alternative configurations for onshore energy production to power vessels from the shore side. Despite the fact that the Brazilian electricity matrix is primarily based on renewable energy sources, which results in lower operating costs and greenhouse gas emissions compared to the global electricity matrix (Energética, 2023), there is still room for improvement.

Figure 27 illustrates a proposed configuration that can provide significant benefits. By utilizing a combination of renewable energy sources, such as wind or solar power, in conjunction with energy storage systems, it is possible to generate and store electrical energy onshore. This energy can then be transferred to the vessel through a shore connection plug, thereby reducing the reliance on traditional diesel-electric solutions and minimizing the environmental impact of vessel operations (Drives, 2015).

Overall, this configuration represents a promising approach to reducing greenhouse gas emissions and promoting sustainable practices in the shipping sector. Further research and development in this area can help to identify additional opportunities for innovation and improvement in the field of onshore energy production for vessel power.

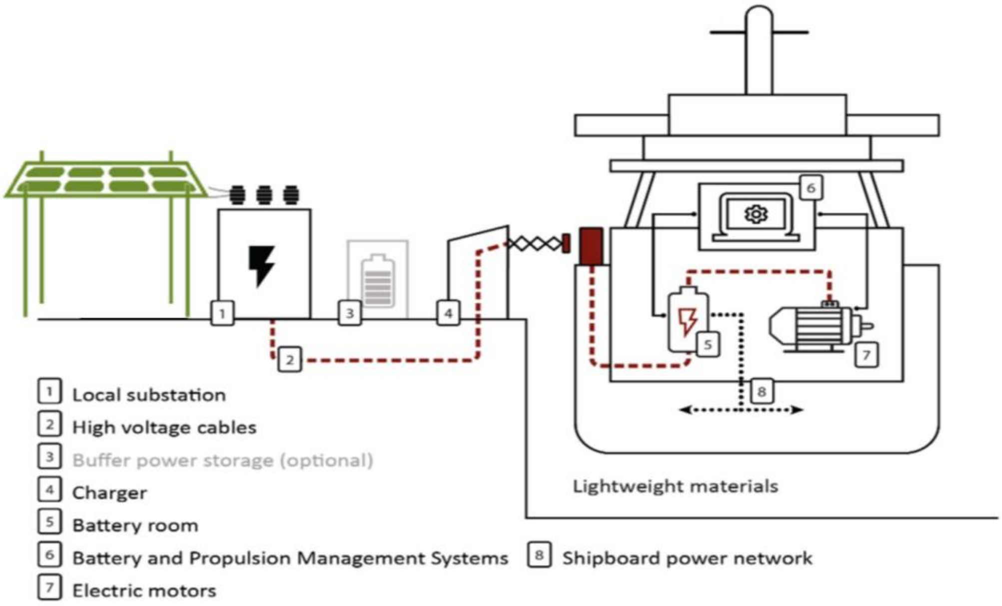

Figure 27 – Illustration of solar power infrastructure designed to provide energy to water vessels. Source: Liebreich et al. (2021). (Author's Design)

Comparative Analysis of Diesel Mechanical, Hybrid, and Electrical Vessels for Inland Waterway Navigation

Vessels used for IWT can be powered by a variety of propulsion systems, including diesel mechanical, hybrid, and electrical. Each system has its own advantages and disadvantages in terms of fuel efficiency, emissions, noise pollution, maintenance costs, and other factors. A short comparison of diesel mechanical, hybrid, and electrical vessels for inland waterway navigation are presented in Table 7, summarizing the key features and provides a comparative analysis of each propulsion system.

Table 7 - Comparison of Diesel Mechanical, Hybrid, and Electrical Vessels for Inland Waterway Navigation (Author's Design)

Feature	**Diesel Mechanical Vessels**	**Hybrid Vessels**	**Electrical Vessels**
Propulsion System	**Diesel engine**	**Electric motor + diesel**	**Electric motor**
Fuel Efficiency	-	+++	+++++
Emissions	--	--	+++

Noise Pollution	--	-	+++
Maintenance Costs	-	--	---
Initial Cost	-	++	++
Charging Infrastructure	-	+/-	+++
Range	+++	+++	--
Payload Capacity	+++	++	-
Research Potential	-	++	+++

Diesel mechanical vessels have a simple propulsion system and lower fuel efficiency, but they have the lowest initial cost and maintenance costs. Hybrid vessels have a more complex propulsion system that combines an electric motor and diesel engine, resulting in higher fuel efficiency and lower emissions. However, they have higher maintenance costs due to the complexity of the system. Electrical vessels rely solely on electric motors, resulting in the highest fuel efficiency and low to zero emissions. However, they have the highest maintenance costs and require extensive charging infrastructure. Diesel mechanical vessels are the noisiest, while electrical vessels produce very low levels of noise. Diesel mechanical and hybrid vessels have longer ranges than electrical vessels. Diesel mechanical vessels have the highest payload capacity, while electrical vessels have a moderate to low payload capacity. Finally, electrical vessels have the highest research potential due to their advanced technology and potential for future development, while diesel mechanical vessels have moderate research potential due to their mature technology.

Predominant Routes in São Paulo Metropolitan Area

Our research aims to implement energy-efficient solutions to reduce traffic congestion within the urban perimeter of São Paulo, Brazil's largest city. By integrating efficient technologies into the Metropolitan Water Ring Project, we seek to reduce the inflow of vehicles and associated costs while mitigating greenhouse gas emissions. This proposal will not only address highway congestion but also enhance the water ring solution proposed by the City Hall's executive.

Our long-term goal is to establish environmentally friendly transportation solutions that can navigate the entire 170 km of the waterway once all stretches become navigable. To prioritize the most heavily trafficked routes within the city, we have identified the stretches with the highest traffic intensity in Table 8.

