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REDUCING ENVIRONMENTAL IMPACT: THE CASE OF INLAND WATERWAY TRANSPORT IN LITHUANIA

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ABSTRACT. It is an established fact that numerous active EU policy initiatives are aimed at reducing the Union's environmental impact. Since the transport sector is one of the greatest polluters in the EU, there is a growing focus among the scientific community on the use of renewable energy sources for road transport. However, inland waterway transport has not been receiving sufficient attention. The aim of this paper is to demonstrate the benefits of developing inland waterway transport, with particular focus on reducing the environmental impact of the transport sector. The study examines the example of cargo transport for the Kaunas-Klaipeda route in Lithuania. The impact on the main external costs is calculated through modelling and comparison and the findings show that external costs are lower when transporting goods by rivers. A positive environmental impact of modal shifting is also evident when a part of the freight flow is transferred from a heavily-used road to a river with a high reserve capacity (despite the greater distance along the river). Further, the research conclusions suggest that the use of alternative power drives will help to achieve emission-free inland shipping in the future. Finally, a market analysis in relation to the potential transition to river transport with zero emissions has yielded evidence that electric ships represent the most viable alternative power drive option for achieving this objective via this route.

JEL Classification: L91, Q53, R41

Keywords: inland waterway transport, external transport costs, alternative power drives, zero emission, electric vessels

Introduction

The climate crisis remains the defining issue of our time (Buky, 2020). The consequences of global warming are undeniable; as a result, the number of extreme weather events are increasing (McCulloch et al., 2024). In response to these challenges, the EU has unveiled the European Green Deal, an initiative aimed at making Europe the first climate-neutral continent by 2050 (Baute, 2024). To achieve this ambitious goal, transport emissions need to be reduced by 90%, which cannot be done without involving all modes of transport in such reductions (Liu et al., 2024). Active use of the more environmentally friendly modes of

transport may be one of the solutions to this problem (Mako et al., 2021; Cavalcante de Barros et al., 2022). As a matter of priority, a large proportion of inland freight transport should be diverted to rail and inland waterways (Rolbiecki & Matusiewicz, 2024).

The underutilization of river transport carrying capacity represents a significant untapped resource for the development of cargo transportation by this means (Havinga, 2020). Inland shipping has traditionally been the most low-carbon mode of transport (Calderon et al., 2024; Cavalcante de Barros et al., 2022; Bu & Nachtmann, 2023; Sihn et al., 2015). The growing demand for new green economy initiatives is creating new opportunities for a more active development of inland waterway transport (Feng et al., 2024; Pande et al., 2021). However, while the topic of road transport is widely discussed (Bekisz et al., 2023; Mesjasz-Lech & Włodarczyk, 2022; Maduekwe et al., 2020; Wang & Wesseh, 2019; Georgatzi et al., 2020), there are fewer such studies on inland waterway transport. A number of seminal works explored the concept of sustainable inland waterway transport and the increasing interest in this mode of transport as a viable and cost-effective alternative to road transport (Gbako et al., 2024; Cavalcante de Barros et al., 2022; Havinga, 2020; Vega-Muñoz et al., 2021; Nowakowski et al., 2015; Leijer et al., 2015; Bu and Nachtmann, 2023). Researchers cite the cost-effectiveness of inland waterway transport as a key factor in shifting freight from roads (Mostert et al., 2016; Osama et al., 2017). Mako et al. (2021) and Feng et al. 2024 study demonstrated that inland waterway transport could substantially reduce CO2 emissions. Ilchenko et al. (2021) stressed that the development of waterway transport promotes rational consumption and production patterns, ecosystem preservation, and reduced energy consumption. Negative transport impacts are typically associated with "external costs," which occur when one person's actions affect others without proper compensation (European Commission[b]). These costs, not borne by transport users, impact societal well-being. Koba et al. (2024), Hofbauer and Putz (2020) conducted a literature review on external cost categories and calculation methods for inland waterway transport. They found fewer studies on inland waterway transport than on rail and road transport, resulting in a less detailed database. This result reflects the need for more research into the external costs of inland waterway transport and illustrates the urgent need to increase the data density for this mode of transport.

The aim of this article is to justify the benefit of the development of inland waterway transport by reducing the environmental impact and to analyse the possibility of transformation to zero emissions in river transport on the example of the Republic of Lithuania. To achieve this goal, qualitative and quantitative research methods were applied. The outcomes are anticipated to provide an impetus for greater use of zero-emission river navigation in various regions of the world.

