# Exploring a framework in designing smart circular ecosystems in the waterborne passenger mobility

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The emergence of climate change is affecting society, economy, and businesses around the world. To tackle this issue, the European Commission has introduced a series of legislative measures aimed at achieving climate neutrality in the EU by 2050. The whole transport sector will have to make a significant endeavour to achieve the goal. In recent years, waterborne public transport services have become an integral component of urban landscapes in numerous cities worldwide. Waterborne mobility can constitute a sustainable alternative in terms of energy consumption, noise, and pollution emissions. It reduces traffic congestion both on roads and on the railroad, supporting more liveable cities. However, there are still challenges to overcome to fully realize the sustainable potential of waterborne passenger mobility (WPM). To address these challenges and promote innovative and sustainable strategies, a holistic approach is required that considers the complex interactions among actors in the WPM ecosystem, including passengers, operators, regulators, and services providers. To achieve a sustainable and circular WPM ecosystem, digitalization can play a critical role. Several studies have shown that digital technologies can promote Circular Economy and circular strategies. Through a literature review, this paper explores the concept of ecosystem and Smart Circular Economy within the waterborne passenger mobility system, aiming to outline the WPM ecosystem and its relationship with smart circular strategies. Finally, the Smart Circular WPM Ecosystem was defined, and a framework was established to provide a foundation for advancing research on designing the waterborne passenger mobility sector towards a technological and circular transition.

***Keywords: waterborne passenger mobility; ecosystem; digital technology; circular economy***

## 1 Introduction

Climate change is a crucial topic that affect society, economy, and business all over the world. To address the issue organizations, institutions and companies are acting on reducing greenhouse gas emissions, promoting renewable energy sources, adopting sustainable practices, and implementing measures to adapt to the changing climate.

As declared in the European Green Deal and in the Sustainable and Smart Mobility Strategy (SSMS), the whole transport sector will have to make a significant endeavour to achieve carbon neutrality.

Urban mobility accounts for 40% of all CO2 emissions from road transport and up to 70% of other pollutants from transport (European Commission, 2019).

In 2019, about the half of the maritime traffic in EU was from ro-ro pax ships (roll-on, roll-off passenger ships/ferries), and cruise ships, which also covered more of the half of the port call activity (59%) (Ansaloni et al., 2022).

The global inland waterborne passenger sector is experiencing an increase on demand and on number of vessels, moreover the market is expected to grow from $1.64 billion in 2022 to $2.11 billion in 2027 (Inland Water Passenger Transport Global Market Report 2023, 2023).

Over the past few years, waterborne public transport services have become an integral component of urban landscapes in numerous cities and regions across Europe and the world (Johansson, 2020).

Waterborne mobility can constitute a sustainable alternative in terms of energy consumption, noise, and pollution emissions. It reduces traffic congestion both on roads, streets and on the railroad, and support more urban liveable cities increasing free land space. As declared by the European Parliament in the report on unleashing the potential of waterborne passenger transport, “making better use of available capacity of waterborne passenger transport could not only help reduce congestion and CO2 emissions, but also improve air quality and provide better transport services overall” (European Parliament Resolution, 2016).

Waterborne transport systems offer great opportunities for mobility in coastal and river cities, particularly in those dense urban areas where road transport has reached its full potential, but fuel-based emissions and high operating costs still limit its mass adoption (Campillo et al., 2019).

Although in the last thirty years the urban development of many cities focused also on revitalization and rejuvenation of waterfronts (Johansson, 2020), the waterborne passenger mobility still has various shortcomings that can hinder the adoption of sustainable and efficient solutions to utilize “natural free water roads”. The still high dependence on hydrocarbon combustion, pollutant discharge, waterway fouling, lack of modern and technological infrastructures, high-energy cost/consumption, and lack of trained personal underline the need of environmental and technological strategies, not only for the waterborne transport system itself but for the entire ecosystem of actors and organizations involved.

The concept of business ecosystem is emerging in the debates of firms, institutions, and scholars, aiming to shape the business model of companies and organizations towards a systemic and sustainable model.

An ecosystem in business is a community of interacting firms going beyond their industry boundaries to “mutually adapt and coevolve capabilities and roles to build a shared vision, set governance rules, and gain sustainable competitive advantage” (Li et al., 2022).

The design of products and services with an ecosystem perspective move the discussion from the traditional vertical relational set-up to more horizontal, integrated relations (Gaiardelli et al., 2021). The approach is not focused on the product or service performance anymore, but it starts from the network: the design process considers needs and aspirations of all the different stakeholders that concur to deliver the service or set of services, or rather the same value proposition.

