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Connectivity Benefits of Small Zero-Emission Autonomous Ferries in Urban Mobility—Case of the Coastal City of Gdańsk (Poland)

Maciej Tarkowski * and Krystian Puzdrakiewicz

Division of Regional Development, Faculty of Social Sciences, University of Gdańsk, 80-309 Gdańsk, Poland; krystian.puzdrakiewicz@ug.edu.pl

* Correspondence: maciej.tarkowski@ug.edu.pl; Tel.: +48-58-523-65-55

Abstract: An increase in energy-efficient transportation is one way that cities try to mitigate climate change. In coastal cities, public water transit is also undergoing transitions. A small zero-emission autonomous ferry seems to be a cutting-edge technology in this field. This study aims to decrease the knowledge gap in research on the impacts of autonomous passenger ferry development on urban mobility. In particular, the central theme regards the extent to which the new transport solution can help improve sustainable mobility patterns. This study explores the local spatial context of ferry development, land-use patterns, and transport network structure, and moderates the shift in urban mobility practices. Regarding land use patterns, the case of the coastal city of Gdańsk has been documented in secondary qualitative and quantitative data, including in a large body of policy documents, accompanying expert opinions, and scholarly literature. This study strongly emphasises that a typical short river crossing, due to autonomous vessels, can regain a competitive position, which was partially lost due to linear routes along the river. The research identified crucial benefits of autonomous ferry shipping on urban mobility by increasing public transport network connectivity, reducing travel distance, and creating modal shifts towards foot travel and bike riding. It appears as an exciting scalable solution for cities where limited or dispersed demand prevents achievement of economies of scale, therefore diminishing the necessary expenditures.

Keywords: connectivity; autonomous ferry; zero-emission ferry; urban mobility; sustainable mobility; public transport; electric propulsion; sociotechnical regime; coastal city; Gdańsk

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1. Introduction

Cities contain more than half of the world's population, consume three-quarters of global energy production, and play a similar role in greenhouse gas emissions; they are the core of climate change mitigation [1] and the core of substantial fields of scientific research on sustainability [1–5]. Transport is a substantial source of urban greenhouse gas emissions. Chen and Kauppila [6] estimated that, in 2015, world urban systems, limited to cities of over 300,000 people, covered 37% of global CO_2 emissions from passenger transport and 20% of the entire transport sector. Cities have tried to increase energy efficiency in transportation. Zero-emission or zero-carbon solutions have become feasible technological solutions, but their implementation involves city authorities enacting complex, multicriteria decision processes that require sophisticated supporting tools [7,8]. As a multilevel perspective on sustainability transitions [9–11] suggests, technological innovation development is insufficient. A profound shift in sociotechnical systems consists of networks of actors, institutions, material artefacts, and knowledge [12], which are all necessary to diffuse the innovation from niche to mainstream, defined as a sociotechnical regime [13]. The sustainability transition factors differ across places and spaces [14]. Therefore, the essential question is how and why are the transitions similar or different across locations [11,15]. By exploring the local spatial context of innovative zero-emission autonomous ferry development, this study helps to answer that question.

This study aims to diminish the knowledge gap in research on spatial or place-based factors of sustainability transition in a broader context. The built environment—land-use patterns and transport network structures—moderates the shift in urban mobility practices, but they are underestimated as transition factors [14]. In a narrow context, the study tries to reduce the gap in the research on the impact of autonomous passenger ferry development on urban mobility. In particular, the extent to which the new transport solution can help improve sustainable mobility patterns is the central theme. From the sustainable mobility paradigm point of view [16], autonomous ferries may change modal shift, reduce travel distance, increase transport energy efficiency, and reduce pollution. The demonstration effect increases public acceptability and supports active mobility in which pedestrians and cyclists are the target group of the small autonomous ferries, therefore raising public health [17]. In coastal and riverside cities, the ferries bridging opposite banks can play a significant role in walkability progress by radical improvement in path and street connectivity [18,19].