The novelty of this study lies in the fact that we will not only carry out specific calculations of the benefits of transferring part of the cargo flow to the river in a specific area and analyse additional actions that can be taken to improve this result, but also study possible options for switching to alternative power drives and select the most suitable option for this route. Lithuania may become a unique example, the lead in this transition of the inland shipping sector: 100% green energy, no CO2 emissions, and nitrogen and particulate matter.

1. Materials and methods

To justify the benefit of developing inland waterway transport to reduce environmental impacts, we structured this study as a mixed-methods research that combines qualitative and quantitative data (*Figure 1*).

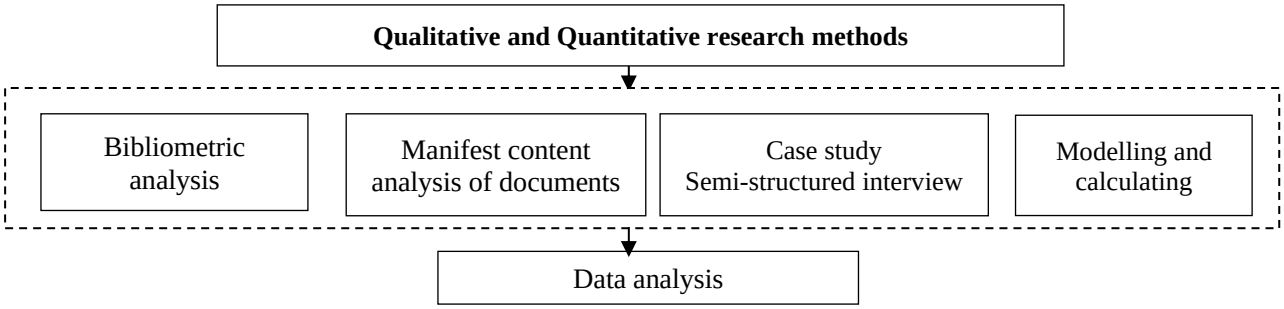

Figure 1. Logical scheme for conducting the research
Source: *own elaboration*

1.1. Bibliometric analysis

In this study, **bibliometric analysis** was chosen to determine the activity of the scientific community in researching this topic by performing a systematic analysis of theoretical research on the development of inland waterway transport while reducing its environmental impact. Bibliometric analysis proves valuable in unravelling and charting the accumulated scientific knowledge and developmental intricacies within established fields. By methodically interpreting extensive amounts of unstructured data, bibliometric studies lay robust groundwork for advancing a field in innovative and significant ways. They empower scholars to (1) obtain a comprehensive overview, (2) pinpoint areas of knowledge deficiency, (3) generate new ideas for exploration, and (4) strategically position intended contributions within the field (Donthu et al. 2021; Ogashawara, 2023).

By utilizing the functionalities of the VOS viewer program, a visual representation was generated to illustrate the co-occurrence network of keywords related to inland waterway transport development reducing environmental impact. In this visualization, circles symbolize analysed items connected to their respective designations. The size of the circle reflects the weight of the element in the network, with larger circles indicating greater significance (Ogashawara, 2023). Gaps between elements denote relevance, and the position and color are employed to group elements into clusters, enhancing the understanding of patterns and relationships within the dataset.

1.2. Manifest content analysis of the documents

Qualitative research, through manifest content analysis of documents, is used as a key source of information for analysing policy initiatives and the normative framework in the EU and Lithuania, highlighting the importance of the development of inland waterway transport in reducing environmental impacts. The method of document analysis was chosen due to its authenticity, wide availability and cost-effectiveness. The following documents were analysed: the Paris Agreement, White Paper, European Green Deal, the 2030 Climate Target Plan, the TEN-T program, the European Commission: Sustainable and Smart Mobility Strategy, the Strategy for National Energy Independence Resolution of the Seimas of the Republic of Lithuania, The National Energy and Climate Plan of the Republic of Lithuania for the period 2021-2030, The concept of the Master Plan of the Republic of Lithuania, The National Progress Plan 2021-2030 of the Government of the Republic of Lithuania, The Lithuanian Transport Infrastructure Development Plan for 2030 and others.