Designing with such a holistic vision can uncover opportunities for sustainable solutions and for switching from a linear to a circular thinking.

The concept of ecosystem has emerged from the interlace among new business models and digitalization, moving the industry boundaries from product-system to systems of systems (Li et al., 2023).

Digitalization can support the expansion of the service offer, can expand the boundaries of the industry, and alter the structure of the supply chain.

At the same time digital technologies play a significant role not only to enable ecosystems, but also to promoting circular economy by enhancing resource efficiency during the usage phase, extending the product lifespan, and closing material loops (Alcayaga et al., 2019).

The promising function of waterborne passenger mobility in urban areas calls for innovative strategies to address challenges and opportunities for innovation and sustainability. This requires a holistic approach that considers the complex interactions among various actors in the ecosystem, including passengers, operators, regulators, and services providers. To achieve a sustainable and circular waterborne passenger mobility ecosystem, digitalization can play a critical role. The interplay between digital technologies and circular economy has been largely discussed in literature in the last few years, endorsing the great potentiality of digitalization in promoting circular systems, defining the concept of smart circular economy, and outlining smart circular strategies and frameworks.

These alliance among digital technologies and circular strategies has never been explored in the waterborne passenger mobility sector although it can unveil meaningful insights for sustainable solutions; furthermore, it was never considered in relation to the design of the entire ecosystem.

The topic of sustainability in waterborne passenger transportation has been addressed in recent years, but there is still limited and fragmented knowledge that lacks a comprehensive ecosystem approach, particularly in the design field. This paper aims to explore the waterborne passenger mobility and the concept of ecosystem to outline the attributes of the waterborne passenger mobility (WPM) ecosystem network.

Furthermore, the study aims to examine the smart circular paradigm and smart circular strategies, and to explore opportunities and challenges of a possible interplay with the waterborne passenger mobility ecosystem. The purpose is to define the framework of the Smart Circular WPM Ecosystem to systematize the knowledge and to extend the understanding on the application of smart circular strategies to the WPM, considering the whole ecosystem. The framework will define the concept of Smart Circular WPM Ecosystem and outline a basis to develop further research in the field and new design methodologies, tools, and practices.

## 2 Research methodology

This paper is centred on the understanding of opportunities and challenges for the design of the waterborne passenger mobility sector by considering its entire ecosystem and the interplay with smart circular strategies.

The research is settled in the emerging issues on circular economy, digital technologies and servitization, and is based on three main topics: the waterborne passenger mobility, the concept of ecosystem in business and design, and the paradigm of smart circular economy, which is described by the intersection of digital technologies and circular economy.

A literature review was carried out on Scopus database combining selected clusters of keywords and using Boolean logic to design search queries. Clusters were defined according to the main topics. As the smart circular economy concept is quite new in literature and it comes from two relevant sub-concepts the category was split in the two clusters of digital technologies and circular economy.

*Table 1. Summary of the keywords' clusters and visualization of the research gaps.*

| **Waterborne passenger mobility** | **Ecosystem approach** | **Digital technology** | **Circular Economy** |
|---|---|---|---|
| waterborne passenger mobility, inland waterborne mobility, waterborne passenger transport, inland passenger mobility | business ecosystem, service system, design ecosystem | smart technologies, digital technologies, technologies Industry 4.0 | circular economy, circular strategies |
| **GAP 1:<br>Waterborne passenger mobility + ecosystem** | | **Smart Circular Economy** | |
| **GAP 2:<br>Smart circular economy + Waterborne passenger mobility ecosystem** | | | |

Papers were selected according to the time frame, starting from 2013, and to subject areas, related with sustainability, technology, design, engineering, business, and management.

Based on these criteria, the search led to the extraction of 164 results.

A first screening was carried out reading titles and abstracts. The selection of those papers was done based on the objectives of the research: defining, describing, and conceptualizing the waterborne passenger mobility ecosystem; exploring the smart circular economy and the opportunities that can offer to the sustainability of the waterborne passenger mobility sector.

After this step, a total of 56 documents remained, which were subjected to a full-text reading and selected with the same criterion. The final 30 papers, used as the basis for this research, concerns with the waterborne passenger mobility system, or the description of its elements, like actors, stakeholders, services, or infrastructures; the sustainability or the use of digital technology in the sector; the meaning of the term "ecosystem" in business and design, within a service system; the definition of smart circular economy, the description of circular strategies, digital technologies, and their mutual roles.