The research procedure consists of five stages and corresponding objectives (Figure 1). The premises are formulated on the basis of previous experiences in waterbus operations, which is the initial research stage. The second and third stages focus on the demand side, specifically, the living spaces and workplaces near the rivers and the location of leisure and tourist attractions. The final step is to evaluate the potential benefits of small autonomous ferry introduction on urban mobility.

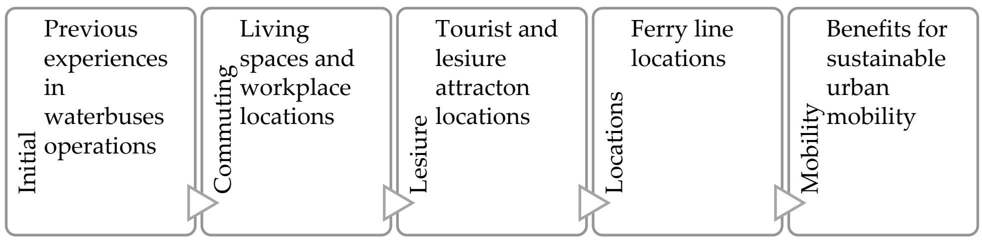

Figure 1. Research stages and aims. Source: own elaboration.

The study emphasises that a typical short river crossing, due to an autonomous vessel, can regain a competitive position, which was partially lost due to linear routes along the river. It also identifies crucial benefits of autonomous ferry shipping on urban mobility, including travel distance reduction and a modal shift towards foot travel and bike riding, resulting in public health improvement. The results support the theorem that cities can be considered a bridge between niches and regimes that provide the actual conditions for implementing sociotechnical configurations [20]. As the case study, the study creates one of the “new varieties that subsequently can be fused through recombinant innovation, triggering a technological transition” [21].

Several experiments on zero-emission autonomous ferries for urban water, mainly in Norway and nearby, was carried out [22]. The Norwegian University of Science and Technology and Zeabus, a spin-off from the university, developed small autonomous passenger ferries in an urban setting. In December 2020, milliAmpere, the first autonomous battery-powered small ferry prototype (5 m long and 2.8 m wide monohull fit for five researchers) completed a fully autonomous operational test in Trondheim. The full-scale prototype (8.5 m long and 3.5 m wide monohull designed for 12 passengers), miliAmpere2, was placed into an irregular trial as a living lab in Trondheim city. The ferry equipment consisted of induction charging, a battery pack, four azimuth trusters, computing hardware, a sensor package (precise positioning system, radar, lidar, optical and infrared cameras), and a dynamic positioning system. They are also currently developing remote support centres, docking stations, and user interaction procedures. Zeabus, in cooperation with the municipality, port authority, local transport operator, and the maritime authorities, will design and launch the first ferry system in 2022 [23]. Trondheim is not the only city developing autonomous ferries. Knoxville, in the United States of America [24]; Teylingen [25]; and Amsterdam, the Netherlands [26], are also in process of autonomous passenger boat development.

Broad literature studies [27] have proven that urban experiments with low-carbon transport mainly focus on low-emission vehicles [28–31] and rapid bus transit systems [32–36]. However, urban water transit plays a significant role in coastal cities' public transport systems [37] as commuter support [38–40] and simultaneously as an attraction for tourists [41,42]. In the case of a dozen large cities worldwide, the electrification of water transit systems is in progress. Newly built or retrofitted ferries equipped with pure electric or diesel–electric hybrid propulsion have been placed into operation. Three dominant pathways of this transition were identified—a comprehensive carbon-neutral policy, a transport sector policy, and a research and development policy [43]. Despite this progress, there are still a large number of cities without conditions and capabilities for large scale low-carbon water transit transition or development. In these cases, the feasible solution may be autonomous small vessels or boats, which require much lower capital and operational expenditures and which allow to scale the project to low shipping intensity [44].