1.3. Case study – semi structured interview

To find out the opinion of potential users of the service regarding the attractiveness of river transport in the context of sustainability, a qualitative study semi structured interview was conducted. According to the authors (Žydžiūnaitė & Sabaliauskas, 2017; Guest et al., 2020), a semi structured interview is a universal and flexible research method that ensures two-way communication between the interviewer and the research participant, allowing for improvisation by asking additional questions based on the answers received. The purpose of a semi structured interview is not limited to the collection of actual information, its application enables the thorough disclosure of the participants' perceptions, experiences, beliefs, values and provides valuable insights into the issue under consideration (Hennink & Kaiser, 2022).

The interview questionnaire included questions on the initial reactions towards the service, attractiveness of inland shipping service, quantities of planned cargo transported, type of cargo, willing to pay and use zero-emission service and if so, based on what conditions.

The reliability of the information collected during a semi structured interview does not depend on the number of participants, but on their experience and knowledge of a predetermined problem area. According to Seidman (2013), reliable results are obtained after interviewing 5-7 persons, if knowledge of the informants about the problem area is similar, and work experience, respectively, is more than 5 years. The research participants were selected using non-probability targeted sampling according to the established criteria: their availability, willingness to be interviewed, direct experience and knowledge related to the topic of interest. Top and middle level managers of 10 companies with more than 5 years of experience and representing various fields of activity participated: 4 – agriculture, 3 – trade, 3 – production. To preserve the confidentiality and privacy of the participants, each study participant was assigned codes such as I1, I2....I10.

The interview was conducted at a time convenient for the participants. The responses were recorded and transcribed. The data obtained during the interview was processed by interpreting, systematizing, analysing, and classifying the answers into categories. 10 in-depth interviews were conducted, which lasted on average 45 minutes. Conduct the interview remotely in the Microsoft Teams program in November-December 2023.

1.4. Modelling and calculating

To substantiate the environmental and economic benefits of the development of inland waterway transport in Lithuania, the external costs estimating method was chosen. External transport costs refer to the difference between social costs (i.e., all costs to society for the provision and use of transport infrastructure) and private transport costs (i.e., costs directly borne by the transport user) (Handbook on the External Costs of Transport, 2019). A description of the external costs considered is presented in *Table 1*.

For analysis, we chose Lithuania as an example of an Eastern European country whose experience in developing inland waterway transport can be used in other countries.

Detailed calculations of external costs were carried out in comparison of the busy highway A1 (section Kaunas-Klaipeda) and the river route along Neman (inland waterway of international importance E41), which provided ideal conditions for regular navigation in this area.

Table 1. Main external costs and their explanations

External costs	Explanation
Accident costs	Costs that are not covered by the risk-based insurance.
Air pollution costs	External costs from the following types of impacts caused by the emission of transport-related air pollutants: health effects, crop failures, material and construction damage, loss of biodiversity.
Climate change costs	The costs associated with all the effects of global warming, including more frequent extreme weather events and crop failures.
Noise costs	Undesirable sounds of various durations and intensities that cause physical or psychological harm to a person.
Costs of habitat damage	Transport affects nature, landscape, and natural habitats.
Congestion costs	The condition in which vehicles prolong their travel time when an additional vehicle slows down the speed of other vehicles.

Source: *own compilation*

Based on analyzed statistical data and conducted potential users of the service interviews, the most realistic scenario for starting regular cargo transportation along the Neman Kaunas-Klaipeda route was accepted. It is 2 million tons cargo per year. Various freight transport models were simulated:

- pusher ship and barge with a lifting capacity of 1000 tons (available);
- pusher ship and barge with a lifting capacity of 1800 tons (planned purchase).

Additionally, different types of energy were assessed: diesel fuel, liquefied natural gas and zero emission shipping. Greenhouse gas emissions and energy consumption were calculated in accordance with the EN 16258 standard "Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services" (CEN, 2012). All energy consumption is converted into standard energy units – MJ:

$$E=F\times eT \quad (1)$$

where:

F – measured fuel or energy consumption and

eT - coefficient of conversion of energy into MJ.

For simulated cases where fuel consumption data are not available, they were calculated as follows:

$$G_d=b_e\times P_e\times k\times T\times 10^{-3}kg \quad (2)$$

where:

b_e - brake specific fuel consumption g/kWh,

P_e is the effective power of the engine in kW,

K – load factor

T – working (sailing time) time h.