Table 8 - Metropolitan Waterring sections (metropolefluvial.fau.usp.br, 2011)

TRECHO	INÍCIO	TÉRMINO	COMP. (m)	N.A.	TRI-PORTOS	TRANS-PORTOS	ECO-PORTOS	DESCRIÇÃO
1A	Km 00	Km 13 + 220m	13.220	712,00	1	1	1	Barragem Edgard de Souza > > Foz do córrego de Carapicuíba
1B	Km 13 + 220m	Km 20 + 385m	7.165	712,00		1	2	Foz do córrego de Carapicuíba > > Barragem-móvel / Eclusa do Cebolão
1C	Km 20 + 385m	Km 31 + 365m	10.980	715,50		1	4	Barragem-móvel / Eclusa do Cebolão > > Foz do Tamanduateí / P_TIE 18
1D	Km 31 + 365m	Km 45 + 25m	13.660	715,50		2	3	Foz do Tamanduateí / P_TIE 18 > > Barragem-móvel / Eclusa da Penha
2A	Km 45 + 25m	Km 55 + 905m	10.880	724,50		1	3	Barragem-móvel / Eclusa da Penha > > Eclusa de São Miguel Paulista
2B	Km 55 + 905m	Km 67 + 300m	11.395	731,00			3	Eclusa de São Miguel Paulista > > Eclusa de Itaquaquecetuba
2C	Km 67 + 300m	Km 79 + 20m	11.720	737,00	1	1	2	Eclusa de Itaquaquecetuba > > Foz do Taiaçupeba-Açu
5A	Km 79 + 20m	Km 83 + 30m	4.010	737,00		1		Foz do Taiaçupeba-Açu > > Barragem / Eclusa do Taiaçupeba
5B	Km 83 + 30m	Km 88 + 415m	5.395	748,00			1	Barragem / Eclusa do Taiaçupeba > > E.TAM 1 / Foz do Taiaçupeba Mirim
6A	Km 88 + 415m	Km 98 + 40m	9.625	750,00 a 767,00		1	2	E.TAM 1 > > E.TAM 6 (Canal Lateral / Escadas de
6C	Km 98 + 40m	Km 102 + 375m	4.335	773,00 752,00 a			1	Eclusas do Taiaçubeba Mirim) E.TAM 6 > > E.EST 4 (Canal de Partilha Estiva – Taiaçubeba Mirim)
6B	Km 102 + 375m	Km 105 + 235m	2.860	766,00				E.EST 4 > > E.EST 1 (Canal Lateral / Escadas de Eclusas do Estiva)
4C	Km 105 + 235m	Km 107 + 930m	2.695	747,50				E.EST 1 / Foz do Estiva > > Eclusa Rio Grande / Dique do Rio Grande
4B	Km 107 + 930m	Km123 + 575m	15.645	747,50		1	5	Eclusa Rio Grande / Dique do Rio Grande > > Eclusa Billings / Dique da Anchieta
4A	Km123 + 575m	Km144 + 615m	21.040	746,50	1	2	25	Eclusa Billings / Dique da Anchieta > > Eclusa de Pedreira
3B	Km144 + 615m	Km 159 + 620m	15.005	722,50		2	4	Eclusa de Pedreira > > Eclusa de Traição
3A	Km 159 + 620m	Km 169 + 830m	10.210	717,50			4	Eclusa de Traição > > Eclusa do Retiro
1C*	Km 169 + 830m	Km 170 + 345m	515	715,50				Eclusa do Retiro > > Eclusa do Cebolão

During rush hour, commuters traveling between the Morumbi region and the Cebolão Dam, which is a distance of approximately 14 km, may experience travel times of up to one hour when utilizing public transportation (see Figure 28). Similarly, travel between the Billings Reservoir and the Cebolão Mobile Dam, which spans nearly 42 km, may take up to 2 hours and 46 minutes during peak times when utilizing roadways (see Figure 28).

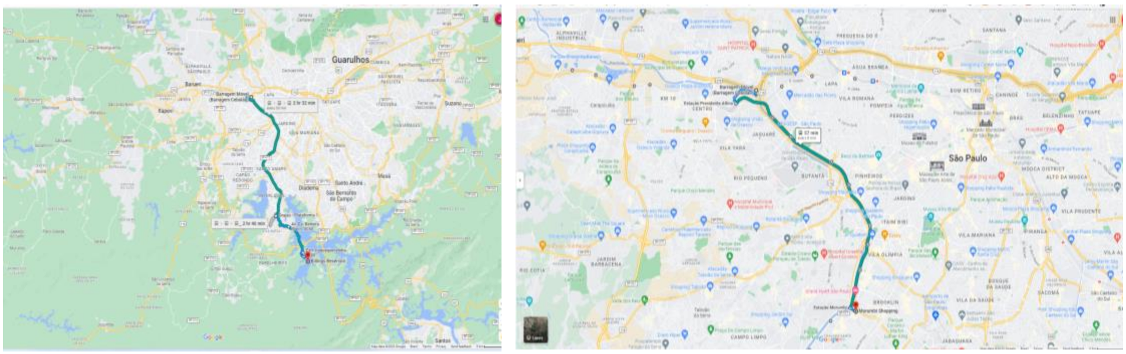

Figure 28 - Map illustrating the route from Billings to Barragem Movel Cebolão (42km length) and Morumbi Shopping to Barragem Movel Cebolão (14km length), as designed by the author.

According to Freitas (2023), São Paulo City Hall has initiated a project called Aquatico SP that will be executed by a consortium of companies. This project aims to establish a passenger transport vessel to connect Pedreira (Point A) in Ademar City and the Cocaia Residential Park in Grajaú. To that end, the project envisages the installation of two water terminals in the neighbourhoods of Cocaia and Pedreira, located in the southern region of São Paulo city, in order to provide daily transport to approximately 10,000 passengers. These locations were identified as suitable for the implementation of the first pilot phase since they are part of the metropolitan waterway project and present better navigability compared to other stretches due to their proximity to the Billings reservoir and respective water density (Freitas, 2023). To cover the distance between both terminals by road, it would require driving for almost 20km. The project aims to reduce this distance to 3km by integrating the waterway with existing public transportation, accomplished through the construction of bus hubs at each end.

Figure 29 – Map showing the distance between Cocaia and Pedreira (Freitas, 2023).

Currently, public transportation users require approximately 1 hour and 30 minutes to commute between the two locations, which are approximately 20km apart. The project aims to significantly reduce this commuting time by integrating the waterway and existing public transportation systems. By building bus hubs at each end and implementing an efficient waterway connection, the goal is to create a seamless and time-saving transportation option for commuters (see Figure 30).