A study relating to all the above-mentioned questions fits into a multi-level transition perspective [9–11], examining shifts in sociotechnical regimes towards electromobility instead of technical development issues broadly documented in scientific publications [44,45]. The literature of the field in the study is modest due to the thus-far initial implementation stage of the small autonomous ferries concept. The authors developing the milliAmpere project in Trondheim outlined the requirements for a maritime autonomous surface ship in urban passenger transportation [46]. They mainly identified technical questions of safe and secure navigation. However, outlined questions are a starting point for a shift in sociotechnical regimes. Amsterdam's experiment, which involves autonomous platforms combined to form floating bridges and stages, as well as to collect waste, deliver goods, and transport people, has also been discussed [47]. Operational benefits for autonomous water taxis in logistics were also a subject of the study [44]. The results showed that autonomy can lead to substantial savings on travelled distance due to the number and locations of parking terminals, feasible only for autonomous systems.

The city of Gdańsk seems to be an interesting case of using a small autonomous vessel to improve the connectivity of the public transport system and to make urban mobility more sustainable. The city, inhabited by about 471,000 people, is located on the southern coast of the Baltic Sea. With Gdynia and Sopot, it forms the core of one of the largest metropolitan regions in Poland, populated by approximately 1.6 million people. Regarding functional specialisation, the region is classified in category four (the lowest) of the Metropolitan European Growth Areas, with several other urban regions such as Bordeaux, Genoa, le Havre, and Southampton [48]. The location in the mouth sections of the large river (Vistula) and its tributary (Motława) were determinants in the city's spatial development directions. The historic Hanseatic city centre; the port; and industrial, residential, recreational, and tourist areas occupy the banks of these rivers. The beds of these rivers constitute a transport barrier, as the possibility of building permanent bridges is limited by the necessity to maintain the patency of the waterways. In recent years, two kinds of attempts have been made to alleviate this problem. As part of the revitalisation of the downtown river island, they built two pedestrian drawbridges.

Unfortunately, the attempt to revive the waterways by launching waterbuses ended in a fiasco. From 2008 to 2019, it served two seasonal lines connecting essential city points located on both sides of the rivers, which were equipped with appropriate harbours. The lack of modern ships, low running frequency, and high operating costs were all significant for servicing tourist traffic. However, this project did not constitute an attractive offer for commuters [49]. The COVID-19 pandemic and concurrent financial difficulties have brought it to an end. Studies on replacing the ships used thus far with modern vessels with pure electric or hybrid diesel–electric propulsion have not shown a possibility of significantly reducing the costs of servicing waterbuses [50].

For this reason, Gdańsk is an excellent example for proposing a radically different model for the development of urban passenger shipping. Instead of long routes parallel to riverbanks that are serviced by large waterbuses operated by a crew, this study verifies the effects of introducing a set of small autonomous vessels to cross the river and link to two or three points on opposite sides. Moreover, the Autonomous Vehicles/Vessels Working Group has started its activity in Gdańsk [51], which is the outcome of the regional smart specialisation strategy introduction.

This study adds the next aspect to the discussion on benefits for a small autonomous ferry. It focuses on spatial conditions of potential progress in sustainable mobility, especially walkability that emerged from vessel autonomy. This study is not a feasibility study. It omits detailed technical solutions and legal conditions that still do not regulate the use of autonomous vehicles.

2. Materials and Methods

Case studies are a leading research method, the outcomes of which are referred to in this study. It is a qualitative tool effectively used in various fields of social science research to investigate the impact of policy and practice [52,53]. The method is also widely adopted in urban studies [54,55]. Five primary research stages make up the research procedure (Table 1). A specific research objective was assigned to each of them. Appropriate research methods were applied at each stage, adequate to the problem and available sources. The premises were formulated on the basis of previous experiences in waterbus operations as an initial research stage. The second and third stages focused on the demand side, specifically the living spaces and workplaces near the rivers. In the case of Gdańsk, the one kilometre buffer was especially interesting due to the concentration of human activities related to waterfront areas [56]. On the basis of previous operational experiences and potential demand analysis, the location decision process was carried out. The final step was to evaluate the potential benefits of introducing a small autonomous ferry on urban mobility. The public transport timetable was used to assess the benefits of reducing travel time between areas on the opposite shores and estimates of travel time by foot and car, generated by Google Maps. The extent to which these benefits are consistent was also verified with the expectations contained in the urban development master plan. The master plan consisted of several loosely related documents such as socio-economic development strategy [57], operational programmes [58], and general spatial management plans [59] in the Polish legal framework. The local revitalisation program [60] also plays a significant role in Gdańsk.