An additional search for grey literature targeting reports, organizations' websites and European projects was made using Google's search engine, as complementary to the scientific knowledge.

Building on the results of the literature review, the three main topics were described to address the gaps and provide a definition of the waterborne passenger mobility ecosystem and its interplay with smart circular economy.

Finally, the Smart Circular WPM Ecosystem was defined, and a conceptual framework was established. This framework provides a foundation for advancing research on designing the waterborne passenger mobility sector towards a technological and circular transition.

# 3 Results and discussion

This section presents definitions and results of the research. Sections 3.1, 3.2, and 3.3 describe the three main topics, respectively, the waterborne passenger mobility, the concept of ecosystem in business and design, the Smart Circular paradigm. Sections 3.4 outlines the WPM ecosystem and its characteristics, whereas in section 3.5 the Smart Circular WPM Ecosystem is defined, and the framework is proposed. Section 3.6 describes possible opportunities and challenges that can be envisioned by applying the defined framework to literature and cases examples.

## 3.1 Waterborne passenger mobility

The research is focused on domestic waterway passenger mobility in the transportation sector. Waterborne mobility refers to the mobility service that moves people, or rather passengers, through waterways. This kind of transportation usually happens in inland or intercoastal waters, such as rivers, lakes, lagoons, or canals, and it is often identified also as inland passenger transportation (Ansaloni et al., 2022). Waterborne public transport includes canal passenger transportation, intercostal transportation of passengers, lake passenger transportation, water shuttle services, river passenger transportation, ship chartering with the crew, water bus and taxi services. When it refers to public transport, it includes vessels that transport people in scheduled services in urban areas (Johansson, 2020).

Although it is often overlooked in the common understanding of "public transport", passenger waterborne transport can be particularly useful in areas where other modes of transportation are limited due to geographical constraints, such as mountainous or coastal regions, or where land-based infrastructure is insufficient or underdeveloped. It can also be a more sustainable and environmentally friendly alternative to road-based transport, particularly in congested urban areas.

Around the world, plenty of cities are located on a body of water, like Venice, London, Liverpool, Gothenburg, Oslo, Amsterdam, Istanbul, Lisbon, Stockholm, Hong Kong, New York, Hamburg, and many others. The importance of water as a route for transportation of goods and people has had a profound impact on the development of human society, shaping the geography and economies of cities around rivers, lakes, and oceans (Cheemakurthy et al., 2018).

Historically, cities, cultural centres and economic exchanges were developed around inland and coastal waterways, but in the second half of the 20th century many cities experienced a decrease of industrial activity on their waterfront and a decline of use of the waterborne mobility. In the last thirty years, thanks to the revitalization of waterfronts, waterborne public transport services have become an integral part of the urban landscape in many places, cities and regions around Europe and the World (Johansson, 2020).

Waterborne mobility can play a significant role in future urban sustainable mobility schemes. It can reduce traffic congestion both on roads, streets and on the railroad, and support more urban liveable cities increasing free land space. It is often faster than road-based transport in congested urban areas and more flexible in case of accidents as the route can be change and easily re-controlled (Johansson, 2020). It can take advantage of natural infrastructures, "roads of water", already there. Moreover, it can provide a more scenic and enjoyable way to travel, which can attract tourists and provide a more pleasant experience for locals.

Despite the progress of the sector and the opportunities that it can offer as sustainable public transport means, waterborne passenger mobility still remains a relevant source of greenhouse gas and other pollutant emissions, harmful for the environment.

Several studies and European projects, started in the last few years, are working on the sustainability of the maritime sector, incentivized by the IMO (International Maritime Organization) strategy on GHG emissions and the climate neutrality target of the sector.

The majority of the work is about cargo ships or long-range routing ships, even though there are studies on ro-ro pax ships and ferries, especially on new propulsion systems and alternative fuels, on hull design, or on operational measures, such as improved navigation and vessel allocation systems (Grosso et al., 2021).

Few case studies adopting a systemic approach referred to the mobility service are emerging, but none of them deeply explore the ecosystem perspective potentiality. Interesting studies on green ports and smart ports develop a holistic and network-based perspective, but the viewpoint is on the port domain and its logistics, not on the transport domain.

Digitalization, servitization and automation are the major trend impacting the urban mobility sector which are affecting the waterborne passenger mobility too.

The constant tracking, monitoring, and connectivity capabilities enabled by digital technologies have facilitated the development of innovative transportation concepts such as Mobility-as-a-service and Automation-as-a-service.