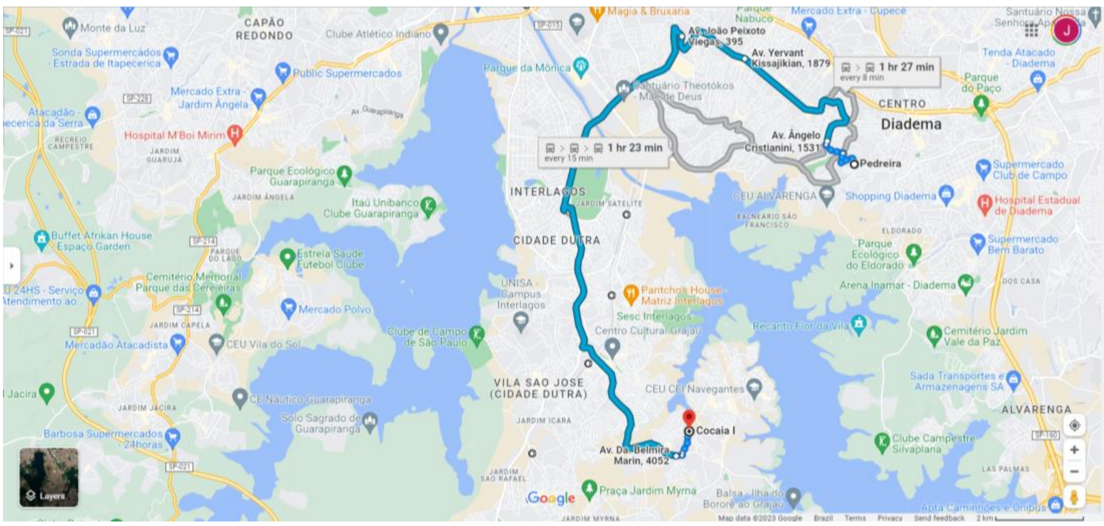

Figure 30 – Public transportation travel time from Cocaia to Pedreira (Author's Design).

According to Jornalismo (2023) and Pelegi (2022), the mayor of São Paulo has issued a decree to expropriate land at both ends of the river in order to begin earthworks and construct ports.

Pelegi (2022) reported that the Aquático SP project will cover a length of approximately 3km, which can be traversed in about 15 minutes. According to Jornalismo (2023), the project will integrate with the existing public transport system, allowing passengers to acquire a single ticket for both bus and boat rides, and reducing travel time between locations. Passengers will arrive by bus at the water ports located at the extremities, namely the Cocaia Dockside Terminal and Pedreira Dockside Terminal, and proceed to travel by water, with an estimated journey time of 15 minutes per leg.

The project aims to extend the Aquático SP as a reference in a phased and simplified way, as seen in Figure 31. The stretches following the Alvarenga Terminal connect directly to the main stretches that enter the urban perimeter. The project is expected to leverage learnings for the more than 170km of potentially navigable waters constituting the waterway ring.

As shown in Figure 31, the stretches following the Alvarenga Terminal connect directly to the main stretches that enter the urban perimeter.

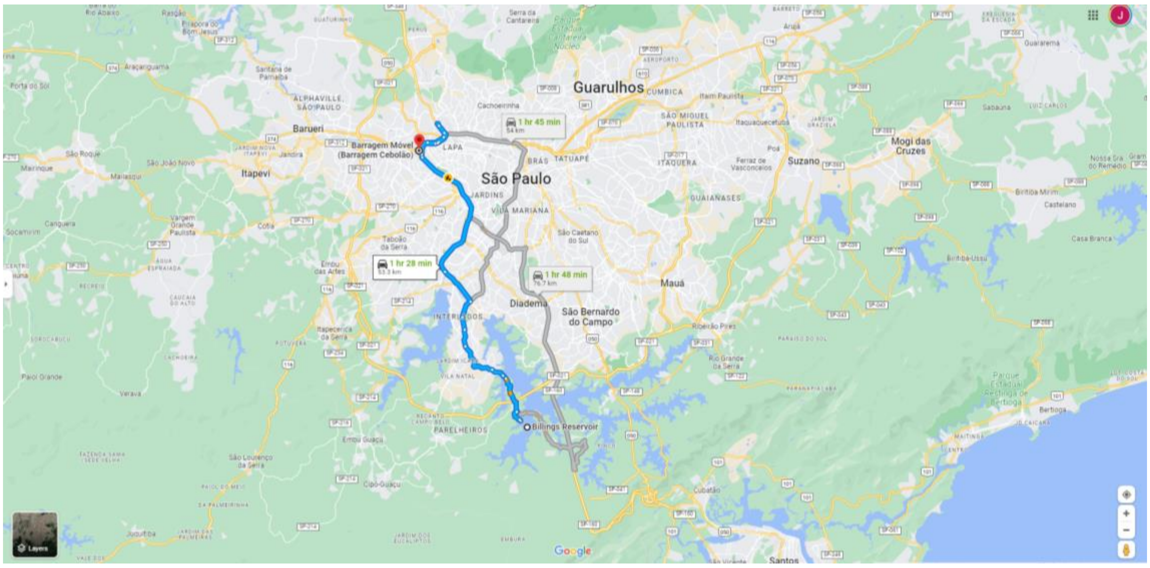

Figure 31 – Map showing the extension from Alvarenga Terminal to Barragem Móvel (Barragem Cebolão), depicting the waterway route for cargo and passenger transportation in São Paulo, Brazil (created by the author).

Nonetheless, conducting a thorough literature review and drawing insights from similar endeavors in different areas becomes crucial. It allows assess potential risks associated with the implementation of expansive solutions. Integrating waterway transportation on a large scale with other modes of transportation is an intricate undertaking, encompassing multidisciplinary projects that extend beyond mere considerations of vessel navigation and operation. By proactively identifying risks that could impede the successful implementation, stakeholders can make informed decisions and take necessary precautions to avert potential failures.

Intermodal transport between waterways and other means of transportation

Integration with different logistics modals is essential for ensuring the functioning of a waterway. In addition to basic infrastructure for overcoming various barriers such as floods, currents, locks, and other obstacles, investments must be made to ensure the smooth connection with road, rail, river and air systems (Vilarinho et al., 2019).

Figure 32 depicts the scheme of an intermodal logistics chain, considering the interconnection points with land transport systems, excluding the transfer stages located at the ends of the chain (Gerais, 2019).