The analysis was initiated through a comprehensive set of quantitative and qualitative data regarding waterbus system performance, current land use, and directions of spatial development, as well as tourist flow patterns. Expert opinions and strategic development documents helped in developing a better understanding of the nature of small autonomous ferry implementation conditions and to specify the possible benefits for urban mobility. In order to identify the spatial distribution of the most important areas of concentration of city-forming functions, we used spatial data, which are presented in Figures 1 and 2. These data contain information on the transport system of Gdańsk riverside areas, including data on the number of registered inhabitants and the concentration of jobs by transport regions, which were provided by the Gdańsk Development Office.

Table 1. Research stages, objectives, materials, and methods.

Stage	Objective	Materials	Methods
Initial (1)	Identification of autonomous ferry introduction premises on the basis of previous experiences in waterbuses operations	Data of the transport operator (Municipal Transport Authority) [61,62] Results of the expert opinion on the operation of waterbuses [63] Research studies on the waterbus system in Gdańsk [49,50]	Spatio-temporal statistical data analysis Literature review
Commuting demand (2)	Specification of demand in terms of commuting on the basis of analysing living space and workplace locations	Geodetic and cartographic data available from public resources [64–66] Data with high spatial resolution on the number of inhabitants and workplaces [67]	GIS method: choropleth maps
Tourist and recreational demand (3)	Specification of demand in terms of location and rank of attractions for tourism recreation and leisure	Location of the most crucial tourist attractions [66,68]	GIS method: single symbol map
Ferry line locations (4)	Specification of ferry line locations	Research stages 1, 2, and 3 outcomes	GIS method: spatio-temporal accessibility analysis
Benefits in mobility (5)	Identification of ferries' potential support for sustainable urban mobility	Research stage 4 outcomes Public transport timetables [69] Google Maps [70] Urban development masterplan [57–60]	Spatio-temporal accessibility analysis Strategic and operational development goals and qualitative analysis

Source: own elaboration.