2. Conducting research and results

2.1. Bibliometric analysis of inland waterway transport for reducing environmental impact

2.1.1. Scientific Production and Article Citations

This paper provides a comprehensive review of scientific articles pertaining to the role of inland waterway transport in reducing environmental impacts. A meticulous three-step approach was employed to gather the data. Initially, a systematic search for articles was conducted within the Clarivate Web of Science database, recognized for its extensive coverage of peer-reviewed journals. The exploration was confined to the topic, encompassing article titles, abstracts, author keywords, and keywords plus. Subsequently, the obtained results were refined by filtering for the English language. Resulting in a curated dataset of articles. This collection was subjected to analysis using the specialized software VOS viewer, applying visualization, and clustering techniques. For bibliometric analysis, relevant details such as article titles, authors' names and affiliations, journal names, publication dates, abstracts, and cited references were extracted.

The search utilized keywords such as “inland waterway transport” and “environment impact” or “zero emission” or “sustainable transportation” or “green transport”. The bibliometric analysis encompassed the entire period from 2013 to 2023, as no specific years within this range were specified. The search resulted in the identification of a limited number of publications. Specifically, only 12 publications were found in the Web of Science database during this timeframe (it is worth noting that a similar topic for road transport is much more researched). *Figure 2* illustrates the number of publications (represented as bars) and citations (depicted as a line) associated with the specified search terms.

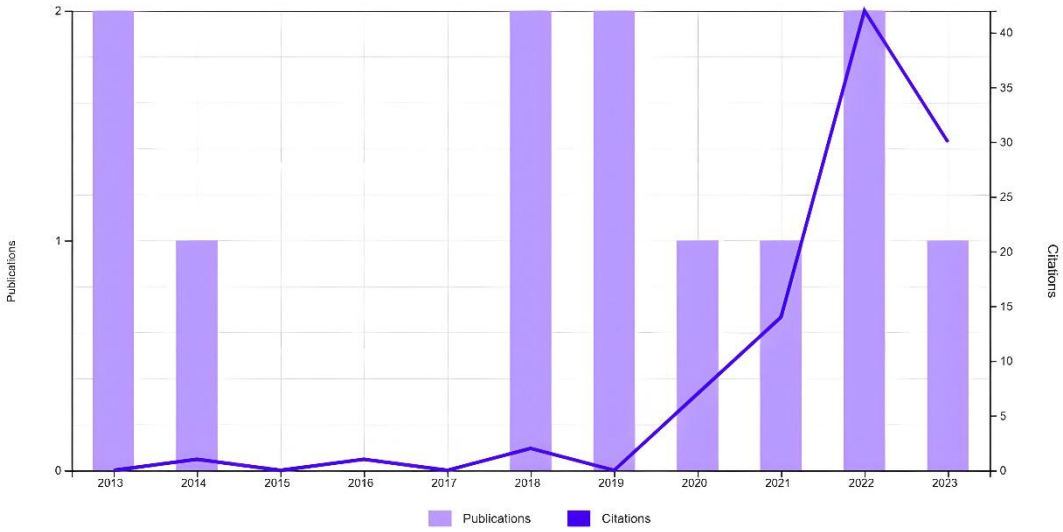

Figure 2. The number of articles and citations per year
Source: *Web of Science database*

Highlighting the productivity trends, it is noteworthy that 2013, 2018, 2019, and 2022 each witnessed the publication of two articles. In contrast, in 2014, 2020, 2021, and 2023, only one article was published per year. Regrettably, there were no articles on the subject published in WoS journals from 2015 to 2017. These findings raise concerns regarding the overall scarcity of publications on this topic.

The subsequent phase of the bibliometric data analysis focused on citation patterns, as depicted in *Figure 2*. From the examination of publications and their respective citations during this period, it became evident that only after 2019 did the number of article citations begin to increase. In 2020, the publication received 7 citations, and in 2021, it garnered 14 citations. Notably, 2022 emerged as the most productive year in terms of citations, with 42. The publication that received the most citations was "Analyzing barriers to inland waterways as a sustainable transportation mode in India: A dematel-ISM based approach" by Trivedi, A; Jakhar, SK and Sinha, D, accounting for a remarkable total of 64 citations. Unfortunately, in 2023, a decrease in the number of citations of articles is expected.

2.1.2. Co-occurrence analysis

Analyzing the co-occurrence of keywords enabled us to investigate the interconnected network of research themes and developments related to reducing the environmental impact of inland waterway transport. Additionally, an analysis of all keywords was conducted to examine the progression of topics from 2013 to 2023. The keywords (of the 87 keywords, 87 meet the threshold) reflect an article's intellectual content, and studying their simultaneous occurrence allowed for the identification of thematic trends and advancements within a scientific domain.