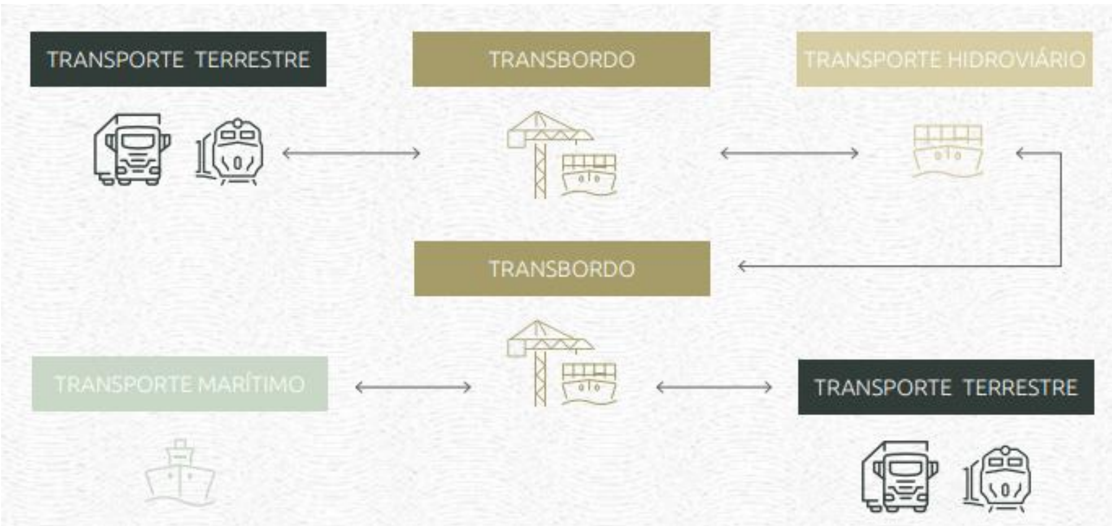

Figure 32 – Schematic of an intermodal process including waterways (Transporte C. N., Aspetos Gerais da Navegação Interior no Brasil, 2019).

According to previous chapters, intermodal transport will depend on the type and profile of the vessel. There will always be a need to guarantee intermodal connectivity with existing transport modes, but it is important to focus on implementing solutions that support the energy transition and do not rely on fossil fuels. Three types of vessels that may require intermodal transport include passenger vessels, service vessels, and distribution vessels.

Passenger Vessels

The Aquático SP Project an excellent measure by the municipality to integrate passenger transport by rivers and dams with collective public transport, cycle paths, and car sharing services as determined in the Strategic Master Plan (SMP) of the city of São Paulo in 2014 (Paulo P. d., 2014) (Pelegi, 2022). The project considers intermodal transport with buses operated by the same company and plans to modernize the fleet with 100% electric buses or buses that use biofuels. However, it is crucial to implement necessary measures to mitigate the possibility of unsuccessful implementation. It is important to note that waterborne transport represents only a fraction of the overall project, which involves numerous multidisciplinary stakeholders.

Furthermore, the municipality of São Paulo should strive to integrate IWT with different transportation modes, such as road, air, and rail, as well as encourage the use of bicycle paths for urban mobility.

Drawing inspiration from Lusail City in Qatar, it is worth exploring small-scale possibilities as well. One promising prospect is a hybrid system that combines Personal Rapid Transit (PRT) with water taxis, offering significant potential for success.

Service Vessels

As explained above, service vessels play an extremely important role in improving and maintaining navigability conditions in urban rivers. Currently, their support is vital for the continuity of the de-pollution program of the Tiete and Pinheiros rivers, which are essentially used for the dredging process and movement of urban waste for treatment in waste treatment areas. In this situation, there must be an integration with the road system, which allows the movement of debris from the strategically located tri-ports to the respective treatment areas. Likewise, service vessels may be used in heavy industry, construction materials, urban waste collection, and reverse logistics. Its intermodality will essentially relate to road and rail, also needing to be suitable for possible articulations with airway transport option.

Floating distribution centers and last mile delivery

A FDC is a concept where a distribution center is situated on a floating platform or a vessel, allowing it to operate and move along waterways or coastlines to serve different locations. Electrical or hybrid FDCs poised to revolutionize logistics operations, as the utilization; of environmentally friendly propulsion systems could be meticulously designed to optimize efficiency, overcome logistical challenges, and contribute to sustainable urban logistics. The FDC serves as a hub for receiving, storing, and distributing goods, and it can be strategically positioned to optimize its operational efficiency and effectiveness. At the core of its operation, the FDC functions acts a pivotal point in the supply chain. Upon the arrival of goods, sourced from diverse suppliers and manufacturing facilities, the FDC swiftly receives and unloads them. A spacious and organized warehouse or dedicated storage areas facilitate efficient storage, enabling seamless inventory management. As an operational hub, the floating distribution center seamlessly integrates into the urban landscape. It becomes a central point for the receipt, storage, and distribution of goods within the city, extending its capabilities to the final leg of the delivery process—the last mile. By positioning the FDC closer to urban consumers, it significantly reduces the distance and complexity of the last mile, addressing one of the most critical challenges in urban logistics. This reduced distance translates into shorter last-mile routes, enabling faster and more efficient delivery to urban customers.

The proximity to urban markets facilitates the use of alternative and sustainable transportation modes for the last mile. Embracing electric vehicles, cargo bikes, or any other environmentally solutions, the FDC contributes to reducing emissions and enhancing sustainability in urban environment. FDC’s solutions can be optimized to navigate through the narrower canals of SP´s city, smaller vessels can be utilized to reach areas that are not accessible by trucks.

Furthermore, electrical or hybrid FDCs contribute to sustainable last-mile delivery by utilizing electric or hybrid vehicles, assisted, or non-assisted cargo bikes. These eco-friendly transportation modes enable seamless navigation through congested urban streets, pedestrian areas, and restricted zones, while minimizing emissions and noise pollution.

Conventional Bicycles

Recently, due to the public transportation overcrowding and endless hours lost in the chaotic traffic of SP, several actions were witnessed by the city hall aiming to encourage the use of bicycles in urban space. Currently, to ensure the safety of cyclists, the city has 566.5 kilometers of roads with permanent cycling treatment (Sampa, 2023).

Similar intermodality model to the one used by DHL (see Figure 33) in Amsterdam channels can be analyzed for implementation, in which case the floating distribution center can transport conventional bicycles, to carry out small deliveries within the urban perimeter.

Figure 33 - DHL's Conventional Bikes on a Floating Distribution Center for Last Mile Delivery Source: (Kuzeyliden, 2023).