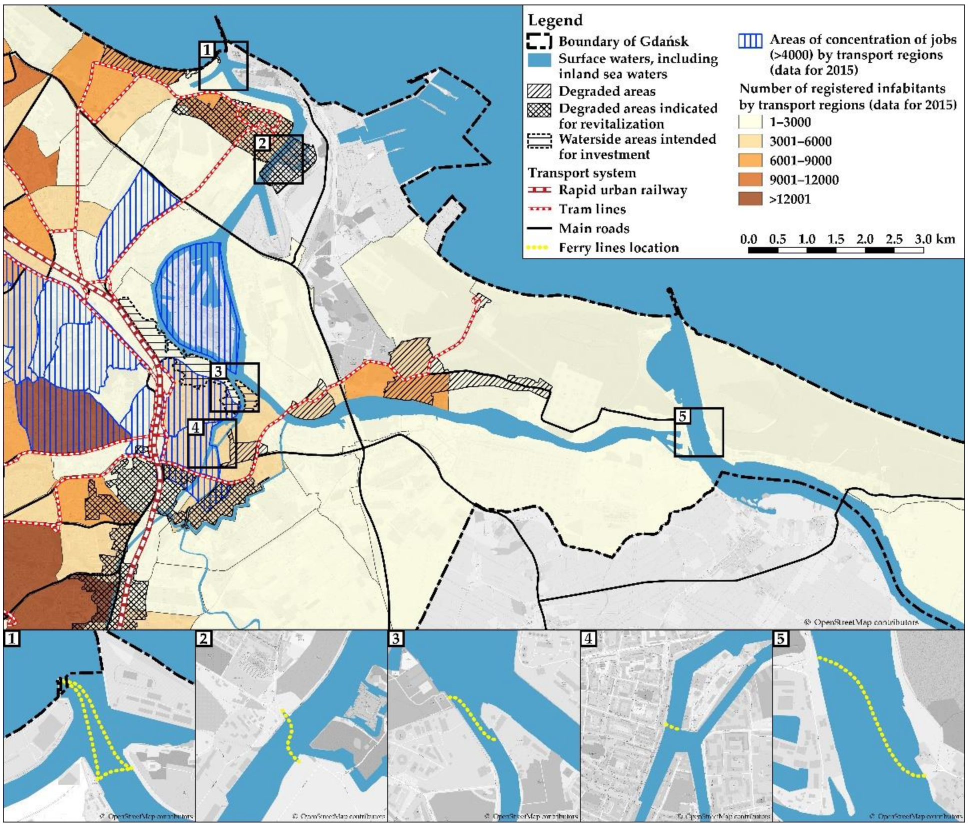

Figure 2. Location of the small autonomous ferry crossing in Gdańsk on the background of living space and workplace spatial patterns. Source: own elaboration based on [64,66,67].

3. Results

This study formulated two kinds of outcomes: The first covers river crossing locations serviced by autonomous ferries and important functional features such as travel distance between riverbanks and dominant function, traffic intensity, and seasonality. The second summarises the direct potential benefits of reducing travel time. The potential indirect advantages for walkability and public health benefits were also reported.

3.1. Autonomous Ferry Line Locations and Their Main Features

Spatial variability of demand examination combined with spatio-temporal accessibility analysis allowed for specifying five locations for river crossing serviced by small autonomous ferries (Figure 2).

Four of the connections are linear between two opposite riverbanks, while another establishes links between three stops, separated by a fairway and a harbour basin. The ferry crossing length does not exceed 500 m (Table 2). However, in three locations, it is much shorter. Tourism and recreation are essential to the function of all ferry crossings. Each line connects stops that are in the vicinity of the most visited attractions [68], which are anthropogenic (historic downtown buildings, post-shipyard areas related to the heritage of the Solidarity protest movement, place of the symbolic beginning of the Second World War) and natural (green areas and beaches) (Figure 3). However, besides historic downtown, there are no densely inhabited residential areas, service/industry parks, or workplaces near the ferry stops. Therefore, the substantial demand from commuters is limited to two locations (Młode Miasto–Polski Hak and Muzeum Morskie–Sołdek). In the first location, travel demand will result from the bold revitalisation of post-shipyard areas (Młode Miasto as the new city downtown) and new residential and service buildings (Polski Hak). The detailed design solutions of the planned nearby river crossing tunnel, depending on the extent to which it will be friendly to pedestrians and cyclists, will also impact ferry crossing attractiveness. Due to the short travel distance, favourable nautical conditions, and the possibility of the location of the remote support centre nearby, the ferry crossing at the heart of historic downtown (Muzeum Morskie, Sołdek) can play the role of living laboratory for autonomous vessel development. The dominant function directly connects with the degree of seasonality because tourism in Gdańsk is seasonal.

Table 2. Essential features of the small autonomous ferry lines in Gdańsk.

Location Number (Figure 2)	Direction	Distance (m)	Main Function	Traffic Intensity	Seasonality
1	Brzeźno–Latarnia Morska–Westerplatte	440/215	Tourism and recreation	High	Seasonal
2	Nabrzeże Zbożowe–Twierdza Wisłoujście	220	Tourism and recreation	Moderate	Seasonal
3	Młode Miasto–Polski Hak	175	Commuting/ tourism and recreation	Moderate	Year-round
4	Muzeum Morskie–Sołdek	70	Living lab/ tourism and recreation/ commuting	Moderate	Year-round
5	Górki Zachodnie–Górki Wschodnie	400	Tourism and recreation	Low	Seasonal

Source: own elaboration.

