

Article

Is It Possible to Develop Electromobility in Urban Passenger Shipping in Post-Communist Countries? Evidence from Gdańsk, Poland

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Abstract: Reducing emissions of pollutants from transport is clearly one of the main challenges of the constantly developing world. Because the environmental impact of different means of transport is significant, it is necessary to cut down on fossil fuels and turn to more eco-friendly solutions, e.g., electric vehicles. Almost all European countries are now adapting their transport policies to this new paradigm. Nonetheless, due to large economic disparities, these processes are currently at different levels of implementation in Western and Eastern Europe. The main focus is on private electric cars and more traditional means of transport, rather than water trams. This article presents possible means of developing water tram lines in Gdańsk served by hybrid or full-electric vehicles. The analysis presented herein reflects the multidimensional nature of the issue. The article provides data on the socio-economic situation in the city, technical issues related to the implementation of such tram lines, and the possible consequences of introducing a new means of transportation into the existing system. A key part of the analysis is the identification of anticipated economic and environmental consequences of introducing both hybrid and full-electric vehicles into the system. A comprehensive socio-economic and technical-environmental analysis of the possibilities of developing urban electromobility in the form of urban passenger shipping in post-communist countries, such as that presented in this paper, has not been previously published.

Keywords: electromobility; public transport; passenger ferry; shipping

1. Introduction

Reduction of energy consumption and better use of renewable energy resources are two main directions of electromobility development to realize a low-carbon economy. This transformation is not only of a technological nature, but also concerns a complicated ecosystem which consists of means of transport productions, suppliers, and local and national public actors addressing clean energy transition [1]. Currently, one of the most popular manifestations of this transformation is the popularization of electric vehicles, at least in highly developed countries. This issue has also received attention in the scientific literature, as documented in a literature review by Bireselioglu et al. [2].

In addition, passenger shipping electrification is currently expanding. The introduction of the first all-electric car ferry by Norwegian Sognefjord in 2015 was a symbolical act, reflecting these ongoing changes. A review of the existing practices identified 22 similar projects. More than half of these concern interurban passenger shipping in European cities, such as Amsterdam, Copenhagen,

London, and Stockholm, in addition to Calcutta and Kaoshiung, Taiwan. The introduction of new electric vehicles or modernization of the existing fleet has also occurred in the case of ferries operating in near-shore areas, particularly in the Nordic countries. Technical development has also allowed electrification of important international ferry lines. Pioneering solutions have been implemented on the route connecting Helisngorand Helsingborg in Danish–Swedish Oresund.

The scientific literature on these issues, excluding pure technical problems concerning propulsion systems, is relatively poor and a broad geo-economic approach is not usually applied. A separate section below explores the current state of the art. Here, it is worth mentioning that Gagatsi et al. [3] provides the most comprehensive study. However, taking the rapid pace of development into account, some data provided by the above-mentioned author and her team is already out of date.

The main objective of this article is to discuss opportunities for electrifying urban passenger shipping in Gdańsk. There are several reasons for selecting this city as a research area: (1) In contrast to large European seaside cities, the so-called pioneers of urban passenger shipping electrification, this mode of transport is of marginal importance in the passenger transport system of Gdańsk. (2) However, urban passenger shipping in Gdańsk is perceived as a significant tourist attraction and part of the tourist infrastructure, and tourism is a vital sector of the city economy. (3) The existing system does not meet the current demand and the fleet is old and decapitalized. (4) Popularizing sustainable mobility and reducing greenhouse gas emissions are two significant strategic objectives of the city. (5) The city authorities have gained significant experience in obtaining and using external financing sources (mainly EU funds) for the development and modernization of the urban transport system. (6) Companies located within the urban area of Gdańsk take part in designing and manufacturing hybrid or all-electric ferries.

Due to these factors, Gdańsk appears to be a good example of a less-developed city which, nonetheless, represents the extraordinary pace of transformation of the urban transport system. This occurred initially during the systemic transformation period, and then under the conditions of European integration, which provided the finance for costly infrastructural and fleet projects. The experience of Gdańsk largely affects the directions and scope of electrification. This case also makes a valuable contribution to the knowledge regarding the perspectives for increasing the use of electromobility. The contributions of the article relate to four issues. The financial, environmental, and socio-economic conditions of introducing electric or hybrid ships into a water tram operation are examined. Among the main results, the importance of local conditions was identified, in particular the role of spatial development, including population density, size of the labor market, number of potential users, and the connection of the planned connections with the existing public transport system.

The substantive scope of this article relates to the study by Biresselioglu et al. [2], who reviewed a wide range of literature and identified the main motivators and barriers to the diffusion of electric vehicles. Although their study focused on cars, the main results can also be applied to electric vessels. More importantly for this study, the motivators and barriers were determined in the context of a decisive process in which three different units/bodies take part: a formal social unit, a collective decision-making unit, and an individual level unit. In the case of Gdańsk, the perspectives of local authorities (formal social unit), responsible for organization of public transport services, and of the operator (collective decision-making units) are of significant importance. Therefore, the current analysis addresses the following factors that play a role in the decision-making process [2], namely: operational features (e.g., range, charging time, grid technology, and availability); charging infrastructure; charging solutions; economic performance (e.g., price, maintenance costs, and energy consumption); regulations, policy practices, and incentives; and environmental aspects (e.g., CO₂ emissions, noise, and air quality). The above-mentioned elements were subject to economic and environmental analyses, and results constitute the foundation for final conclusions regarding the criteria of effectiveness, i.e., efficiency. However, according to Wee and Roeser [4], each policy should also take the criterion of equity into account. Hence, the current study also analyzes broad socio-economic consequences, thus implementing a more pluralistic, context-sensitive approach. This approach is a

distinctive feature of this article, in contrast to most previous publications, which focus neither on economic analysis or environmental issues. The local context of the study, represented by the case of Gdańsk and its development objectives and directions, is also a valuable asset.

The spatial scope of the study covers the city of Gdańsk, particularly the waterfront areas where the passenger shipping infrastructure is located. Because the analyzed services are of supra-local character, this paper periodically refers to a larger area—the urban region of Gdańsk. The temporal scope of the article is the period of 2006–2018. The first water trams began operation in Gdańsk in 2006. Most of the analyses were based on the data for 2018. The financial calculations regarding the shipbuilding works and operation of all-electric ferries cover a period of 13 years, ending in 2031.

The structure of the article reflects the research agenda. Section 2 provides the scientific background concerning urban passenger shipping, including its functions and vulnerability to electrification. Section 3 is the empirical core of the publication. Here, research methods used to determine the motivators of, and barriers to, electrifying the ferry shipping system in Gdańsk are described. Detailed characteristics of the research area in the context of the experience of the ferry system operation in Gdańsk to date are also presented. Additionally, financial, environmental, and socio-economic motivators and barriers are analyzed. In the concluding section, all of the results are summarized and the main factors that affected their accuracy are listed.

1.1. The Idea of Public Transport Development Based on Electromobility

The idea of electric transport is consistent with the concepts of both electromobility and the smart city, which effectively uses its resources in line with the idea of sustainable development. If Poland wants to achieve the goals set by the European Climate Change Programme and become an innovative and truly modern country, it will be necessary to transform into a low-carbon economy. Developing such a strategy involves integration of all of its aspects, including urban transport systems based on low-carbon technologies and practices, efficient energy solutions, clean and renewable energy, and green technological innovations.

In 2009, the 2020 Climate and Energy Package was adopted by the EU [5], which sets three main targets to be met in 2020:

- 20% reduction in greenhouse gas emissions (from 1990 levels) with an option to increase this reduction to 30% if the global climate change agreement (the Paris Agreement) is achieved;
- 20% of EU energy from renewables;
- 20% improvement in energy efficiency.

These objectives are also part of the Europe 2020 Strategy for smart, sustainable, and inclusive growth, which was adopted in 2010 [6]. One of the main goals listed in this strategy is to reduce greenhouse gas emissions.

Another European document in which the necessity to shift to alternative energy sources is mentioned is the 2011 White Paper [7]. One of the targets set in this document was a 20% reduction in greenhouse gas emissions (from 2008 levels) and a 60% reduction (from 1990 levels) by 2050. One of the most important goals is to achieve CO₂-free city logistics in major urban centers.

In 2014, the issues mentioned in the 2020 Climate and Energy Package were reexamined and a new strategy was adopted—the 2030 Agenda. The 2030 climate and energy framework foresees a 40% reduction in greenhouse gas emissions, a renewables share in the EU's energy mix of at least 27%, and an increase in energy efficiency of at least 27% [8].

The European Commission's 2011 Energy Roadmap for 2050 set out four main routes towards a more sustainable, competitive, and secure energy system in 2050 [9]. The EU goal set in this document is to reduce greenhouse gas emissions by 80–95% by 2050.

The European Union promotes electric transportation. Such a recommendation can be also found in the Communication from the Commission entitled "Clean Power for Transport: A European alternative fuels strategy", and in the "Urban Mobility Package", which were both adopted in 2013.