The use of non-assisted cargo bikes for cargo distribution brings, besides the benefits related to sustainable mobility: reduced fuel consumption, reduced emission of pollutant gases and noise pollution. In addition, there are numerous benefits for the quality of life of users, such as reduced cholesterol levels, increased cardiorespiratory function, weight loss, strengthens the muscles, increases physical conditioning, and reduces stress levels, among many other benefits (Sampa, 2023). It's worth noting that there are various types of cargo bicycles available for different purposes, which can be adapted according to the product to be distributed and the access conditions (see Table 9).

Table 9 – A Comparative Analysis of Cargo Bike Types for Sustainable Urban Logistics: Evaluating Capacities, Cargo Types, Advantages, and Disadvantages (Nürnberg, 2019).

Type of Cargo Bike	Description	Capacity	Suitable for Cargo Type	Advantages / Disadvantages
Two-Wheeled Cargo Bike	A cargo bike with two wheels and a large platform in the front for cargo	Up to 100 kg	Smaller items and parcels	Easy to maneuver in traffic, can use bike lanes and bike paths, low emissions and noise pollution. Limited capacity compared to larger vehicles, limited by the weight of the cargo
Three-Wheeled Cargo Bike	A cargo bike with three wheels, two in the front and one in the back, with a large platform in the front for cargo	Up to 250 kg	Larger items and parcels	More stable than two-wheeled cargo bikes, can carry larger and heavier loads, easier to balance when stopped. More difficult to maneuver in traffic, requires more space on bike paths and bike lanes, can be more expensive than two-wheeled cargo bikes.
Longtail Cargo Bike	A cargo bike with an extended frame, allowing for a larger cargo platform behind the rider	Up to 200 kg	Larger items and parcels, can also carry passengers	More maneuverable than traditional cargo bikes, can handle a variety of cargo types, can also transport people. Longer and heavier than traditional cargo bikes, can be more difficult to park and store, can be more expensive.

Electric Cargo Bikes

Nevertheless, due to its design to carry heavy loads, dependent on circumstances, cargo bikes can become difficult very difficult to ride, and at the end adding extra costs to final user.

In order to solve this issue, logistic operators are considering electric bikes on their fleet, basically, the assistance provided by an electric bike motor, makes easier the task moving larger loads around for longer distances (Norman, 2023). So, the Figure 34 shows some examples of e-bikes that can be used for last mile delivering, similar to the ones used by Amazon and DHL.

Figure 34 – Electric bikes used in the logistics industry: Amazon Electric Bike (left) and DHL Electric Bike (right). Adapted from Bike (Toll, 2023) and (Bradley, 2023)

Eco Friendly Vehicles

Global logistics companies are accelerating their strategy to implement environmentally friendly transport solutions. Several companies are replacing their fleets of combustion vehicles with more environmentally friendly options. This trend towards green logistics solutions is evident among logistics companies worldwide. These solutions include increasing the of electric vehicle fleet to decarbonize transportation and ensure logistics chain sustainable.

Electric vehicles are increasingly being used to perform last mile delivery due to their many benefits, including reduced emissions, an improved economic and environmental sustainability. Figure 35, shows some examples of last mile delivery electrical vehicles.

Figure 35 – Examples of electric vehicles used in last-mile delivery: electrical truck, electrical van, and solar-powered electric mini-train (adapted from (Benelux, 2023), (Vous, 2023), and Teubner, 2013), respectively).

5.1.1. Main Benefits of using inland waterway transport

The appeal of a clean and well-maintained city, with navigable rivers, provides added value to São Paulo's image. The possibility of tourist boats crossing the city (even if only in specific stretches) opens up new opportunities to attract tourists. Certainly, some of the above-mentioned benefits are in line with greater economic returns from revitalization, but they also bring significant gains for public well-being and health (Vilarinho, Liboni, & Siegler, 2019).

The investment in the use of IWT modal presents as an active way of promoting different spheres of sustainability, environmental, economic, and social benefits (Vilarinho, Liboni, & Siegler, 2019). The city of SP has turned its backs on its rivers in recent years, unilaterally breaking the ecosystem and exposing residents to risks inherent in the high levels of water pollution in the country's main city (Pinheiros, 2023).

The project to revitalize and reintegrate urban rivers into the city's ecosystem brings several advantages to address the root cause of the high pollution levels experienced by the city. These include the conservation of biodiversity, recovery of the environmental quality of water resources, contribution to the reduction of flooding; adoption of climate change adaptation measures; reduction of atmospheric pollutant emissions and greenhouse gases, and articulation of joint actions for conservation and recovery and environmental inspection between the municipalities of the Metropolitan Region and the State Secretariat for the Environment.

Moreover, the IWT modal has enormous potential to move and reduce high congestion levels from roadways to river canals, as well as reducing high pollution levels from cities, given its environmentally friendly characteristics compared to other means of transportation (Vilarinho, Liboni, & Siegler, 2019).

From an economic perspective, the revitalization and dynamization of the riverside area is attractive point for private sector investment. For instance, the creation of the bike path in Mario Covas Park has boosted the installation of commercial establishments to meet the demand of cyclists. Similarly, the modernization of the space where the Plant of Betrayal was previously located will give rise to a significant private investment of approximately R$300M (Mello, 2023).

The de-pollution of the rivers and the adequate treatment of the adjacent areas will result in an immediate appreciation of the spaces currently cohabiting with the polluted areas of the rivers Pinheiros and Tiete. In addition to improving public well-being and health, it will allow residents to reintegrate the river into their routines and valorize the properties located in areas close to the riverbed. The improved condition of the urban canals will create the possibility for citizens to carry out leisure activities on their waters and attract tourists to the city.

In our work, besides the collateral advantages associated with the revitalization of waters, the main focus is related to the fight against climate change through the implementation of environmentally friendly means of transport, reduction of emissions of air pollutants and greenhouse gases, reduction of the number of vehicles entering the city daily; reduction of time spent in road traffic; reduction of the deterioration of roads and urban centers.