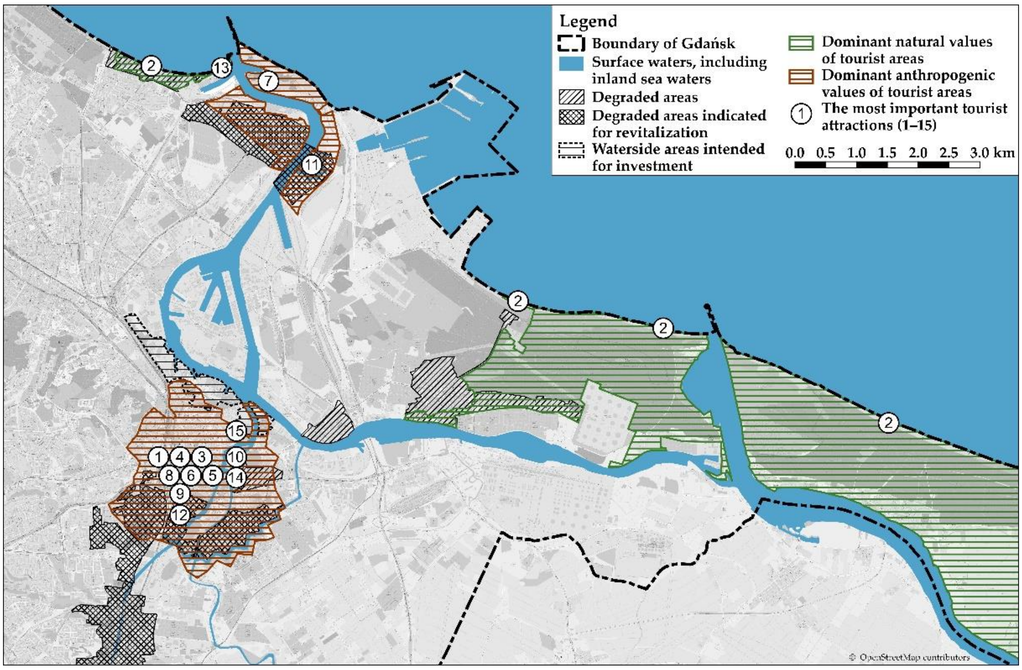

Figure 3. Location of the main tourist attractions in Gdańsk. Source: own elaboration based on [59,64,66,68].

The scope of this study does not provide a possibility to quantitatively estimate passenger flow. However, data on passenger traffic regarding the former waterbus system [62] and tourist destination attractiveness [68] allow for quantitative estimation of potential traffic intensity (Table 2). The incidence of high tourist attractions and many waterbus passengers point out the Brzeźno–Latarnia Morska–Westerplatte location as a high-intensity ferry crossing. In contrast, the Górki Zachodnie–Górki Wschodnie ferry crossing indicates low potential traffic intensity. However, this connection will become attractive for bicyclists as an alternative to the current course of the EV10 international bicycle trail. The remaining three places have average potential traffic volumes. For the two historic downtown locations, significant demand may be limited by the availability of alternative pedestrian routes. The following section discusses this issue.

3.2. *Benefits of Autonomous Ferry Development in Sustainable Urban Mobility*

3.2.1. Travel Time Reduction

The savings in travel time versus distance better reflect the impact of transport investment for urban mobility [71,72]. Evaluation of the travel time benefits of the proposed ferry crossing development are based on the following assumptions: ferry average cruise speed of 5 km/h, shortest travel table time for public transport with excluded outliers, and estimated car riding and walking time in which Google Maps tools was used. Car riding time estimations regard off-peak hours. In both cases—public transport and private car—the necessary walk to the ferry stops was added. The mean waiting time for the ferry and the other means of public transport was not included. These cautious assumptions led to results showing substantial travel time savings in the case of all ferry crossings (Table 3). These ferry stops are now located on the fringes of the city's transportation system. Moving between them requires overcoming long circular routes with heavy traffic. In the case of public transport, transport changes are necessary, which will extend the journey time. The connection of opposite shores radically improves the conditions of travel between them. It is also of significant importance for increasing the cohesion of the city's public transport network. Furthermore, the ferry crossing placed nearby two pedestrian drawbridges (Muzeum Morskie–Sołdek) offers competitive travel time.

Table 3. Travel time comparison between the most common urban transport modes.