In the waterborne transportation sector digital technologies are improving door-to-door trips making them adaptive and integrated across modes, moreover, they are enabling safe operation of assets, capacity use of available space and infrastructure. The whole lifecycle management of assets and equipment is monitoring constantly, enhancing business and policy decision making (European Inland Waterway Transport Platform (IWT) & European Barge Union (EBU) and the European Skippers Organization (ESO), 2020).

Companies in the waterborne passenger mobility sector are also increasing the use of technology for enhancing the passengers experience before the travel and on-board, like the development of apps or digital touchpoints to consult routes, book the ticket easily, evaluate ferry operators, and check the status of their travel in real time (Inland Water Passenger Transport Global Market Report 2023, 2023).

## 3.2 Ecosystem

The word “ecosystem” has different meanings according to the field, the discipline, and the context of use.

Coming from biology, the concept spread in other disciplines setting new theories and approaches, e.g., industrial ecosystem, economy as an ecosystem, digital business ecosystem and social ecosystem.

Moving into the fields of design and business, it can be described as a network of interconnected people or organizations that resembles a natural ecosystem due to the complex interdependencies.

Over the past twenty years the term has spread in discussions of strategy, both in research and practice (Adner, 2017).

Moore was the first author to conceptualize the definition of ecosystem in business as an “extended system of mutually supportive organizations; communities of customers, suppliers, lead producers, and other stakeholders, financing, trade associations, standard bodies, labour unions, governmental and quasigovernmental institutions, and other interested parties.” These communities work together in a highly self-organizing way (Moore, 1996).

The definitions emphasize two significant aspects of an ecosystem: the interactions within the system and the decentralized organization among different actors at different levels.

A business ecosystem is a community of interacting firms going beyond their industry boundaries in order to “mutually adapt and coevolve capabilities and roles to build a shared vision, set governance rules, and gain sustainable competitive advantage” (Li et al., 2022). The value is created through relations and networks. Thus, considering the whole system of actors and interactions involved in the development and delivery of products or services means to shift from a traditional linear perspective into a holistic network, circular, and ecosystem perspective (Li et al., 2023).

The design of products and services in an ecosystem perspective move the discussion from the traditional vertical relational set-up to more horizontal, integrated relations (Gaiardelli et al., 2021). The approach is not focused on the product or service performance anymore, but it starts from the network: the design process considers needs and aspirations of all the different stakeholders that concur to deliver the service or set of services, or rather the same value proposition.

Designing with such a holistic vision can uncover opportunities for sustainable solutions and for switching from a linear to a circular thinking.

The ecosystem perspective has emerged from the interlace among new business models and digitalization, moving the industry boundaries from product-system to systems of systems (Li et al., 2023). Technology can activate interaction between customers, machines, and service providers in an increasing complex system.

In service design the concept of ecosystem and its integrated approach is emerging over the last few years, with the definition of service ecosystem as a self-regulated and self-sufficient system of resources which is constituted of actors linked by shared system disposals and the same value proposition created through service exchange (Nie et al., 2019).

Designing with an ecosystem perspective implies to be involved in the arrangement of actors, processes, and technologies, considering interactions and touchpoints, and entails an approach which combines design and system thinking.

### 3.3 Smart Circular paradigm

The interest in the Circular Economy has grown in recent years and digital technologies have demonstrated a potential synergy to achieve circular goals. Digitalization can boost the transformation towards a more sustainable circular economy by providing accurate information on the availability, location and condition of products: it can help closing the loop, slowing the material loop and narrowing the loop with the increase of resource efficiency (Trevisan et al., 2021).

Circular Economy is an economic system which aims to change the current linear economy, reshaping the way resources are managed, products are made and used, and materials are treated afterwards. It is based on three principles: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature (Ellen MacArthur Foundation (EMF), 2023)

It is supported by a transition to renewable energy and materials. Moving towards a circular economy implies a systemic shift on decoupling economic activity from the consumption of finite resources, generating long-term resilience, business and economic opportunities, and environmental and societal benefits. Circular economy entails system redesign and aims to cyclical closed loops.

Circular strategies are groups of activities that intend to extend product lifecycle and close the material flows. In the academic literature, Laskurain-Iturbe et al. summarize the main circular strategies in four R-principles (Laskurain-Iturbe et al., 2021):

- Reduce: minimizing input consumption (raw material, energy, and water) and waste and emissions.
- Reuse: extending the useful life of products by reusing the product or its components when discarded by another consumer fulfilling their original functions.
- Recovery: extending the useful life of products and their parts by repairing, remanufacturing and components reuse.
- Recycling: reprocessing the materials to obtain a high degree of quality able to replace the use of natural resources.