Regarding electromobility, the Polish legal system adopted Directive 2014/94/EU of the European Parliament and the Council of 22 October 2014 regarding the deployment of alternative fuels infrastructure. The main target is to achieve 1 million electric vehicles in Poland by 2025. There is no regulation on what kind of vehicles these should be. The main points mentioned in this document are as follows:

- the necessity to introduce low-emission vehicles to fleets managed by companies providing public services (including urban passenger shipping);
- supporting development of public transportation systems by introducing low-emission vehicles.

Moreover, the document lists 32 agglomerations and densely populated areas (including Gdańsk) where it is necessary to replace the currently operating vehicles with low-or zero-emission vehicles (Uchwała Rady Ministrów z dnia 29 marca 2017 r.).

The act of 11 January 2018 on Electromobility and Alternative Fuels [10] is the subsequent stage of the implementation of Directive 2014/94/EU of the European Parliament and the Council of 22 October 2014 for the deployment of alternative fuels infrastructure. Although the act places emphasis on private cars and urban public transport systems (electric buses and trams, trolleybuses), it is also an essential legal act in the case of water trams that meet the zero-or low-emission requirement (i.e., full-electric and hybrid trams). The act sets specific requirements for all regions with population exceeding 50,000 citizens. In these areas a certain percentage of vehicles must meet the zero-or low-emission requirement in the following years. Water trams are not mentioned in the Act because urban passenger shipping is negligible compared to other modes of urban transportation.

1.2. What Does Electromobility Look Like in Post-Communist Countries?

Public transport systems in post-communist countries are mainly based on buses, trams, trolleybuses, and fast urban trains, including the underground. Although the idea of urban passenger shipping is not a novelty in Western Europe, it is regarded as innovative in post-communist countries. There is a noticeable gap in the development of individual motorization between the highly developed countries of Western Europe and the developing countries of Eastern Europe. Historically, collective transport in post-communist countries played a key role and, due to a lack of liquid fuels, electric vehicles constituted an important part of urban transport systems. At present, due to climate change, it is necessary to change the transport policies of European countries. Some Eastern European countries, particularly those who are members of the European Union, do not have to create new electric transport systems—they have the option of modernizing and developing the existing infrastructure. As already mentioned, electric transport systems in post-communist countries are usually based on trams and trolleybuses. The vast experience in managing and maintaining such systems has allowed those countries to shift to modern battery technologies with relative ease. In many countries of the region, particularly Poland, the transformation of urban transport systems is progressing rapidly. In fact, Poland has become a leader in the implementation of electrified public transportation across the region.

A systemic support system has been created to support implementation of electric vehicles in urban transport systems. A special national fund has been created under which cities can apply for grants to purchase electric or hybrid buses and develop the charging infrastructure. An assumption of the E-Bus program is that 1000 new electric buses will have been bought by 2020. In December 2019, 216 electric buses were operating on Polish roads and 1589 new electric buses had been ordered. In addition to the above-mentioned projects, which mainly concern urban buses, a program for school buses has been introduced, and an E-Car program for the design and manufacture of a Polish electric car is underway. Moreover, all Polish fast train, tram, and trolleybus systems, and the underground in Warsaw, have been modernized and developed using European funds.

1.3. Implementation of the Idea of Sustainable Development and Electromobility in Gdańsk in Previous Years

During the 1980s and 1990s, Poland underwent spectacular socio-economic transformation, which led to a severe economic crisis and the financing needs related to urban transportation were unable to be met. During the communist period, urban transport systems were centrally financed; following the transformation, this became an obligation of local authorities. As a result, costly public transportation systems, including their fleets and infrastructure, gradually became dilapidated, particularly the electric systems (trams and trolleybuses). Significant changes prior to Poland's accession to the EU included additional funding, which was used by Gdańsk, among other Polish cities. In addition, the Gdańsk Urban Communication Project (GUCP) was launched and its subsequent stages have been implemented since 2003. Most of the actions taken under the GUCP concerned modernization and development of the electric urban transport system served by trams. The Gdańsk Urban Communication Project allowed several sections of tram rails to be repaired, new trams to be purchased, and existing operating diesel buses to be replaced with eco-friendly buses. Therefore, Gdańsk has a rich experience in the implementation of new transport projects aimed at reducing greenhouse gas emissions and making urban transportation more accessible to its citizens [11].

2. Scientific Background

Geo-economic studies concerning interurban passenger shipping have been carried out under the new mobility paradigm for almost two decades. This paradigm includes urban transport, anthropogenic climate change, and energetic transformation issues [12]. It constitutes part of the research regarding sustainability, particularly sustainable accessibility [13]. Empirical studies concern both large coastal cities in developed countries, e.g., New York, London, Goteborg, Copenhagen, Hamburg, and Brisbane, and megacities in South-East Asia, such as Bangkok [14]. This diversity results in a wide range of aspects that are focused on by the studies' authors. In the case of the first group of cities, the role of technical innovations in the development of urban passenger shipping is the most frequently raised issue. The greatest attention is paid to the implementation of electric/hybrid propulsion systems to reduce operation costs, and enhance travelling comfort [3,15]. Due to the fact that urban passenger ferries operate on fixed and short routes, electrifying such systems is relatively easy—the number of locations where additional charging infrastructure must be placed is limited and the batteries are not required to have large capacity. Regarding the second group of cities, a significant role of the transformation of urban regimes in the context of urban transportation systems is emphasized because these result in optimization and functional-structural changes, supported by technical innovations [16,17]. Regardless of the level of socio-economic development, urban water transport systems contribute to the reduction in greenhouse gases and other pollutant emissions [3]. According to Baird and Pedersen [18], emissions generated by shipping are a significant source of air pollution, generated by the combination of sea and land transport. This problem is particularly burdensome in port cities [19]. Moreover, vessels are subject to less stringent regulations than cars. However, even relatively simple and low-cost modernization solutions, such as replacing existing diesel propulsion systems with hybrid systems, may significantly contribute to reducing pollution [20]. The role of urban ferry systems in enhancing the coherence and accessibility of transport systems in seaside cities [21–25] is also of scientific interest, for all regions of the world and levels of economic development. Numerous port cities are also popular tourist destinations, which are required to cope with intense tourist traffic. Thus, their public transport systems are partly tourism-oriented [26]. It appears that urban passenger shipping is of particular significance in the provision of transport services to tourists. In some cities water transport systems are dedicated solely to servicing tourist traffic. The extent to which water transport systems specialize in providing tourism-oriented services depends on the general attractiveness of the city and the places connected by waterways, whether these places are of residential or leisure character, and on the competitiveness of other modes of urban transport [13].

Scientific examination of the operation of urban passenger shipping in Poland has become more intense since 2006, when means of water transport were implemented in cities and regions situated on the north western shores of Gdańsk Bay and Puck Bay [27]. In the period of 2006–2014, due to subsidies provided by local governments, it was possible to reduce the cost of tickets and consequently, the number of passengers increased. Nonetheless, the routes served by the means of water transport did not fulfill a classic inner-city function; rather, they mainly provided tourism-oriented services within a larger urban region. In Gdańsk, typical inner-city passenger shipping, as a form of water tram system, was launched in 2012, and has subsequently operated seasonally, also serving as an additional tourist attraction. All of these transformations have attracted particular attention of numerous researchers. The highest number of studies concerns the metropolitan area of Tricity [27–35]. Almost all of the publications listed above are descriptive and authors have usually analyzed inner-city passenger shipping or water transport systems operating seasonally within the urban region and providing services mainly to tourists. In these studies, the authors described legal, organizational, and financial frameworks of the systems, routes and connected tourist attractions, operation frequency, and travel times and costs. Additionally, the onshore infrastructure and vessels were described, in addition to selected features of the passenger traffic. The performance and economic outcomes of the systems were also investigated. Considering the above-mentioned issues, the existing research does not accurately reflect the new paradigm of mobility. Issues such as the transformation to collective transport, the energy transformation required to maintain environmental equilibrium, and the need to reduce transport pollution, are not usually addressed in the existing research. Nonetheless, the publications by Muszyńska-Jeleszyńska [36] and Kunicka and Litwin [37] on electric propulsion systems in urban passenger shipping should be noted.