Location Number (Figure 2)	Direction	Ferry	On Foot	Public Transport	Private Car
1	Brzeźno–Latarnia Morska	5.5	24.0	23.0	7.0
	Latarnia Morska–Westerpaltte	2.5	Not applicable	62.0	20.0
2	Nabrzeże Zbożowe–Twierdza Wisłoujście	2.5	Not applicable	95.0	12.0
3	Młode Miasto–Polski Hak	2.0	28.0	Not applicable	20.0
4	Muzeum Morskie–Sołdek	1.0	10.0	Not applicable	12.0
5	Górki Zachodnie–Górki Wschodnie	5.0	Not applicable	60.0	30.0

Source: own elaboration based on [69,70].

Estimated travel time savings are not only relevant to the sustainable mobility paradigm. They also meet the need of the city of Gdańsk urban development master plan. This directly fosters the achievement of all objectives in the strategic field of transport and mobility. The objectives include improving pedestrian and bicycle traffic conditions, increasing public transport attractiveness, improving internal and external transport accessibility, and promoting sustainable transport and active mobility [58]. The proposed ferry crossing development also covers spatial development objectives, such as continuing inwardly oriented development, enhancing the quality and attractiveness of public spaces, and developing city-creating functions in port-industry concentrations and the coastal belt.

3.2.2. Potential Benefits for Walkability and Public Health

The primary purpose of the small autonomous ferry is pedestrian transport or, eventually, bikers and other users of personal transport devices. Therefore, this is the tool that directly supports walkability. The radical improvement in street connectivity provided by the proposed ferry crossing also facilitates walkability. What is more, most of the connected places are essential public spaces in Gdańsk. They are pedestrian-friendly and offer many possibilities of spending time. This is why a small autonomous ferry development also supports the city's strategic objective of improving public spaces quality. Another city development objective, namely, public health improvement [58], can also be supported by analysing the project. The interactions between walkability, physical activity, and public health are becoming increasingly more recognised [73,74].

4. Discussion

This study reduces the research gap on the impact of autonomous passenger ferry development on urban mobility, in particular by examining the extent to which the new transport solutions can help improve sustainable mobility patterns. The method used in this study helped to identify land use conditions favourable for introducing small autonomous ferries and their impact on the distance of urban travel and utilisation of different public transport means. The case of the coastal city of Gdańsk has been documented in secondary qualitative and qualitative data regarding land use patterns, location of living spaces and workplaces, public transport network patterns, and performance through a large body of policy documents (urban development master plan), accompanying expert opinions, and scholarly literature. The results should be considered to contribute to scientific knowledge in sustainable urban mobility and autonomous shipping. Because the designs of small autonomous ferries assume zero-emission propulsion systems [22], the study also supports the study on transport electrification, especially in urban areas. Thus far, research on urban autonomous ferry systems has not been numerous, and the research usually does not go beyond technical issues. As the present study shows, the broader sociotechnical transition perspective seems to be a promising research field, especially for urban mobility.

First, the study strongly emphasised that a typical short river crossing, due to autonomous vessels, can regain a competitive position, which was partially lost due to linear routes along the river [75]. As the study shows, it is an exciting solution for cities in which limited or dispersed demand prevents achieving sufficient economies of scale for a ferry system to reduce or at least justify the costs incurred by public institutions. The system consists of a small autonomous ferry that is much more scalable. Each ferry crossing is independent of others such that lines can be successively added as financially possible. The smaller dimensions of an autonomous ship versus a human-crewed vessel generate much lower investment and operational expenditures, especially in terms of labour costs [44,50].

Second, the research identified crucial benefits of autonomous ferry shipping on urban mobility, travel distance reduction, and a modal shift towards foot travel or bike riding, resulting in public health improvement. According to the sustainable mobility paradigm [16], there are some indirect advantages, such as pollution limitation to reduce travel distance results and assumed installation of a zero-emission propulsion system, which is also more energy-efficient. This demonstration effect may also increase public acceptability for a shift in mobility patterns. In order for the support for sustainable mobility to be summarised, it is worth framing the proposed project in the "avoid–shift–improve" concept to evaluate sustainable mobility policies [27]. A small autonomous ferry should "avoid" transport work volume, should result in a "shift" in modal split towards public transport modes, and should "improve" vessel energy efficiency.