Often the application of circular practices faces with some implementation gaps, but the use of digital technologies can help preventing those barriers. Digital technologies comprise tools, systems, and applications that enable the creation, manipulation, and transmission of digital data.

Digitalization enables to share and spread information along vertical and horizontal value chains, and even beyond them in larger networks. This permits to constantly track, provide and collect information along the system and across the lifecycle stages, to increase resource efficiency and improve decision making, helping to implement circular strategies (Bressanelli et al., 2022; Cricelli & Strazzullo, 2021; Tavera Romero et al., 2021; Trevisan et al., 2021; Kristoffersen et al., 2020; Alcayaga et al., 2019; Antikainen et al., 2018).

There are various classifications of digital technologies, and currently there is not a unique and clear consensus in the literature on how to categorize them. Nevertheless, different digital technologies often overlap each other and operate together in synchronicity within a system, such as Artificial

Intelligence which collects and analyses Big Data taken by IoT devices. Among different categorizations in literature, digital technologies can be clustered in Internet of Things (IoT), Big Data and Analytics (BDA), Additive Manufacturing (AM), Cybersecurity and Blockchain (CB), and Augmented and Virtual Reality (AVR). (Laskurain-Iturbe et al., 2021; Alcayaga et al., 2019; Lopes de Sousa Jabbour et al., 2018)

The IoT describes physical objects embedded with sensors connected within a network through internet, able to share information and to communicate with other systems.

BDA refer to the analysis of large amounts of unstructured data using data mining and advanced analytics techniques. This helps identify patterns, trends, and associations that can be used to improve decision-making and optimize processes. Artificial intelligence is often used to collect and analyse this data, and to train machine learning and deep learning algorithms.

AM are additive manufacturing techniques used to create three-dimensional objects, depositing materials in layers, starting from a digital computer-aided design. This technology is able to increase the level of flexibility, production speed and customization in manufacturing.

Cybersecurity refers to the practice of protecting computer systems and networks from theft, damage, or unauthorized access, whereas Blockchain is a digital, decentralized ledger that allows the secure and transparent recording of transactions.

Augmented and virtual reality (AVR) technologies enable the addition of digital elements to the real world to allow simulating real situations and provide an enhanced user experience. AR adds digital elements to a live view, while VR is based on computer-generated simulations of three-dimensional environments.

Recent research on the combination of digital technologies and circular economy has been set up the paradigm of Smart Circular Economy. This emerging concept can be defined as an industrial system that uses digital technologies during the product lifecycle phases to implement circular strategies and practices aimed at value creation (Bressanelli et al., 2022). Alcayaga et al. conceptualize smart circular systems as "industrial systems that are restorative and regenerative by intention and design, where smart use, maintenance, reuse, remanufacturing, and recycling are included in product-service systems' business models, enabled by digital technologies" (Alcayaga et al., 2019).

Bressanelli et al., in defining the Smart Circular Economy Framework, explored the roles of technologies during the lifecycle phases. When talking about Circular Economy and circular principles, lifecycle assessment cannot be avoided.

### 3.4 The waterborne passenger mobility ecosystem

In general, a transportation system refers to the combination of elements and their interactions that generate demand for travel and supply transportation services (Cascetta, 2013).

Waterborne public transport includes canal passenger transportation, intercostal transportation of passengers, lake passenger transportation, water shuttle services, river passenger transportation, ship chartering with the crew, water bus and taxi services.

Beyond the vessel itself, the waterborne passenger mobility system embodies all the facilities and services related with the transport domain, which refers to the activities about the handling of vessels, either during the route or as they are approaching or leaving terminals. Moreover, the system includes those activities related with the terminal domain, like shifting of passengers between vessels or other modes of transport, and administrative functions. Thus, these ensembles of activities are carried out from the interactions among multiple different actors, like vessel owners, terminal operators, port and transport authorities, fuel and energy providers, service providers. On the other hand, end users like passengers are the customers who demand for those activities.

The waterborne passenger transport system can be summarized in some basic elements (Gracan & Jugovic, 2022):

- Employees at the passenger shipping companies.
- Passengers ship as a means of transport.
- Waterways as the traffic route.
- Passengers as the objects of transport.
- Passenger terminals as infrastructures.