The co-occurrence analysis revealed 9 distinct clusters, illustrated in *Figure 3*, each distinguished by a different color. The size of each point corresponds to its occurrence, with keywords such as "inland waterway transport," "sustainability," and "port" exhibiting the highest strength. The proximity of three keywords indicates their relative strength and thematic similarity. Circles within the same color group suggest a shared thematic focus among the publications. The largest of the 9 clusters were four: red indicates cluster 1, which is formed by 13 keywords; cluster 2 (green) is formed by 12 other keywords; cluster 3 (blue colour) is formed by 11 keywords; and cluster 4 (yellow colour) – is formed by 10 keywords. The smallest is cluster 9 (purple colour), which is formed by 4 keywords.

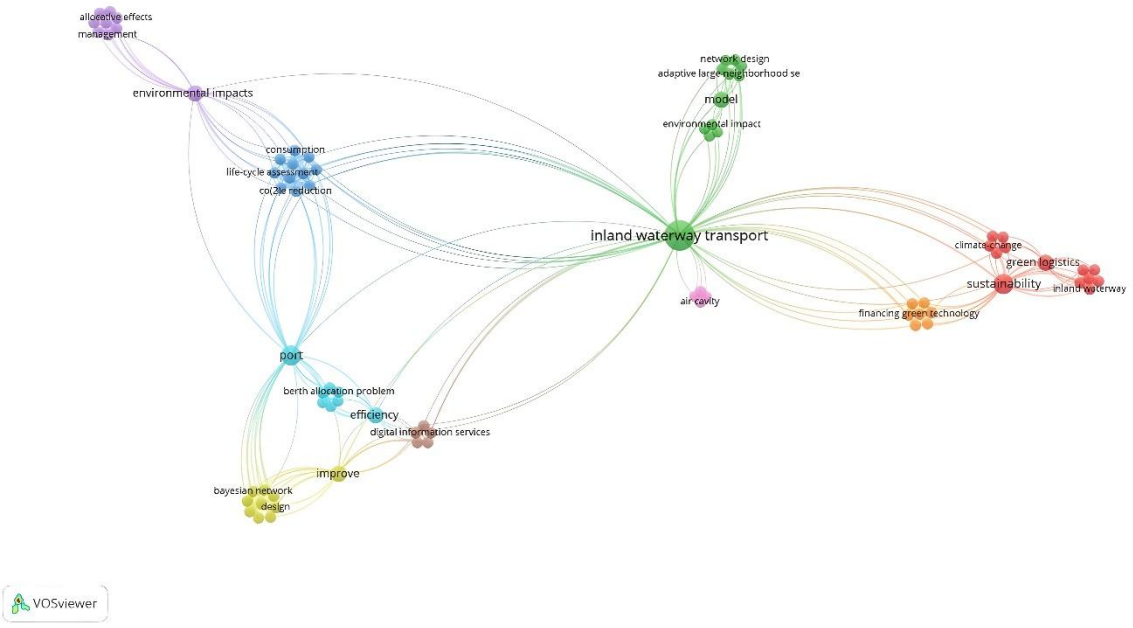

Figure 3. Overview of co-occurrence clusters created in VosViewer software.
Source: *own compilation in VosViewer software*

The red cluster is the most extensive, encompassing terms related to sustainability, climate-change, green logistics, and inland waterways.

The most frequently encountered keyword is inland waterway transport. This is understandable because we set it as a constant for the search. This is the main topic of our interest. The second most important keyword is related to sustainability. It appears in many clusters, which emphasizes the importance of this concept. These include sustainability, sustainable development, sustainable transport, sustainable transportation, and sustainable navigation.

In contrast, the keyword "zero emission" did not appear at all. This indicates that this concept has not been studied for inland waterway transport contributions to reducing environmental impacts. This fact confirms the novelty of this paper, in which we consider the use of alternative power drives to achieve zero emissions for inland waterway transport.

2.2. Policy context of inland waterway transport for reducing environmental impact: The EU and Lithuanian frameworks

Political initiatives at the EU level in recent years have been studied and analysed. *Table 2* identifies those that are considered relevant to the topic of the contribution of inland water transport to reducing environmental impact.