Third, while the potential benefits of implementing small autonomous ferries are comprehensive, the question of their ability to transform entire urban transport systems remains open. The examined case suggests that the solution effectively increases connectivity of the peripheral parts of transport networks. The extent to which it supports daily commuters, tourists, or city inhabitants during leisure also regulates the transformation of the urban transport system [76].

Fourth, developing ferry systems fosters the economic development of revitalised waterfronts, and is not the only answer for commuting demand [75]. The analysed case confirms this rule—two of five planned ferry crossings are neighboured with waterfront properties under revitalisation processes. This circumstance creates an opportunity to involve private capital in the development of autonomous ferries.

Fifth, this study supports the assumption that inventing a new technology is not enough to change societies. Changes in markets, user practices, policy, and culture are also indispensable [77]. Cities that create development policy provide the actual conditions for implementing sociotechnical configurations [20].

Setting the scope of analysis to local patterns and consequences of zero-emission small autonomous ferry development is a significant limitation of this study. The development of new systems for ferries brings cities noticeable discursive and material benefits. Instead of avoiding a negative environmental impact, they may relocate outside the city (energy production or ferry manufacturing-related emissions) [78].

5. Conclusions

City activities, including urban mobility, play a crucial role in climate change mitigation. Urban mobility has a significant share in global transport greenhouse gas emissions. To lower the emissions rate, we need to introduce comprehensive policies and measures. Zero-emission autonomous ferries are one of the feasible solutions. This study investigated whether and how this cutting-edge technology can foster shift in urban mobility towards sustainability. Thus far, research on urban autonomous ferry systems is not numerous, and they usually do not go beyond technical issues. This study acknowledged that the broader sociotechnical transition perspective seems to be a promising research field, especially for urban mobility. As the study showed, small zero-emission autonomous ferries have become an exciting solution for cities where limited or dispersed demand prevents achieving economies of scale, thus diminishing the necessary expenditures. The examined case suggests that the solution effectively increases the connectivity of peripheral parts of transport networks. It is also more scalable because each ferry crossing is independent of others such that the lines can be successively added when financially possible. The smaller dimensions of an autonomous ship versus a human-crewed vessel generate much lower investment and operational expenditures, especially in terms of labour costs. The "avoid–shift–improve" concept evaluates small autonomous ferries as a tool of sustainable mobility policies that "avoid" transport work volume, that result in a "shift" in modal split towards public transport modes, and that "improve" vessel energy efficiency. The study outcomes have policy implications for urban stakeholders and policymakers. The small zero-emission autonomous ferry solution will become increasingly excellent and more affordable. They will therefore become difficult for policymakers to ignore. Stakeholders and policymakers should investigate emerging technical solutions and then choose the most relevant ones for their urban conditions, demand, and political promises. Cooperation with relevant water transport authorities is also necessary to develop the rules, standards, and certification procedures to ensure shipping safety and security.

Examining only essential specialities of small autonomous ferry introduction are the limitations of this study. Indicated ferry crossing locations require verification in terms of equipping the appropriate infrastructure. A multicriteria assessment of the introduction of small, zero-emission autonomous ferry outcomes for sustainability is needed to identify infrastructural needs. This multi-level perspective suggests that technology and economics assessment is insufficient. The equity criteria also should be taken into account [79]. The urban development master plans and sustainable urban mobility plans, in particular, should propose ways of using innovative means of transport in line with the city's development goals and the global climate change agenda. However, these analyses overlook one key aspect. They focus on the benefits of increased efficiency in operating a new means of transport, but they ignore the ecological costs (e.g., equipment and energy production) transferred outside the city [78]. The COVID-19 pandemic adds one more exciting research direction. Uncrewed small ferries offer much safer working and travel conditions for health [80,81]. Finally, this study suggests one available future research direction. More case studies are necessary to systematise recombinant innovation to trigger a technological transition [71] in sustainable urban mobility.

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