An ecosystem can be defined as “the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize” (Adner, 2017).

Based on the definitions of the WPM and the definitions about the concept of ecosystem, the authors defined the WPM ecosystem as the system of actors and their multilateral interactions that concur to co-create the mobility service of passengers’ transportation through waterways. Starting from the value proposition the ecosystem “identify the set of actors that need to interact in order for the proposition to come about” (Adner, 2017).

The value proposition of the waterborne passenger mobility is to provide the moving of passengers from a location to another through waterways in urban areas. It implies that the service offer concern not only the journey on water, but also departures and arrivals at terminals.

The waterborne passenger mobility system incorporates various actors, at different levels and with diverse complementary roles. It includes ship owners, shipbuilders, ferry operators, ship staff on-board, maritime and transport authorities, fuel providers and energy suppliers, terminal operators, service, and maintenance providers (Bjerkan et al., 2019).

Actors have been categorized in different ways according to roles, domains (waterway transport, port or hinterland transport) (Bjerkan et al., 2021), actions (government and other policy influencing institutions, port and infrastructure providers, operators, passengers) (Kubek, 1999).

Based on the literature analysed, a categorization of actors has been done to describe the main roles that are addressed in the waterborne passenger mobility ecosystem.

- Passengers: the individuals who use the waterborne transportation system to travel from one location to another.
- Transport operators: companies or organizations that own and operate the waterborne vehicles and infrastructure used for passenger mobility.
- Infrastructures providers: entities that build, maintain, and operate the physical infrastructure that supports waterborne passenger mobility, such as ports, docks, and terminals.

- Service providers: companies or individuals that provide ancillary services related to waterborne passenger mobility, such as ticketing, food service or entertainment.
- Energy providers: companies that provide fuel or electricity for vessels and infrastructures.
- Regulators: government agencies or authorities that oversee and regulate the operation of waterborne transportation systems, ensuring safety and compliance with applicable laws and regulations.

Those sets of actors have been analysed to identify their relations and roles within the ecosystem.

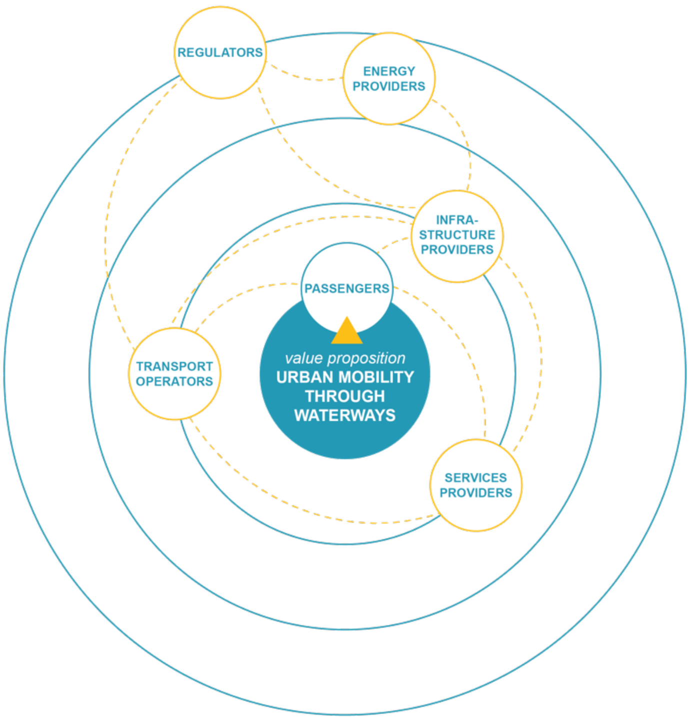


*Figure 1. The ecosystem map of the waterborne passenger mobility system.*

The WPM ecosystem map describes all the players that collectively create the value proposition of the system. Those are the actors who perform practices and deliver services or value to passengers.

The ecosystem map also identifies interactions among them, and the information required, used, or shared within the system. Interactions describes their roles and unveil touchpoints and dynamics.

Transport operators offer to passengers a transport means (vessels) and transport services on-board. Infrastructure providers offer to passengers a place to arrive, to depart, to shift route, and to wait (terminals) and various related services. At the same time, infrastructure providers offer to transport operators a place to operate with departures and arrivals, an area to dock and a service of bunkering and energy recharge.

Service providers offer to transport operators and infrastructure providers services which will be delivered to passengers on-board or at terminals (e.g., ticketing, food, entertainment), moreover, they offer services directly to passengers (e.g., apps for booking or purchasing the travel).