5.1.2. Challenges in implementing inland water transportation

From the review of existing literature, it becomes evident that several barriers hinder the implementation of IWT. Here is a breakdown of the main challenges identified:

Boudhoum, Oztanriseven, and Nachtmann (2021) emphasized that the failure of inland waterways would impact more people than anticipated during the conception of the transportation system. Hendrickx and Breemersch (2012) highlighted the need for cost-effective transport and the impact of extreme weather events on navigation conditions, cost advantage, and reliability of IWT. Jan and Nepveu (2020) and Vilarinho, Liboni, and Siegler (2019) discussed the challenges associated with additional transshipment and administrative work, which can become a cost-effective issue. Vilarinho, Liboni, and Siegler (2019), Jan and Nepveu (2020), and Janjevic and Ndiaye (2014) pointed out technical issues related to infrastructure weaknesses, investment, institutional weaknesses, and intermodal services. Inadequate fairway conditions were mentioned by EC (2011) as a factor leading to suboptimal load factors, increased fuel consumption, safety risks, and decreased reliability. Gołębiowski (2016) highlighted the slow speed of inland navigation and the preference for comprehensive 'door-to-door' solutions by shippers and freight forwarders. The EC (2011) noted the long lifetime of vessels and engines as a challenge in improving the environmental performance of existing vessels. Porto, Alencar, and Theodoro (2019) discussed the challenges of rehabilitating polluted rivers in major cities due to urbanization and population density. Boudhoum, Oztanriseven, and Nachtmann (2021) emphasized the need for cooperation among stakeholders, while De Oliveira et al. (2019) highlighted the lack of confidence among carriers and retailers, leading to the need for inspections of goods delivered in commercial establishments. Tobias, Ramos, and Rodrigues (2019) discussed the lack of access and mobility as social challenges, emphasizing the importance of equity, accessibility, and mobility in transport. Bedla and Halecki (2021) highlighted the challenges posed by climate conditions, such as urban flooding, while Wang, Geng, and Rodríguez-Casallas (2021) mentioned the risk perception of climate change and its impact on sustainable initiatives. Vilarinho, Liboni, and Siegler (2019) mentioned the need for significant investments in infrastructure and the challenges of obtaining funding from local governments.

5.2. Objective

The main purpose of the framework proposal is to provide a structured and comprehensive approach that can serve as a foundation for investigating the details involved in our study on implementing inland transportation in the city of SP. The framework is intended to facilitate a thorough analysis of the subject matter, and to ensure that all relevant aspects are taken into consideration.

In developing our framework, we have used as a basis an assessment framework for urban transportation systems (Vilpponen, et al., 2021), which has been proven to be effective in other research studies. By utilizing this tool, we are confident that our framework will be robust and reliable and will provide a solid foundation for our research.

5.3. Framework

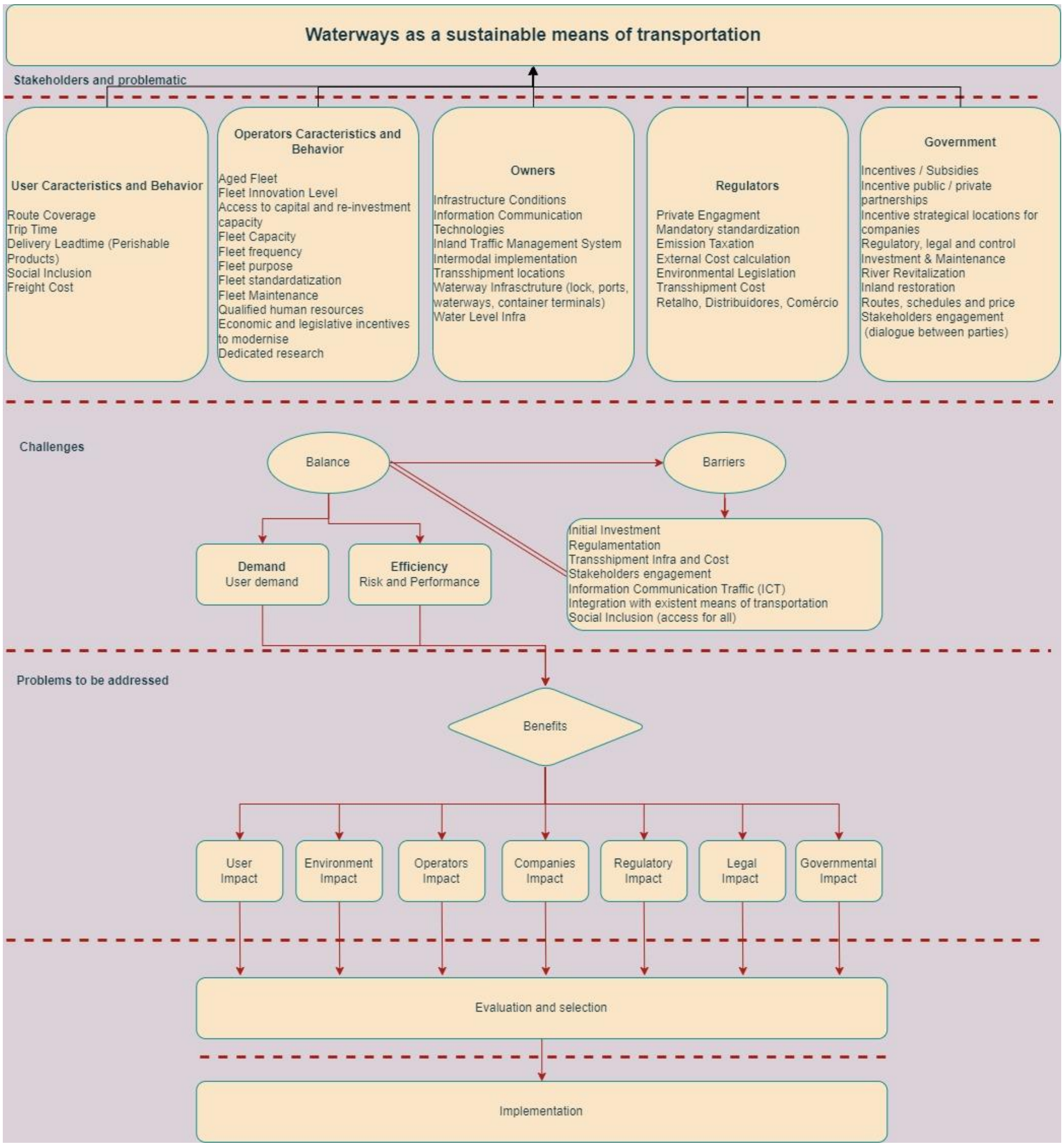

Figure 36 – Framework for the Implementation of Inland Waterway Transportation with emphasis on sustainability and stakeholder engagement (Author's Design).