3. Methods; Research Area and Results

3.1. Methods and Data Sources

Cost-benefit analysis (CBA) was selected as a general research method for this study. It is a commonly used method when determining viability and economic-financial effectiveness of certain investment actions [38,39], including those regarding transportation [40]. In its classic implementation, CBA is of a monetary nature and is mainly focused on the direct financial costs and benefits of a particular project. In this study, the authors used the net present value (NPV) as a synthetic measure of financial effectiveness:

$$NPV = \sum_{t=0}^n \frac{NOCF_t + NICF_t + NFCF_t}{(1+d)^t} \quad (1)$$

where $NOCF_t$ are net cash flows from operating activities in year t , $NICF_t$ are net cash flows from investing activities in year t , $NFCF_t$ are net cash flows from financing activities in year t , d is the discount rate.

$$NOCF_t = Rev_t - E_t - L_t - D_t - Sp_t - M_t - I_t - Mng_t - Pr_t \quad (2)$$

where Rev_t are revenues from ticket sales in year t , E_t is the cost of electricity and fuel in year t , L_t are labor costs in year t , D_t are demurrage costs in year t , Sp_t is the cost of ship preparation for the season in year t , M_t is the cost of ship maintenance in year t , I_t is the insurance cost in year t , Mng_t are management costs in year t , and Pr_t are promotion costs in year t .

$$NICF_t = \begin{cases} -AC_t - Rep_t, & t \in [1; 12] \\ Res_t, & t = 13 \end{cases} \quad (3)$$

where AC_t is the cost of assets in year t , Rep_t is the cost of major repairs and battery replacement in year t , Res_t is the residual value in year t .

$$NFCF_t = LD_t - LC_t - LI_t - O_t \quad (4)$$

where LD_t is the loan disbursement in year t , LC_t is the loan capital repayment in year t , LI_t is the loan interest repayment in year t , and O_t are other financial costs in year t .

Due to the 13-year period of the project, it was necessary to make some assumptions concerning the directions and scope of changes that the analyzed parameters may undergo in the future. These assumptions are elaborated in a subsequent section. Firstly, the calculations allowed estimation of the impacts of the project on the city budget. These were also helpful when verifying the project assumptions and preparing the detailed description of the fleet and the current offer. However, the costs and benefits are not limited to issues that can be easily monetized and assessed. The fact that such intangible issues are difficult to incorporate into CBA analysis is the main drawback of this method, and this is widely discussed in the literature. Jones et al. [38] identified the main weaknesses of CBA. There are three important issues in the context of this study: difficulties in incorporating environmental impacts (difficult to monetize with large uncertainty ranges), local impacts (agglomeration and land use interaction), and equity (monetization is not universally accepted). To estimate a potential environmental impact of the project, the authors calculated possible changes in greenhouse gas (GHG) and other pollutant emissions resulting from replacing internal-combustion diesel vessels with all-electric or hybrid vessels. Pollutant loads generated by the fuel combustion process were calculated using the following formula:

$$E_R(i) = F_C(i) \times WTF \times E_F \quad (5)$$

where E_R are emissions per route in the operational season, $F_C(i)$ are medium fuel consumption for the type of drive (kilograms of diesel per hour), WTF is the working time of the ferrys per specific route during the operational season (hours), E_F are emissions factors for compounds per burned kilogram of diesel (kilograms per kilograms of burned diesel), and index (i) represents the type of drive used in a ferry.

The results were not monetized because interactions between GHG and other pollutant emissions and different aspects of socio-economic development are too complex. According to Bergh [41], such estimations are highly inaccurate.

Establishing possible interactions between the ferry system, agglomeration, and land use provided vital data concerning the local impact of the project. Using geographic information system (GIS) methods, the authors were able to determine shipping routes and the locations of stops. Moreover, the population of residents and people working in the area were estimated as a group of potential beneficiaries of the project. The analysis also involved preparation of a detailed inventory of tourist infrastructure and valuable natural areas. The results were then used to estimate the potential demand for transport services and to make assumptions concerning their supply. Using GIS methods made it possible for the authors to incorporate a local legal framework for spatial planning into the analysis. All of the planned shipping routes and stop locations exist within this framework. Therefore, it was not only possible to determine environmental and local impacts, but also to set the CBA in the wider spatial planning context. The need to do this was also mentioned by Eliasson and Lundberg [40]. The results of the GIS analysis proved to be particularly helpful when formulating and verifying some of the assumptions necessary to carry out the CBA analysis.

According to Wee and Roeser [4], each policy shall take account of three criteria: effectiveness, efficiency, and equity. The CBA enabled incorporation of the first two of these into the analysis, whereas the issue of equity was completely omitted. As the authors cited above noted, CBA is based on the willing to pay (WTP) approach. Reducing the analysis to purely profitability and issues that can be expressed in monetary terms excludes numerous vital moral and ethical problems that are an integral part of transport policies. The most important of these include potential contradiction between economic viability and moral obligations in the form of political promises, identification of winners and losers, and recognition of accessibility to certain places as an elementary social good. Thus, the authors attempted to evaluate intangible benefits and costs of the analyzed project by analyzing the content of the Gdańsk Operational Programmes 2023 [42], which complements the actual development strategy of the city [43]. This analysis made it possible to better address the urban planning context

when determining the project benefits and costs. The high complexity of the analyzed issues justifies implementing a wide range of research methods and data sources (Table 1). As suggested by Wee and Roeser [4], a more pluralistic, context-sensitive approach was adopted. Therefore, the analysis was not limited to tangible issues that can only be expressed in monetary terms.

Table 1. The content and sources of data used at each stage of the research procedure.

Research Stage	Data Content	Data Sources
Water tram lines design	Spatial data in the form of vector layers defining the features of the existing and planned land use with related information on the number of inhabitants and jobs	Gdańsk Spatial Development Office
Environmental costs and benefits	Operational information on existing ships (diesel propulsion) operating on water tram lines in Gdańsk; Technical specification of the proposed drive systems (electric and hybrid propulsion)	Gdańsk Shipping Co. (Żegluga Gdańska); Reports of the Gdańsk Economic Development Agency; Specialist portals/magazines, manufacturers' websites
Financial costs and benefits	Financial information on the current operation of water tram lines; Market information on the costs of building and operating electric and hybrid ships	Gdańsk Shipping Co. (Żegluga Gdańska); Reports of the Gdańsk Economic Development Agency; Specialist portals/magazines, manufacturers' websites
Other socio-economic costs and benefits	Information on the strategic goals of the city's social, economic, and spatial development	Gdańsk City Hall

3.2. Case Study—Gdańsk

Gdańsk is a city on the Baltic coast of northern Poland, situated in Gdańsk Bay (Figure 1). Existing within the city administrative boundaries is a network of waterways based on the rivers and canals of Martwa Wisła, the Kaszubski Channel, Wisła Śmiała, Stara Motława, and Nowa Motława. Gdańsk is a city with over 1000 years of tradition, and its coastal location has been perceived as a valuable asset through its history. The city initially grew along these rivers and channels before sprawling towards Gdańsk Bay.



Figure 1. Location of the city of Gdansk.

Water transport and the trade-industry sector connected to it remains of great importance, not only in terms of city development, but also that of the wider urban region. At present, the port of Gdańsk is one of the largest and fastest-developing ports on the Baltic Sea in terms of transshipment and is expected to be the main transport hub by 2027. One of the newest infrastructural projects is the Deepwater Container Terminal located in the Northern Port, away from the city center. The Inner Port

uses the outlet stretch of the Martwa Wisła River with the Kaszubski Channel and is of less relevance in the context of transshipment volumes [44,45]. The rivers and canals in Gdańsk are currently used as waterways for leisure and tourist shipping, and are concentrated mainly in Śródmieście where the proper infrastructure and marinas (Nowa Motława and Stara Motława) are located.

3.3. Characteristics of the Previous Experience and Conditions for Operation of Electric Ferries

Poland has little experience in urban passenger shipping. The existing urban ferry systems have been used to connect two banks of a canal or river. The same situation can be observed in Gdańsk. Urban passenger shipping is considered a tourist attraction and, despite having a favorable environmental location, Gdańsk has not used its waterways to develop this mode of transportation. This is mainly the result of lack of relevant experience during the communist period.

During the past three decades, passenger ships have operated on tourist routes from Gdańsk to Gdynia, Hel and Jastarnia, or to provide cruises from downtown to Westerplatte or the port of Gdynia. Initial experience was gained when a project aimed at launching a water tram line was implemented in the first decade of the 21st century. The project was launched simultaneously in Gdynia and Gdańsk. During two months of the holidays in 2006, a water tram line connecting Gdynia and Hel was launched. The line was served by high-capacity catamarans owned by the Żegluga Gdańska company. Before launching the line, it was assumed that 142,600 passengers may be interested in the cruise, representing 36.5% of the maximum seating capacity. The ticket price was calculated in relation to the cost for 4 people to travel via road from Gdynia to Hel. The tickets were planned to be relatively cheap to encourage citizens and tourists to change their transport behaviour. Therefore, the tickets were externally subsidized. The line was a successful, and in the first season 72.3% of the maximum seating capacity was used. Gdańsk introduced a similar strategy. In cooperation with the same operator, a line connecting Gdańsk and Hel was launched. In the first season the ticket revenues covered 54.5% of the total operation cost. In 2006, which was a pilot season, the offers of both cities were not integrated, which caused chaos in the port of Hel. In 2007 a decision to cooperate was made and a joint promotion campaign was launched. Additionally, regulations concerning ticket sales were harmonized [26]. Significant interest in both lines during 2006–2007 made it possible to lower the amount of the subsidy needed. Additionally, in 2007 both cities conducted market research. The overall assessment of the services was very high. The two most frequently mentioned aspects were the cheap price and the attractiveness of the cruise between Tricity and the tourist resorts located on the Hel Peninsula. According to M. Wanagos [28], who also conducted a similar study, the water tram lines were accepted well by the respondents. However, they mentioned problems with purchasing the tickets. In subsequent years, the number of passengers steadily increased. During the period of 2006–2014, more than 3.2 million passengers were served by the water trams of Gdańsk and Gdynia. However, since 2012 the number of daily cruises has been gradually reduced due to the high cost of subsidizing the system. However, at the same time a new inner-city water tram line was developed connecting Gdańsk and Sobieszewo (line F4).