Energy providers deliver fuel and electricity for infrastructures and terminals, which are also used by transport operators to load and restock ships.

Finally, regulators design and deliver guidelines and rules for energy providers, transport operators and infrastructure providers, to regulate and manage safety, environmental and technical issues.

## 3.5 The Smart Circular Waterborne Passenger Mobility Ecosystem

The WPM ecosystem and its definition were explored in relation with the concept of Smart Circular Economy.

The Smart Circular Waterborne Passenger Mobility Ecosystem is a transportation system for passengers on waterways, which performs circular strategies and practices enabled by digital technologies, through its network of actors, to enhance sustainability.

Based on the aforesaid definition established by the authors, the Smart Circular WPM Ecosystem framework is proposed, which interrelates the WPM ecosystem with smart circular strategies to explore possibilities of the use of digital technologies in enabling circular practices.

Starting from the core, the framework is composed of the WPM ecosystem, with its actors and relations. Moreover, it considers the life cycle phases of the ecosystem itself, of its dynamics among actors and of its touchpoints. Then, the framework accounts the Circular Economy R-principles which can be implemented into the ecosystem using digital technologies. The role of digital technologies in enabling circular principles throughout the life cycle of the ecosystem can generate smart circular strategies to foster the ecosystem itself towards sustainability.

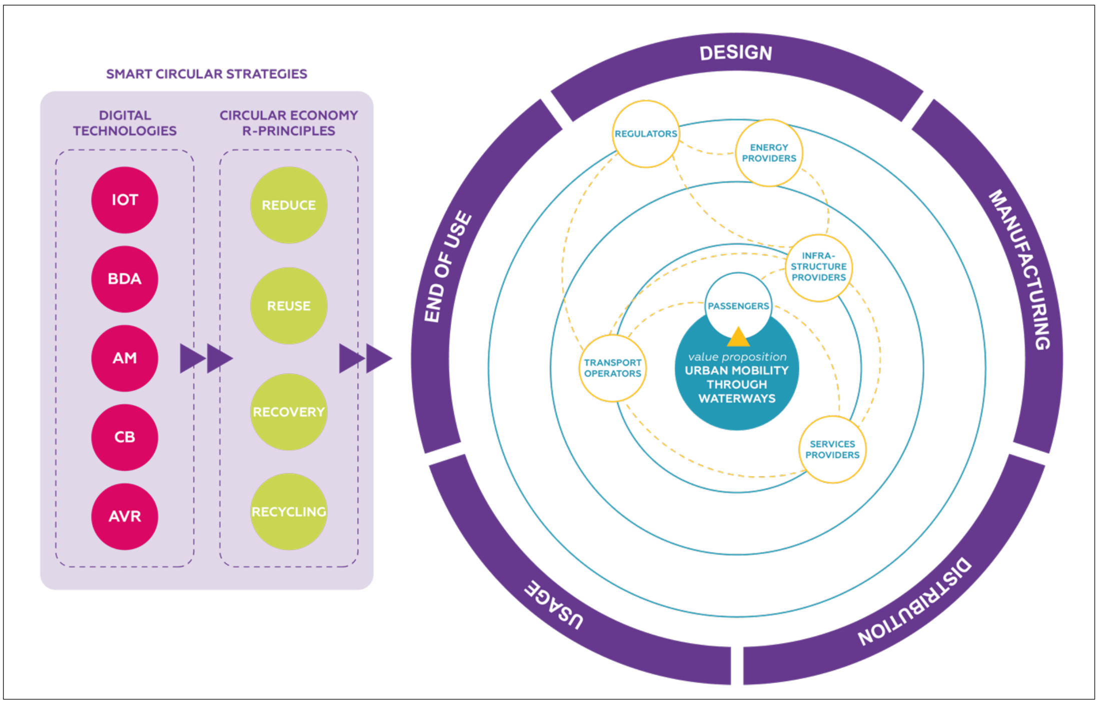


*Figure 2. The framework of the Smart Circular Waterborne Passenger Mobility Ecosystem.*

The framework shows the complexity of applying Smart Circular Economy to a systemic dimension, where the network can be considered at different levels and from different actors' perspectives.

By crossing the concepts contained within the framework and investigating the interplay among the different elements, new needs and relations among actors can be envisioned, and opportunities and challenges for the conceptualization and the design of a sustainable waterborne passenger mobility ecosystem can be underlined.