5.4. Main Stakeholders and problematic

The literature shows that it is of utmost importance ensuring participation and commitment of key stakeholders to decrease risk of failure on implementing alternative vehicles for mobility. Stakeholders are those who hold an interest in the decision to be made, even they do not have a formal role in the decision-making process (Cieplińska, 2019), should be able to create the right synergies to deliver high quality transport services, by engaging both public and private sectors on identifying key challenges, pursuing appropriate solutions to better facilitate the implementation of feasible and innovative solutions.

From the literature review, it was possible to identify freight and passengers transport main stakeholders, pertain both, the private and public level: public authorities, shippers, freight transport operators, receivers, residents and owners (Galkin et al., 2019) (Quak, Nesterova, & Kok, 2019) (Cieplińska, 2019).

Shippers are considered the main stakeholders responsible for the goods being transported. "Shipper is the person or company who is usually the supplier or owner of commodities shipped" (also called Consignor) (Transportation, 2008, p. 91). Normally "are employed by retail and wholesale establishments, manufacturing companies and general industry" (Galkin et al., 2019). They select the most cost-effective freight operator provider, by ensuring delivering the goods safely to a receiver. Ideally, shippers' location should be strategically positioned allowing transshipping and bundling goods before transferring between intermodals, diminishing major impacts on the possibility to introduce various transportation options for urban freight.

Residents are people living in the cities who, in the of most cases, are the recipients of the parcels that circulate in the congested and polluted urban environment. At the same time, because of the need to travel for professional or personal purposes, they actively contribute to massive increase in trafficking within urban environment. In passenger transport, residents are the main stakeholders, who need to travel from one place to another. While on the one hand, they want to receive their goods in the shortest possible time, and move faster between places, on the other, they seek a better quality of life from the best sustainability practices at the service of society.

Users and receivers are a very important of the process, as they are target groups to receive goods from shippers. They play a crucial role in the success of the IWT sector, as they drive demand for the services and contribute to the economic and social benefits of the sector.

Users of IWT include companies that produce and ship goods, such as manufacturers, agricultural producers, and mining companies. Receivers of IWT include companies or organizations that receive the transported goods, such as wholesalers, distributors, retailers, and other end-users (Comission, 2023).

Owners in IWT are the individuals or companies that own or operate the vessels used for transporting goods or passengers on waterways. These may include companies that specialize in IWT, as well as individual vessel owners who lease or charter their vessels to transport companies (Comission, 2023).

Freight Transport Operators (transporters) are responsible to coordinate the process of consolidation of shipments from different shippers into one truck to get it as close as possible to the full load (Dente & Tavasszy, 2017). Transport operators plays a very important role in the logistic chain, where inter-plant distribution to warehouses, terminal or sales points is the most common activity among some other operations. According to OECD, transport operators can be divided into two categories: conventional and modernistic. Conventional, refers to firms confined to a limited activity (modal operators). Modernistic, firms that were free to move from their original transportation modal and have become organizers of transport chains working with various transport modals at the same time (Transport, 2023). Is that to say, transport organizers are responsible to integrate passengers and goods flows within urban environment (Cieplińska, 2019).

Regulator typically is a government or regulatory authority responsible for overseeing and enforcing regulations related to navigation and shipping on inland waterways, it may include shipping companies, port authorities, trade associations among others (Comission, 2023). Due to the great diversity of stakeholders involved, the regulation of the waterway sector in Brazil is highly complex. Elaboration of norms, planning, and development of policies, implementation, and maintenance of waterways, regulation of monitoring systems, availability of resources, and financing, are some examples of the most diversified stakeholders involved in the regulation of the sector (Transporte C. N., Aspetos Gerais da Navegação Interior no Brasil, 2019).

Public authorities play a key role in managing and organizing urban mobility. Their function is wide-ranging, considering different aspects, from the environmental to the economic. According to Janjevic and Ndiaye (2014), public authorities have mostly dedicated themselves to passenger transport in urban environments, focusing on a portfolio of solutions for this purpose.

Lately, due to the increasing demand observed in big cities, there is a clear need for more insight in sustainable freight transport in urban environments. Public authorities are responsible for promoting and participating in a wide range of activities, even those carried out in the private sphere, to encourage the implementation of environmentally sustainable measures that improve the quality of life of citizens. Moreover, local authorities are responsible to engage all stakeholders in preparing information system process taking into consideration ICT technology possibilities (Cieplińska, 2019).

5.5. Barriers

The regulations and norms governing inland navigation in Brazil are currently derived from regulations that originated from the maritime sector. However, many of these directives do not take into consideration the unique characteristics of the hydrographic basins found in Brazil. The regulations related to inland navigation in Brazil include the Constitution of the Federative Republic of Brazil of 1988, laws and decrees of the Presidency of the Republic specific to the waterway sector, norms of the Brazilian Navy, and resolutions of Antaq. There is a gap in the regulatory framework that has been identified, which allows for the simplification of the normative processes of inland navigation (Transporte C. N., Aspetos Gerais da Navegação Interior no Brasil, 2019).

5.6. Problems to be addressed

Based on the research conducted, there are some topics that should be prioritized to ensure the successful implementation of the waterway matrix:

Government (political support)

The role of local authorities is crucial in the implementation process, as they can press logistic chain stakeholders to shift towards more sustainable forms of conveyance, thereby accelerating the smart mobility transition within urban centers. Local governments must also collaborate with private companies, providing them the necessary resources such as skilled labor and financial support to promote the development of new green technologies. Due to high initial investment required for infrastructure, the government must reward companies that implement the most sustainable technologies. Additionally, there is a clear need for municipalities to commit to ensuring the de-carbonization transition.

Regulatory framework

Regulation in the sector is a matter of great concern and can have tremendously negative repercussions if not carried out correctly. Currently, due to the involvement of various stakeholders, there is no regulatory framework for the sector, which increases the complexity of regulation.

Navigable conditions

Based on our research, we have found that ensuring navigable conditions is crucial for the effective implementation of the waterway matrix for cargo and passenger transportation. To achieve this, minimum navigability conditions must be met, regardless of external variables such as weather changes. One of the primary considerations is to maintain the volume and density of the rivers at a minimum level to ensure the operability of IWT. Additionally, the construction and maintenance of ports and terminals, as well as the condition of mobile and fixed dams, and their respective operational infrastructure, are critical for the proper integration with other modes of transport.