Finally, the line in Gdynia was cancelled. In Gdańsk the regional lines were also cancelled, but in 2012 two new inner-city lines, labelled F5 and F6, were launched [32] under the Programme for Reviving Waterways in Gdańsk. Line F5 connects Żabi Kruk and Westerplatte with an optional stop near the Lighthouse in Nowy Port. Line F6 connects Targ Rybny and Narodowe Centrum Żeglarstwa with an optional route to Sobieszewo. Line F5 has 8 stops and F6 has seven. Both lines are served by two small vessels with 40 seats. The vessels were purchased specially to operate on line F5, whose route runs under low bridges over the Motława river. There are three cruises on each line every day. A regular ticket costs 10 PLN, a discount or bike ticket costs 5 PLN. Both lines are served by Żegluga Gdańska, which is a subcontractor hired by the Public Transport Authority of Gdańsk.

Launching lines F5 and F6 was an attempt to bring new life into the waterways in Gdańsk and to create a route which will be attractive for both citizens and tourists [46]. When implementing the project in the period of 2008–2012, the necessary infrastructure was built with the assumption that

water trams will become part of the urban transport system. Ten new water tram stops were built under the project: Żabi Kruk, Zielony Most, Targ Rybny, Sienna Grobla II, Wiosny Ludów, Westerplatte, Nabrzeże Barkowe, Tamka, Stogi, and Narodowe Centrum Żeglarstwa.

The overall length of both routes (line F5 and F6) launched in 2012 is 45.1 km. During holidays and on selected weekends, the length is 53.3 km. During the period of 2012–2017, there were three cruises a day, and since 2018 the number of cruises on line F5 has been doubled. The tenders to operate the lines in the periods 2015–2017 and 2018–2020 were won by the Żegluga Gdańska company. The lines are served by two vessels, named *Sonica* and *Sonica I*, which have low superstructures, allowing them to pass under the bridge over Stażewna Street. The vessels have a seating capacity for up to 40 passengers and 5 bicycles. Since 2018, line F6 has been served by a larger vessel with a seating capacity for up to 140 passengers and bicycles. The overall length of the route is approx. 14.3 km and the cruise takes approx. 100 min. Regarding line F5, the overall length of the route is approx. 12.8 km and the cruise takes approx. 98 min. The number of passengers has steadily increased since 2012.

In 2018 (from May to September) the total number of passengers travelling on line F5 was 40,824, and on line F6, 24,803. The total number of bicycles transported by the vessels was 1553 (F5) and 898 (F6). The average percentage of seats taken was approx. 54.5%. For the two smaller vessels operating on line F5 it was 79.1% and for the larger vessel operating on line F6 it was 36.0%.

These positive experiences gained from the seasonal lines have encouraged the local authorities to consider launching full-year water tram lines.

3.4. Design of the Electric Water Tram Lines in Gdańsk

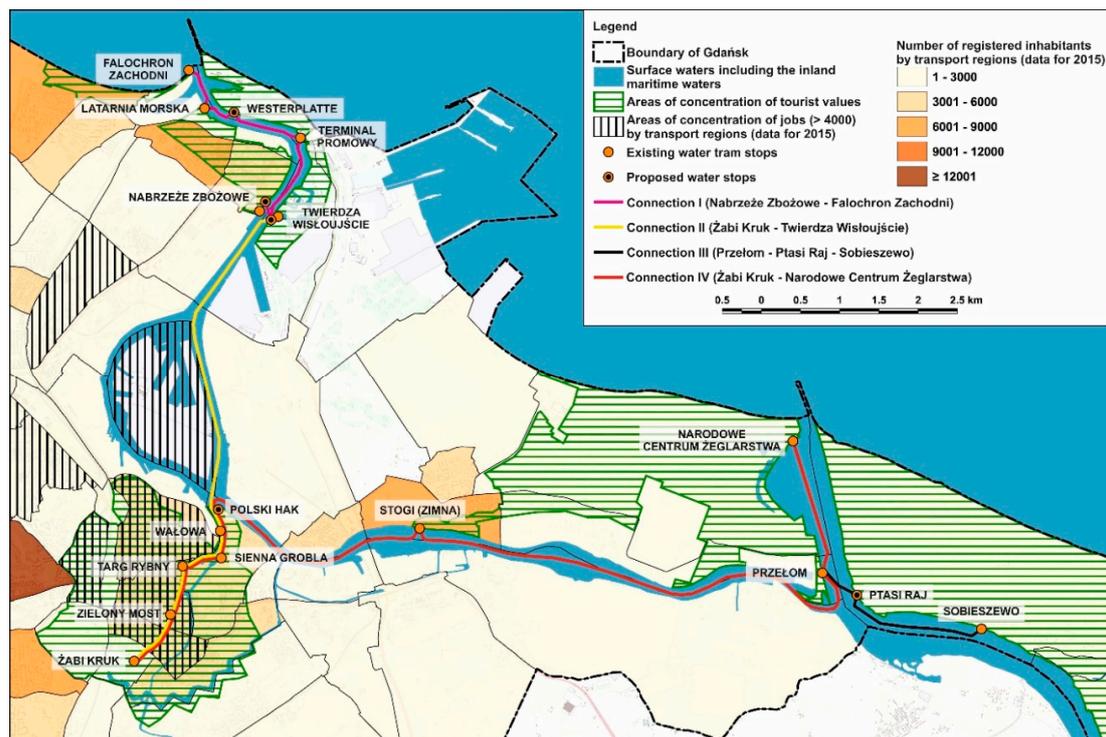
The analysis of the urban passenger shipping system in Gdańsk, and multidimensional studies of the conditions of its operation, allowed the authors to assess the possibility of further development of this kind of urban mobility. The authors determined the most attractive routes, periods of the highest demand for such services, monthly and daily frequencies, and the maximum seating capacity of the vessels. Considering the pro-environmental city policy, which aims to increase the mobility of Gdańsk citizens and tourists by developing an efficient urban transportation system, green solutions were planned, assuming implementation of full-electric ferries and hybrid passenger vessels.

Analysis of the existing water tram lines, F5 and F6, and commercial tourist lines operating mainly on the routes connecting Zielona Brama and Targ Rybny with Westerplatte, showed that the most popular lines are those from the city center to Nowy Port/Brzeźno and Westerplatte. Line F6 towards Wyspa Sobieszewska is less popular. Therefore, the city center has a higher tourist-transportation potential than the shipyard area. The existing route and the proposed modifications should be divided into two areas: (i) the center of Gdańsk and (ii) the area of Nowy Port–Brzeźno–Westerplatte. Due to both the necessity to cover a relatively long distance with no opportunity to pick up new passengers (no intermediate stops) and the low maximum speed required by law, this route is more suitable as a tourist attraction. In the case of line F6, which is longer than F5, (by approx. 6.5 km, one way), the situation is even more complicated. The route runs through less built-up areas and the end stops are more attractive for tourists (Górki Zachodnie, Narodowe Centrum Żeglarstwa, and Sobieszewo).

Table 2 presents the proposed water tram lines in Gdańsk. It is suggested to restore the all-year line connecting Nowy Port (Nabrzeże Zbożowe), Twierdza Wisłoujście, and Falochron Zachodni served by an all-electric double-ended ferry with a seating capacity for up to 30 passengers and 20 bicycles (line I). The ferry should be able to operate under all weather conditions and have the capacity to carry a medium-sized emergency vehicle. This will be an emergency solution in the case of any disturbances in traffic taking place in the tunnel under the Dead Vistula. Assuming that the ferry operation hours are from 8.00 a.m. to 8.00 p.m., its frequency will be 20 cruises each way (Figure 2).

Table 2. Routes of the proposed water tram lines in Gdańsk. Data from [47].

Line Name	Route
I	Nabrzeże Zbożowe–Twierdza Wisłoujście–Terminal Promowy–Westerplatte–Latarnia morska–Falochron zachodni (Brzeźno)
II	Żabi Kruk–Zielona Brama–Targ Rybny–Sienna Grobla–Wałowa–Polski Hak–Twierdza Wisłoujście
III	Przełom–Ptasi Raj–Sobieszewo
IV	Żabi Kruk–Zielona Brama–Targ Rybny–Sienna Grobla–Wałowa–Polski Hak–Stogi (Zimna)–Przełom–Narodowe Centrum Żeglarstwa (NCŻ)

**Figure 2.** The proposed development directions of the inner-city water tram lines.

The above-mentioned routes require the onshore infrastructure to be adapted and modernized. The existing infrastructure can serve only low-freeboard vessels. The marinas at which double-ended ferries are planned to dock require modernization (line I–2, III–2). The remaining options require standard docking places (similar to the existing). Table 3 presents all lines and their options. The solutions are combined in options: I + IB and III with IV.