## 3.6 Opportunities and challenges

As mentioned before, the knowledge on circular economy applied to the WPM sector using digital technologies is still poor and fragmented, but interesting opportunities and relative challenges can be envisioned by applying the defined framework to literature and cases examples.

Starting from digital technologies, some examples of circular practices applied to the WPM ecosystem can be individuated.

IoT technologies allows for products to share information over their lifespan. It facilitates operational excellence during the manufacturing of vessels or waterfront infrastructures by reducing scrap rates and equipment wear and tear, decreasing the environmental impact. It allows for tracking and monitoring the WPM service to ensure a more efficient navigation and a better scheduling of maintenance and repairs of the service facilities. IoT technology can monitor the delivery and bunkering of fuels and energy at terminals, improving operations and minimizing leakages. Finally, IoT helps capture lifetime information, and minimize uncertainties involved in recovery strategies, promoting better decision-making for circular strategies such as reusing, remanufacturing, and recycling.

BDA can help to improve resource management across the entire product lifecycle by analysing data from the IoT. They can also be used to support decision-making on the logistics of the WPM service both improving route and scheduling and optimizing energy and resource supplying. Additionally, data mining and advance statistical analysis can enable preventive, predictive, and condition-based maintenance of the assets and infrastructures of the system.

AM can enable circular practices allowing local, on-demand, efficient, and real-time production, reducing material waste, and transportation needs. It is particularly relevant for maintenance strategies which can extend the lifetime of products and facilities' component of the system by enabling on-demand production of spare parts for repair and upgrading purposes (e.g., retrofitting or restoration of terminals or vessels furniture).

By providing trust, transparency, traceability, and security, cybersecurity and blockchain can ensure the tracking of resources across the value chains within the service exchanges among the ecosystem stakeholders, fostering systems integration and circularity.

AVR technologies through virtualization can facilitate the redesign of vessels and infrastructures towards more circular, repairable, and modular solutions. Moreover, it can also encourage more flexible work by providing remote assistance and guidance during service and maintenance activities, reducing transportation needs.

The greater challenges in the application of a smart circular model to the WPM lays in the ecosystem dynamics: the role of the actors, their interactions, and co-operation are fundamental to achieve long-term and integrated solutions. Regulators have the role of enhancing a normative infrastructure that can support the adoption of digital technologies and the application of circular strategies. On the other hand, transport operators, infrastructure, and energy providers, need to co-operate together through the value chains integration enabled by digitalization.

# 4 Conclusions and further developments

The framework of the Smart Circular WPM Ecosystem lays theoretical foundations to new research streams on sustainability, mobility systems, and Smart Circular Economy, not only for design and management, but also to many other disciplines, thanks to the holistic and interdisciplinarity aspect of the theme.

This primary study based on academic and grey literature highlighted the knowledge gap both from a theoretical and practical perspective. By exploring the relations among the WPM sector, the concept of ecosystem and the smart circular paradigm, the Smart Circular WPM Ecosystem framework was established as a method to analyse the state-of-the-art and emerging practices, moreover, to envision possible opportunities by understanding how digital technologies can trigger circular practices in the WPM system of actors.

The concept of Smart Circular WPM Ecosystem will be further developed with deeper insights and findings from both theoretical and empirical studies, to approach the smart circular concept with a more holistic and integrated perspective.

Future research needs to work on better defining the WPM ecosystem with stakeholders' interviews, case studies analysis and field analysis, to outline further attributes and details on actors, interactions, and touchpoints. At the same time, smart circular strategies will be further analysed by exploring the possible roles of each digital technology to implement Circular Economy R-principles.

The aim of developing this knowledge is to understand how actors or categories of actors and their mutual relationships can influence and be influenced by smart circular strategies, and consequently, how the ecosystem can be rethought, redesigned, and reshaped to foster circularity throughout its lifecycle.

Questions to be answers would be: what actions can each actor take within the ecosystem, as well as with other stakeholders, to implement sustainability and circularity? Which digital technologies would be beneficial in different stages of the lifecycle to facilitate circular strategies? How can the ecosystem be modified to become "smart and circular"? Would it be necessary to conceive new actors, relationships, or touchpoints?

A deeper knowledge on the Smart Circular WPM Ecosystem concept can lead envisioning new opportunities and challenges for the sustainability of the waterborne passenger mobility sector.

Starting from this definition, exploration and conceptualization further research will define a methodological framework within developing strategies, guidelines, and tools to design Smart Circular WPM Ecosystem.

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