Conclusion

The main objective of the study was to conduct research to evaluate the main challenges of implementing waterway transportation in the urban circuit of the city of São Paulo. The first activity was conducting a thorough investigation of related works, aiming to identify the main barriers and factors of success. The study also analyzed the history of urban planning in São Paulo to understand the reasons for the city's relationship with its rivers. The analysis identified the main challenges to implementing a waterway, categorized into multidisciplinary factors, such as Technical, Environmental, Economical, Governance, Social, and Legal.

The study emphasized that the city's mobility projects should not be carried out independently, as they are part of an urban ecosystem with interdependent actions.

While the revitalization of the Pinheiros and Tiete rivers offers significant benefits to São Paulo, waterway transportation presents a highly credible alternative with a lower carbon footprint and the potential to relieve the heavily congested main avenues of the city. However, despite the numerous benefits of IWT, it is important to remember, that a failure of the inland waterways would impact more people than anticipated during the conception of the transportation system.

The implementation of sufficient transshipment locations along the canals and adequate space for loading and unloading on the city's river margins is crucial to allow for efficient loading and unloading assessments. The lack of this infrastructure will result in additional time and cost increases for various stakeholders.

There is a clear need for the development of intermodal transport networks to facilitate the efficient movement of goods and passengers. Increasing investment in transport infrastructure can improve connectivity and reduce congestion, making inland waterway transport a more viable alternative to road transport. The study recommends integrating IWT with different modes of transportation, such as road, air, and rail, as well as encouraging the use of bicycle paths for urban mobility.

Service vessels can be used to maintain navigability conditions in urban rivers and may be used in heavy industry, construction materials, urban waste collection, and reverse logistics. Floating distribution centers can be a solution to reduce the number of vehicles circulating in São Paulo by using smaller vessels, such as electric or hybrid boats, to distribute small parcels within the city center. Using smaller vessels such as electric or hybrid boats for distributing small parcels within the city center could be a viable solution to reduce the number of vehicles circulating in São Paulo and alleviate the highly congested main avenues. This approach could also facilitate navigation in regions with low water density and integrate with other means of transportation. Moreover, implementing last-mile delivery with emission-free vehicles such as electric bicycles or electric vehicles can promote sustainable transportation and access areas that are not accessible by trucks. The state government should adapt the existing cycle paths for small parcel distribution, aiming to fully integrate different modes and ensure the effectiveness of city distribution. São Paulo has more than 500km of bicycle paths that could also be evaluated for use in supporting the city's logistics.

Despite the various applications of the waterway in supporting the improvement of urban transportation, several precautions need to be taken into account. During the literature review process, we came across some warnings regarding the analysis for implementation and the need to focus on specific sectors to facilitate the approach and its respective implementation.

The integration of IWT in the intermodal supply chain can face several economic challenges. One major challenge is the need for investment in infrastructure, including locks and canals, which can be costly and limit adoption by some businesses. In addition, the initial cost of purchasing cargo bikes and associated equipment for last-mile delivery can also be high, discouraging adoption by some companies.

The adoption of electric vessels may require significant capital investment and additional costs for operation and maintenance compared to traditional vessels, which can discourage some operators from investing in electrification.

Climate change can also have significant economic consequences for IWT, increasing costs associated with maintenance and repair of infrastructure and disrupting transport services due to extreme weather events.

Regulation and taxation can also pose economic challenges. A lack of clear regulatory frameworks can hinder investment in the sector, and policies related to fuel taxation and subsidies can impact the cost competitiveness compared to other modes of transport.

To encourage investment, it is crucial to address these economic challenges. Innovative financing mechanisms, including public-private partnerships, can foster collaboration between diverse stakeholders and promote investment in intermodal transport infrastructure.

It is also important to consider the long-term economic benefits of intermodal transport systems when making investment decisions, as they can lead to cost savings and improved efficiency in the long run. However, it is crucial to check the users' perceptions related to the usage of waterways as a mode of transport before starting a macro project to ensure its success. Large-scale projects must be carefully evaluated beforehand to avoid unsuccessful efforts. Our research identified cases in Europe where municipalities attempted to introduce large waterbus solutions but had to adjust their strategy to small, self-sufficient vessels with either pure electric or hybrid diesel-electric propulsion.

Regarding the limitations of the research, since it is a narrative research study, the conclusions and recommendations are mostly based on the author's interpretation of the data gathered. Additionally, the study may rely on interviews with stakeholders which can introduce biases and limitations. Furthermore, that should be noted there is a lack of research on the current situation of São Paulo´s rivers, and how waterways can be integrated in the city's ecosystem. The absence of clear guidelines and regulations can make it challenging to evaluate the feasibility and potential impact of IWT in the city accurately. Without adequate regulation, it may not be possible to draw firm conclusions or make concrete recommendations on the implementation of IWT in São Paulo. These factors may limit the depth and breadth of the study's findings and recommendations.

The findings of the present study highlight several areas where additional research can contribute to the successful implementation of waterway transportation and promote sustainable urban mobility in São Paulo. Future research should focus on the economic feasibility of waterway transportation, including infrastructure development and last-mile delivery solutions. Assessing the cost-effectiveness of locks, canals, and transshipment locations will provide valuable insights into financial viability. Identifying innovative financing mechanisms, such as public-private partnerships, can encourage stakeholder investment. Economic assessments of last-mile delivery options, like cargo bikes, will shed light on their affordability and long-term cost savings.

Infrastructure and strategic planning are areas that warrant further investigation. Research could focus on developing strategies for efficient routing, taking into account various potential limitations, water navigability, vessel capacity, traffic management, and transshipment locations.

Intermodality between different transport modes is a crucial area that needs to be addressed to ensure full integration into the multimodal network. Investigating connectivity and information sharing systems between modes would enhance the overall efficiency and attractiveness of waterway transportation in the city's ecosystem.

Understanding stakeholder perceptions and behavioral patterns is vital. Future research could delve into public attitudes and acceptance of waterway transportation as a mode of transport.

Lastly, future research could focus on developing regulatory frameworks and policies that support the growth of waterway transportation. Investigating international best practices and benchmarking against successful cases mentioned in this dissertation would provide valuable insights in this dissertation.

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