The planned seasonal seating capacity may be considered as a three-option solution:

- option I + II with 2 vessels serving line II—318,240 passengers and 134,640 bicycles,
- option I + II with 3 vessels serving line II—385,560 passengers and 171,360 bicycles,
- option III + IV—106,700 passengers and 44,020 bicycles.

Table 3. Characteristics of the proposed water tram lines in Gdańsk.

Line Name	Route	One-Way Length of the Route [m]	One-Way Cruise Duration [min]	Potential Daily Frequency (One Way)	Type/Number of Vessels	Maximum Daily Seating Capacity (Both Ways)
I	Nabrże Zbożowe–Twierdza Wisłoujście–Terminal Promowy–Westerplatte–Latarnia morska–Falochron zachodni (Brzeźno)	3355	25	12	Double-ended ferry (1)	720 pas. 200 bic.
				10	Vessel (2)	1100 pas. 600 bic.
II	Żabi Kruk–Zielona Brama–Targ Rybny–Sienna Grobla–Wałowa–Polski Hak–Twierdza Wisłoujście	7010	60	15	Vessel (3)	1650 pas. 900 bic.
				12	Vessel (3)	1320 pas. 720 bic.
III	Przełom–Ptasi Raj–Sobieszewo	2470	20	11	Double-ended ferry (1)	660 pas. 220 bic.
IV	Żabi Kruk–Zielona Brama–Targ Rybny–Sienna Grobla–Wałowa–Polski Hak–Stogi (Zimna)–Przełom–Narodowe Centrum Żeglarstwa (NCZ)	13,660	90	4	Vessel (1)	440 pas. 240 bic.

3.5. Environmental Costs and Benefits

To determine possible environmental effects of implementing the proposed changes to Gdańsk's inner-city passenger shipping system, the authors evaluated the components of the natural environment that may be affected by the system. It was assumed that all of the actions taken in both construction and operation phases of the planned project may affect implementation of objectives determined by different forms of environmental protection, surface water quality, air quality, and acoustic climate. The currently operating diesel vessels were used as a comparative base when assessing the potential environmental changes in the context of the introduction of all-electric or hybrid vessels.

Because Gdańsk is a coastal city with large spatial disparities in urbanization, numerous areas of nature protection exist within the administrative borders of the city. The most important of these include nature reserves and the Natura 2000 protected areas. Although the shipping routes go through or near the borders of the protected areas, the vessels are not perceived as objects that may affect the implementation of development plans adopted by the authorities of the protected areas. The vessels' annual and daily frequency is low and there is no need to establish new infrastructure within the protected areas. The factors with the greatest impact identified for the Natura 2000 areas include [6]:

- potential temporary disturbance to certain species (disruption of their life cycles) resulting from engineering works during the initial stage of the project implementation and increased shipping traffic subsequently;
- potential negative temporary effects resulting from the fact that inland waterway shipping can be a potential source of pollution from ship waste, bilge water, or spills. However, the spills usually result from ship collision or damage, and inland waterway transport has a very high safety record.

The rivers and canals serving as waterways are part of two bodies of surface waters designated as heavily modified, and their chemical status and ecological potential are unstable (significant disparities exist in the quality analyses results of the Martwa Wisła river waters carried out in the period of 2010–2016). The introduction of additional routes served by all-electric or hybrid vessels, in addition to the replacement of the currently operating diesel ferries with all-electric or hybrid vessels, will not negatively impact the water quality. Moreover, the number of spills and water pollutants will be reduced, which is clearly beneficial in the context of the ecological and chemical status of the surface waters. Regarding all-electric vessels, the risk of spillage of lubricating grease or engine oil is low because such substances are not usually used for propulsion mechanisms. The risk is 95% lower than in the case of diesel vessels. Regarding hybrid vessels, the risk is reduced by 50% because their engines are less powerful and of simple construction and, thus, are more reliable. In recent decades, no accidents or other incidents of serious consequences for the environment have occurred. However,

a lack of data on such accidents may result from the relatively young age of the vessels (usually less than 5 years).

The coastal location of Gdańsk results in relatively good quality of the air and limited occurrence of smog. However, in Śródmieście the average annual norm for nitrogen oxide concentration was surpassed in 2017 [48]. The analysis aimed at determining how the proposed shipping routes may affect the aero-sanitary status was based on the calculated values of in situ emissions of pollutants. The emissions generated by the production of energy needed to power all-electric and hybrid vessels were excluded from the analysis. The authors adopted average combustion values of 32.5 kg/h for diesel vessels and 10 kg/h for hybrid vessels. Table 4 presents the unit values of the combustion products.

Table 4. Estimated values of diesel combustion product emissions.

Exhaust Gas Emissions	Carbon Dioxide (CO ₂)	Carbon Oxide (CO)	Sulphur Oxides (SO _x)	Nitrogen Oxides (NO _x)	Hydrocarbons (CH)	Particulate Matter (PM)
kg/kg _{fuel}	2.670	0.027	0.005	0.050	0.005	0.007

Source: [49,50].

The estimated volumes of atmospheric emissions for particular routes were calculated using Formula 5 (Section 3.1. Methods, Table 3). The volumes were calculated for a single operating season and for each propulsion system separately. All-electric ferries are zero-emission vessels and their in situ environmental effect may be expressed as the inverse of the calculated volumes for diesel vessels (Table 5).

Table 5. Estimated volumes of atmospheric emissions for the proposed ferry routes [kg].

No.	Compound	Route I		Route II	
		Diesel Propulsion System	Hybrid Propulsion System	Diesel Propulsion System	Hybrid Propulsion System
1	CO ₂	132,765.75	40,851.00	398,296.25	122,553.00
2	CO	1342.58	413.10	4027.73	1239.30
3	SO _x	248.63	76.50	745.88	229.50
4	NO _x	2486.25	765.00	7458.75	2295.00
5	CH	248.63	76.50	745.88	229.50
6	PM	348.08	107.10	1044.23	321.30
No.	Compound	Route III		Route IV	
		Diesel Propulsion System	Hybrid Propulsion System	Diesel Propulsion System	Hybrid Propulsion System
1	CO ₂	62,347.84	19,183.95	102,047.40	31,399.20
2	CO	630.49	194.00	1031.94	317.52
3	SO _x	116.76	35.93	191.10	58.80
4	NO _x	1167.55	359.25	1911.00	588.00
5	CH	116.76	35.93	191.10	58.80
6	PM	163.46	50.30	267.54	82.32

Route I + II is planned to connect Śródmieście and Nowy Port, and will be served by one all-electric ferry and three hybrid vessels. This option will generate 16% lower emissions compared to the emissions generated by the currently operating route, F5, in 2018, with the assumption that the supply will rise by 263% (understood as the annual number of hours when transport services are available). Route III + IV, connecting Śródmieście and Wyspa Sobieszewska and served by hybrid vessels, will generate approximately 48% fewer emissions than the currently operating route F6 did in 2018 with the supply increased by 89%. If Route III + IV is served by diesel vessels only, the emissions will increase by 198%. The average annual volume of diesel combustion products emitted by a hybrid

vessel is 31% of the volume emitted by diesel vessels. The estimated annual volumes of atmospheric emissions emitted in situ by the entire fleet of hybrid and all-electric vessels that are planned to be introduced include: 173,000 kg of CO₂, 1750 kg of CO, 324 kg of SO_x, 3242 kg of NO_x, 324 kg of CH, and 454 kg of PM. Therefore, introducing the fleet of hybrid and all-electric vessels will reduce the atmospheric emissions, although it will not eliminate them entirely. However, the considerable increase in transport services supply is also worth recalling. The noise pollution from the means of water transport is not subject to acoustic research and was not an issue mentioned in the 2018 noise protection program for Gdańsk. Nonetheless, it can be stated that all-electric ferries significantly reduce the noise level (including vibrations) compared to conventional diesel vessels. The volume levels of all-electric ferries are below average and the only situation when they generate noise is while maneuvering. Hybrid ferries are slightly noisier than all-electric vessels, however, because there are no noise-sensitive objects along the planned routes, this is not recognized as a threat.

3.6. Financial Costs and Benefits

Based on the experiences to date, the authors assumed that the city of Gdańsk will be the body responsible for the transport system organization. The organizer's duties include purchasing the vessels, preparing proper infrastructure, maintenance of the fleet and infrastructure, providing property insurance, and taking actions to promote the idea. Furthermore, the organizer is the fleet owner and collects ticket sales revenues. However, an external body will manage the services and cover the main costs related to transport services provision: energy and fuel costs, labor costs, demurrage costs, seasonal maintenance costs, and civil liability insurance costs. For its services, the carrier will receive remuneration plus a margin. Overall, all the costs incurred by the ferries will be also paid by the city of Gdańsk.

Additionally, the authors made the following assumptions:

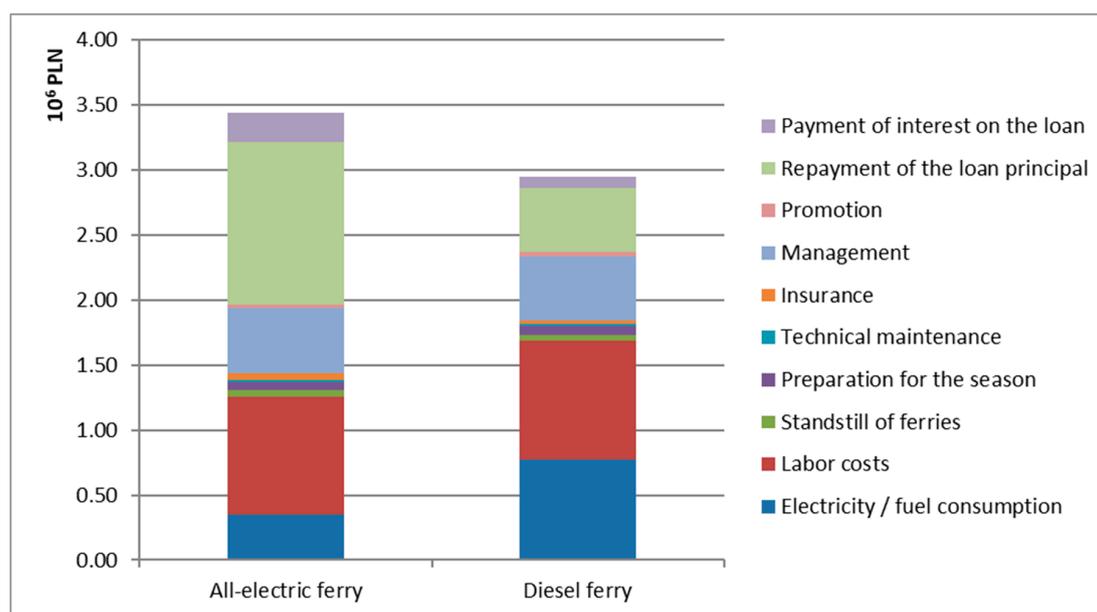
- The analysis covers 13 years, including a 3-year period reserved for shipbuilding works and 10 years of the system operation. This is also a period for which an agreement is usually concluded with a carrier.
- Market prices of goods and services including VAT were used to calculate income and costs of the investment.
- For the basic calculations, a 5% discount rate was used. Usually, in urban transport a 7% discount rate is applied, however, in the case of water transport infrastructure the rate applied is often lower: 3–4% [38]. In this article, the authors used the 5% discount rate, as Gratsos and Zachariadis [51] proposed, which is also an average annual cost of capital in Poland calculated on the basis of the 2008–2018 WIG index.
- The base option assumes that the investment is financed with a bank loan because this is the most likely scenario in Polish conditions. It is assumed that the interest rate at WIBOR 3M plus a bank margin at the level of 0.8% and a bank commission fee of 1% will be applied, and a 3-year grace period will apply to the loan payment. After this period, the loan balance outstanding is to be repaid in equal monthly instalments.
- The residual value of the assets was taken into account in the last year of the system operation.
- The investment costs presented in Table 6 were calculated on the basis of the market price analysis.
- The revenue is derived from the current ticket sales in Gdańsk.

Table 6. Assumed investment costs.

Cost Type	Market Price of a Single Purchase	Price of a Single Purchase Excluding VAT
Purchase of an all-electric double-ended ferry	15,000,000 PLN	12,195,122 PLN
Purchase of a diesel double-ended ferry	6,000,000 PLN	4,878,048 PLN
Purchase of a hybrid vessel	12,000,000 PLN	9,756,098 PLN
Purchase of an onshore charger	500,000 PLN	406,504 PLN
Total cost of onshore infrastructure necessary to modernize a single stop	250,000 PLN	203,252 PLN

According to the Polish central bank EUR = 4.3300 PLN.

Operating costs were calculated on the basis of local market prices. Figure 3 presents a comparison of annual operating costs generated by all-electric and diesel ferries with the same capacity. Regarding the all-electric vessel, the highest costs are generated by the load with which the purchase is financed. Electric vessels are considerably more expensive than diesel vessels. Consequently, the loan interest payments are also higher. Regardless of the propulsion system, the second largest component of the total cost is labor expenditure, which accounts for 26% of the total for the all-electric vessels and 31% for the diesel vessels (908,000 PLN). However, the cost of electricity (347,000 PLN) for the all-electric ferry is lower than the diesel cost (776,000 PLN).

**Figure 3.** Annual operation costs of all-electric and diesel ferries.

In the case of Gdańsk, the ticket revenue will not cover the operating costs. The maximum possible ticket revenue for the whole system is 3,709,000 PLN, whereas the estimated total operating cost is 16,400,000 PLN. Thus, the aggregate cash flow is negative and equal to 12,691,000 PLN. This is the value that must be covered annually by the city of Gdańsk to keep the water transport system operating. The net cash flows for all analyzed activities are negative, with the exception of the last analyzed year, for which the residual value was taken into consideration (Figure 4). The projected NPV of the investment is negative (−83,261,000 PLN), which indicates that the project is not financially viable.

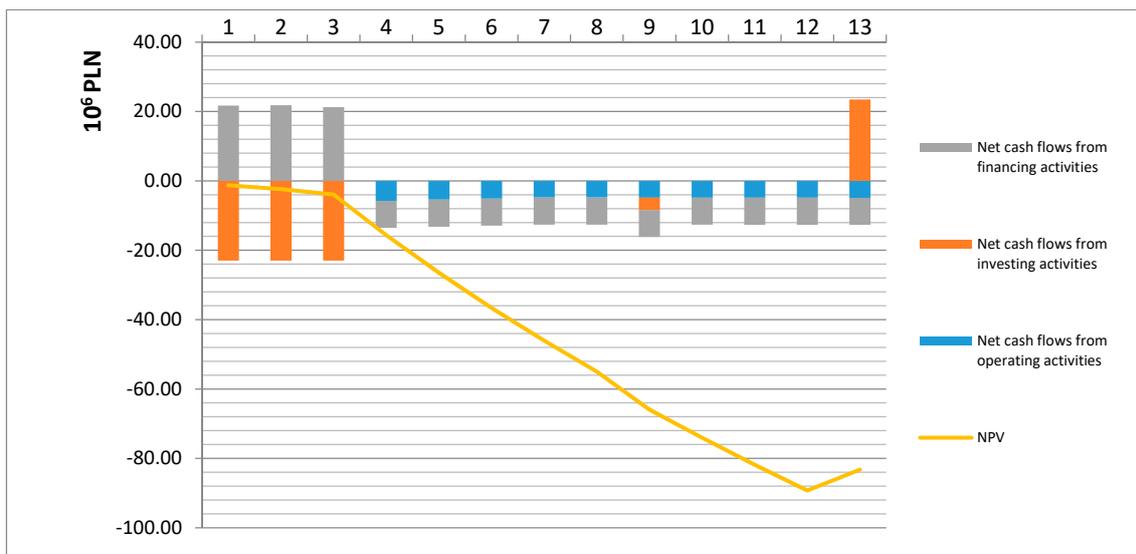


Figure 4. Cash flows and the net present value (NPV) during the investment implementation period and the system operating period.

These low ticket revenues result from relatively low ticket fees and a short operation period limited to five months (May–September), whereas the main costs are incurred throughout the year. Moreover, the labor market situation and lack of a qualified workforce makes it difficult to find crews interested in seasonal contracts. It is likely that workers will be full-time employees.

The financial analysis results were affected by numerous factors that may be vulnerable to the socio-economic situation. Therefore, the values included in the analysis are subject to uncertainty risk. Thus, the authors analyzed the sensitivity of the NPV to changes in the most important parameters (Figure 5).

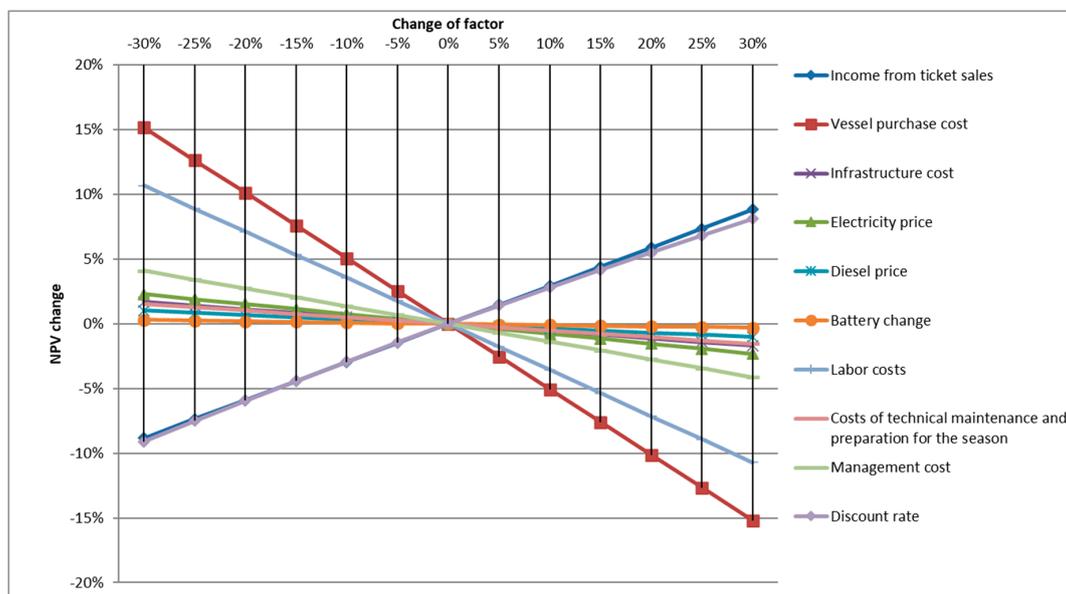


Figure 5. The NPV sensitivity to changes in the main economic factors.

The most significant parameter affecting the NPV value is the vessel purchase cost. Reducing the cost by 10% increases the NPV value by 5.1%. This is vital information in the context of the ongoing development of electric transportation technologies. According to Nykvist and Nilsson [52], the price of lithium-ion batteries, which are currently the most popular available, will continue to drop and costs

among leading producers will be lower than previously expected. In addition, alternative solutions are also being developed at present, including Li-S, Li-air, and Zn-air batteries [53]. Reducing the investment cost may positively affect the financial viability of the project. Another key parameter is the labor cost. Reducing the cost of labor by 10% results in a 3.6% increase in the NPV value. In the context of the current lack of employees and systematic growth in wages [54], the labor cost will likely become the most important factor hampering development of water transport in post-communist countries. The assumed discount rate also has a significant impact on the NPV. The higher the discount rate, the lower the NPV because the sum of the cash flows for each analyzed year (with the exception of the final year) is negative.

Ticket sales revenue also has a considerable effect on the NPV value. The market analysis indicates that, as a result of active promotion, it is possible to simultaneously increase the price of tickets and the number of passengers. At present, the manager of the water transport system in Gdańsk does not offer additional services, e.g., food services or provision of advertising space. Such services may increase the total income. Additionally, the city may negotiate better conditions with the carrier managing the system. If the fleet owned by the city is introduced into the system, it will be possible to reduce the management cost because a considerable portion of the investment risk is borne by the city. The remaining economic factors are of less importance.

Assumptions related to loan financing, external subsidies, and interest rates affecting the amount of interest paid are also significant. Figure 6 presents the NPV vulnerability to shifts in financing conditions.

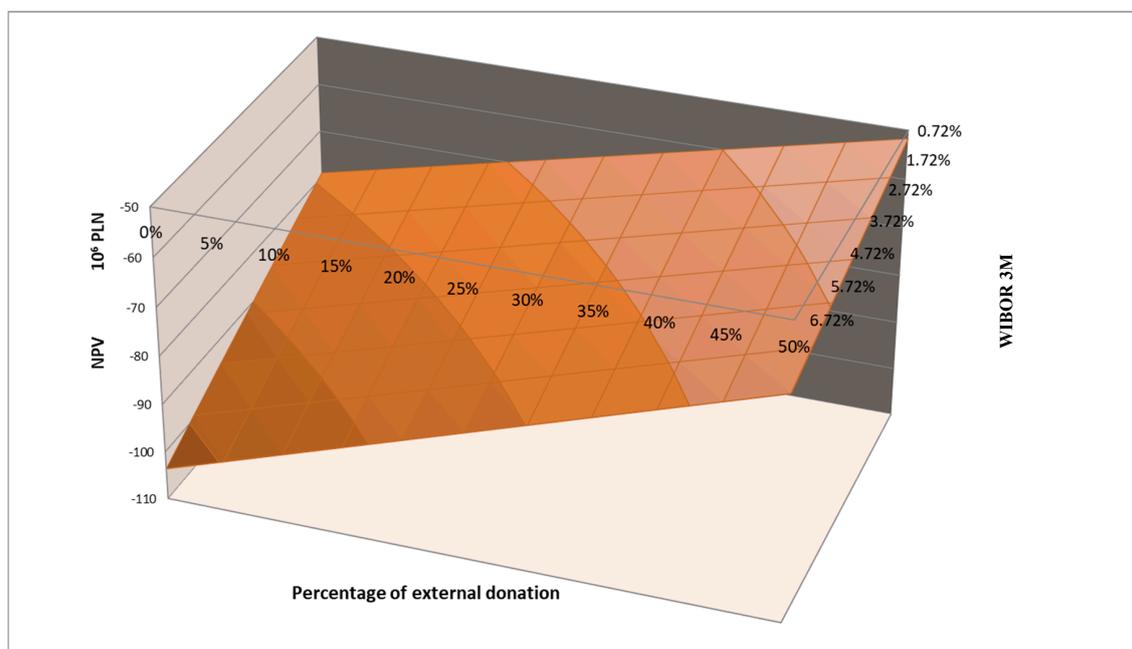


Figure 6. The NPV sensitivity to shifts in financing conditions affected by external donations and changes of the reference interest rate (possible financing scenarios).

External donations may significantly reduce the investment cost and financial viability of the project. Assuming that the interest rate (WIBOR 3M) equals 1.72% (as in 2018) and that 50% of the total project cost is financed by external donation, the NPV equals $-53,719,000$ PLN, which represents an increase of $29,295,000$ PLN. The change of interest rates has also a significant impact on the project's financial viability. The interest rates in Poland are currently low. However, if they increase, the NPV may drop significantly, possibly to $-103,631,000$ PLN if the interest rate increases by 5 percentage points. Therefore, the loan financing option is subject to considerable risk.

3.7. Other Socio-Economic Costs and Benefits

In the analysis of the socio-economic effects of implementing all-electric and hybrid passenger vessels in the transport system of Gdańsk, the content of the 2023 operational programs was taken into consideration [42] because they complement the current development strategy of the city [43]. The analysis indicated a substantial level of coherence between the project and the strategic documents (Table 7). The project may make a contribution to the achievement of eight of the operational program's nine objectives. However, it is difficult to assess the extent to which the proposed changes will influence the socio-economic development of the city. Considering the project scale and nature, the authors conclude that this influence will be insignificant. The most affected areas of city development include infrastructure, mobility, and transport, in addition to public space. Implementing the project may also foster achievement of other strategic objectives, excluding the program's education goals.

Table 7. Implementation of all-electric and hybrid ferries in the transport system of Gdańsk in the context of achievement of the 2023 operational program's objectives.

Operational programs and objectives	Influence of the investment
II. Public health and sports	
II.2. Increasing the participation of the inhabitants in physical culture.	Enhancing attractiveness and accessibility to leisure infrastructure fostering taking up physical activities.
III. Social integration and active citizenship	
III.1. Increasing the development potential of local communities, families, and individuals.	Enhancing attractiveness and accessibility to leisure infrastructure as a tool for creating health potential and cooperative attitudes.
IV. Culture and leisure	
IV.1. Increasing the participation of the inhabitants of Gdańsk in culture and cultural activity.	Enhancing accessibility to cultural institutions, culture-forming public spaces, and cultural events.
V. Innovation and entrepreneurship	
V.3. Increase in innovation and competitiveness of enterprises in Gdańsk.	Gdańsk companies may take part in all-electric ferries and hybrid trams construction processes what will strengthen their position on the market of innovative technologies.
V.4. International expansion of companies and organizations in Gdańsk.	Experience and knowledge on constructing all-electric and hybrid vessels provide access to a growing market of global transport services.
VI. Investment attractiveness	
VI.3. A lasting global recognition of Gdańsk and the metropolitan area as a center of economic success.	Projects aimed at electrifying ferry fleets arouse the interest of international companies/organizations operating on the maritime market and involved in city management due to innovative potential of such solutions. If Gdańsk companies take part in shipbuilding works, it will additionally strengthen the position of local economy as a potential partner for innovative projects.
VII. Infrastructure	
VII.1. Reducing greenhouse gas emissions and air pollution emissions.	Implementing all-electric ferries reduces in situ emissions of GHG and other pollutants. In the case of hybrid trams, the emissions are also significantly reduced.
VII.6. Water protection, including the protection of waters of the Gulf of Gdańsk.	Implementing all-electric ferries reduces the risk of surface water pollution to almost zero. Implementing hybrid trams significantly reduces such a risk.
VIII. Mobility and transport	
VIII.1 Improving the conditions for pedestrian and bicycle traffic	
VIII.2. Increasing the attractiveness of public transport.	Replacing the currently used vessels by modern all-electric and hybrid ones capable of transporting passengers and bicycles directly fosters achievement of all listed objectives.
VIII.3. Improving internal and external transport accessibility.	
VIII.4. Promoting sustainable transport and active mobility.	
IX. Public space	
IX.1. Higher quality of public space.	Enhancing accessibility to public spaces. Supporting actions aimed at enlivening and vitalizing the waterfront, development and revalorization of public spaces.

It was particularly difficult to measure potential benefits of the project in relation to innovation and entrepreneurship, and investment attractiveness. Clearly, being a subcontractor or taking any

other part in the process of constructing hybrid and all-electric vessels may establish a company's position in the still-growing innovative shipbuilding industry. However, although there are companies in the region that are capable of taking part in the project, it is not certain that they will become project partners. Spending public money involves a tendering procedure and it is impossible to directly contract particular companies. Moreover, even if some local companies become project partners, most of the works will likely be undertaken by large international concerns that deliver propulsion systems and their elements. These problems highlight the difficulty in determining regional impacts when conducting CBA analysis at the local scale [38]. This difficulty is the result of a high degree of complexity of value chains triggered by implementing a particular project in the environment of a largely open local economy.

The impact of the project on urban planning also falls within the socio-economic benefits/costs category. In this case, the analysis was based on the content of the main document determining conditions and directions of Gdańsk spatial development [55]. In this document, a necessity to promote the so-called "inward development" is emphasized. This approach aims to block urban sprawl and mitigate some of its negative consequences. Thus, it promotes, e.g., development of the existing urban structures, more intense development of the central service belt, enhancement of public space attractiveness, and development of exogenous services (e.g., tourism). Location and functions performed by the proposed system of all-electric ferries and hybrid trams foster achievement of the objectives laid out in the "Study of Conditions and Directions of Spatial Development", as presented in Table 8.

Table 8. Possible results of introducing all-electric ferries and hybrid water trams into the transport system in Gdańsk, and their impact on the main development directions of the city.

Main Development Directions	Impact of the Project on the Main Development Directions
1. Continuation of inwardly oriented development through densification of the already existing urban structures.	Proximity of some stops favors efficient use of urban space, intensification of inwardly-oriented development, and revitalization of degraded land.
2. More intense development of the Central Service Belt (CSB) area.	Proximity of some stops favors more intense development of the CSB area, especially in the scope of tourist services.
3. Enhancing quality and attractiveness of public spaces and development of endogenous services for the citizens.	Connecting public spaces of different quality and rank will increase their attractiveness through enhancing their accessibility. These will become more attractive places for leisure and other ways of spending free time (culture and leisure).
4. Development of citygenic functions in port-industry concentrations in close proximity to the port and airport, and exogenous services in the CSB and in the coastal belt.	Ferry and water tram cruises are considered tourist attractions themselves. Implementing new ferry connections will increase both accessibility and attractiveness of the places located in close proximity to the stops.
5. Protection of natural (a) and anthropogenic (b) values, and creation of new values strengthening the identity of polycentric structure of the city.	New eco-friendly vessels will contribute to improving the air and water quality as well as to reducing the noise level. Ferry and water trams may become the city's landmark/symbol and they can strengthen local identity among the citizens living in districts near the Vistula River.

4. Conclusions

The process of electrifying transport systems is consistent with the current trend of energetic transformation and is an answer to the challenges of anthropogenic climate change. Many urban transport systems in which water transport plays a significant role are currently undergoing changes, including modernization of existing fleets or purchase of new vessels. Water transport in Gdańsk mainly serves tourist traffic and is primarily a result of specific spatial conditions. Overall, the system of waterways connects tourist attractions and is not used by daily commuters. Thus, it operates mainly during the summer. Because the water transport system is served by old vessels of low capacity and

currently does not meet the needs of commuters, this article attempts to examine the extent to which it is possible to modify the existing offer by introducing new all-electric or hybrid vessels. The main disadvantage of such a solution is high investment costs and the main advantage is low operating costs. Thus, the financial issues appear to be the most importance. Therefore, the financial analysis was the basis for the presented study. However, taking the findings of Wee and Roeser [34] into consideration, the authors adopted a more pluralistic, context-sensitive approach. Both environmental and socio-economic costs were also included in the analysis, thus representing a contribution to the development of socio-economic geography. Nonetheless, the benefits and drawbacks were not always of financial nature.

Regarding the option of all-electric ferries, the highest costs are generated by loan financing because these vessels are considerably more expensive than diesel vessels. The higher the value of the loan, the higher the interest payments. However, the cost of electric energy consumption for all-electric ferries is substantially lower than the cost of fuel for diesel vessels. Regardless of the type of propulsion system used, labor costs constitute a large portion of the total cost. In the case of Gdańsk, the ticket sales revenues will not cover the operating costs. Even assuming that the system achieves the highest possible turnover, total revenues from ticket sales will cover approx. 23% of the total cost. Consequently, the total cash flow is negative, and is equal to −12.7 million PLN. Thus is the amount the city will have to cover annually to keep the system operating. In 2018, the city paid 1.9 million PLN of the operating costs of the current water tram system, which generates a significantly lower supply of transport services. The relevant question is whether the city of Gdańsk is capable of managing expenditure growth of this magnitude. The estimated 2019 total expenditure in the city budget is 3.74 billion PLN. In 2018 the city spent 711.3 million PLN on the urban transport system; it also spent 143.9 million PLN on sport, leisure, and tourism, which is the second sector closely connected to the analyzed investment. The cost of urban transport system maintenance also was 311.3 million PLN [54]. Based on these data, the estimated expenditures may be borne by the city. However, they constitute more than fifty percent of the annual road maintenance costs and exceed the maintenance costs of any other category, e.g., road infrastructure maintenance, road and traffic management, and maintenance of greenery areas next to the roads. The decision to implement the analyzed project will force significant changes on the budget structure [56]. Additionally, it is worth mentioning that all other budget categories mentioned relate to the infrastructure used by the citizens throughout the year; the urban passenger shipping system will operate mainly in the summer and, in general, it will satisfy the needs of tourists. Therefore, the benefits for the citizens are limited, although tourism is an important sector of the urban economy. All of the listed challenges and questions illustrate the main advantages and disadvantages of financial analyses.

The financial analysis of the planned project is obviously forward-looking. Thus, it is subject to the risk of estimation error. The possibility of assessing the extent to which particular factors affect the financial outcome is an advantage of this method. In this case, the vessel purchase price is the most substantial factor. However, current development trends of all-electric/hybrid propulsion systems indicate the prices of the studied vessels may decrease in the future. Furthermore, large Polish cities have already proven that they are capable of catalyzing funds from external donors, e.g., the EU. This is another means of alleviating the financial burden for the city. Moreover, when taking both the current and projected situation of the labor market into account, it cannot be assumed that it will be possible to reduce labor costs, which constitute a vital component of the total project implementation costs.

To remain in line with the aim of including intangible factors in the analysis, the authors attempted to assess the environmental effects. Implementing hybrid vessels instead of classic diesel vessels will allow specific emissions of greenhouse gases and other pollutants to be reduced by a factor of three. However, because the new vessels are planned to be more intensively used, the amount of global emissions will fall between 16% and 45%, depending on the route. Obviously, this is a significant improvement, although it is less than that of the specific emissions. This is an example of the so-called rebound effect [57] that occurs when an increase in energy efficiency leads to an increase in its global

use. In combination, a genuine need to increase transportation supply, willingness to enhance the financial outcome, and substantial reduction in GHG emissions create a favorable environment for increasing transportation supply.

Socio-economic issues that cannot be interpreted using quantitative methods or monetized were also included in the analysis. The study revealed that most of the project's planned outputs are consistent with the strategic development objectives of the city. However, it is difficult to determine the extent to which the project will affect the process of city development. Due to the scale and nature of the project, this extent is likely to be small. However, the project may contribute to numerous goals of urban policy. Determination of the project outcomes that will be discounted locally or regionally, and that will create demand for products and services provided by international corporations, was particularly problematic. In this context, a key issue is the construction of the vessels and their servicing.

In conclusion, it is financially possible to implement the analyzed project in the city of Gdańsk; however, it requires external funding. The solutions described in this work can be financed via the sources of the European Commission, which is interested in implementing the development of electromobility through the European Green Deal Strategy, among other initiatives. In addition, a Low Carbon Transport Fund has been established at the national level to support the projects described in this article. Without these funds, significant shifts in the city budget will be necessary. The environmental benefit is noticeable, although it will be reduced by the planned increase in the supply of transport services. However, this increase addresses real social and economic needs. The project is also consistent with the strategic development objectives of the city, although its impact on the development process will be limited because the passenger shipping system is tourism-oriented and because of seasonal fluctuations in service provision.

The CBA approach allows us to estimate the potential financial impact of the electrification of passenger ferry shipping on the city budget. This impact is of a monetary nature. Impossibility to take non-monetary effects into account is the main disadvantage of the CBA method. Not only the criteria of efficiency but also equity should be included in the assessment of complex infrastructure projects. The attempt of the project's environmental as non-monetary socio-economic impact estimation has been made in the paper. Both issues allow us to root the CBA outcomes in local conditions and show how the specificity of the place affects or may affect the final configuration of technical and organizational solutions in the process of electrification of urban passenger shipping. Nevertheless, using this approach still leaves a gap in the field of complex evaluation of overall potential project impact. This is the main limitation of the study. As further research, the qualitative reconsideration of monetary—non-monetary tradeoff in the field of public transport electrification is suggested. This would enable us to make academic study in this field not only more profound but also more consistent.

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