Table 2. Main EU policy initiatives related to the development of inland waterway transport

Policy initiative, date	Description- changes relevant to inland waterway transport
Paris Agreement, entered into force in 2016.	The document was adopted by 196 Parties. Greenhouse gas emissions must peak before 2025 at the latest and decline 43% by 2030.
United Nations Economic Commission for Europe: White Paper on the Progress, Accomplishments and Future of Sustainable Inland Water Transport, 2020	Transfer 30% of road freight traffic over 300 km to rail and water transport by 2030, and above 50% by 2050. The initiative to reduce greenhouse gas emissions by 35% compared with 2015 by 2035, reduce pollutant emissions by at least 35% compared with 2015 by 2035.
European Green Deal, approved in 2020	The ambition for Europe to be the first climate-neutral continent by 2050 - to reduce CO_2 emissions by 55% by no later than 2030. A substantial part of the 75% of inland freight carried today by road should shift to inland shipping and rail.
European Commission set of legislative proposals (the 'Fit for 55' package), 2021	Align existing EU rules with the climate targets. Most impact on inland shipping - the changes proposed in the areas of alternative fuels, renewable energy and taxation.
European Commission: The 2030 Climate Target Plan, 2020	The transport sector had the lowest share of renewable energy in 2015, with only 6%. By 2030, this has to increase to 24%.
TEN-T program. TEN-T Regulation, the European Commission, 2021	Expand the section related to multimodal freight terminals and to add focus on climate resilience regarding good navigation.
European Commission: Sustainable and Smart Mobility Strategy (SSM Strategy), 2020	An increase in IWT and short sea shipping by 25% by 2030 and 50% by 2050. Boosting the uptake of zero-emission vehicles, renewable & low-carbon fuels and related infrastructure.
NAIADES III- (the successor of the projects NAIADES and NAIADES II), 2021	Compared to its predecessor, focuses on the transformation of EU transport systems towards zero-emissions, and on modal shift.

Source: *own compilation*

As an analysis of the main policy initiatives at the EU level has shown, much effort is being made to achieve climate goals. Their main purpose is to bring existing EU rules into line with climate goals. It should be noted that this is not only a set of specific wishes about the future development of the EU, but the documents also set specific goals with clear percentages for reducing environmental emissions over the coming decades.

In practice, this means:

- Take decisive action to shift more activity towards more sustainable transport modes among which inland waterway transport occupies an important place.

- Adopt measures that significantly reduce the current dependence on fossil fuels (by replacing existing fleets with low- and zero-emission vehicles and boosting the use of renewable and low-carbon fuels).

The Lithuanian government, in the context of the overall development of Europe, is also committed to achieving results in the development of sustainable mobility, development and the promotion of clean and alternative fuels and supporting infrastructure. In *Table 3*, we have selected the main political initiatives of recent years in Lithuania related to the considered topic.

Table 3. Main Lithuanian policy initiatives related to the development of inland waterway transport

Policy initiative, date	Description
The Strategy for National Energy Independence Resolution No XI-2133 of the Seimas of the Republic of Lithuania, 2012	Provide for promoting the use of vehicles powered by alternative fuels (especially electric).
The National Energy and Climate Plan of the Republic of Lithuania for the period 2021-2030 Protocol No 52 of the Government of the Republic of Lithuania, 2019	Promoting environmentally friendly, clean, alternative fuel-powered transport and the production and use of alternative fuels. The purchase of clean and alternative fuel vehicles.
The concept of the Master Plan of the Republic of Lithuania, Resolution No XIII-3021 of the Parliament of the Republic of Lithuania, 2020	Highlights environmental aspects, ensuring the competitiveness of the transport sector, synergies, multimodality, and connectivity between cities, regions and countries.
The National Progress Plan 2021-2030 Resolution No 998 of the Government of the Republic of Lithuania, 2020	The need for more eco-friendly energy solutions in transport. Increasing the use of energy from renewable energy sources and alternative fuels in the transport sector, promoting sustainable intermodal mobility and reducing environmental pollution caused by transport.
The Lithuanian Transport Infrastructure Development Plan for 2030 Order no. 3-86Minister of Communications of the Republic of Lithuania, 2022	A plan focused on global issues, including climate change and the need to reduce greenhouse gas emissions. In accordance with national and international recommendations, national planning documents were developed to address transport sector problems.

Source: *own compilation*

It is expected that the results of the political initiatives discussed above will contribute to the decision-making process for the transition of the transport system from the current setup to a new structure.

The problems that have hampered the active development of inland waterway transport in Lithuania are similar to the problems in this sector in other Eastern European countries. The uneven development of water transport infrastructure is a serious problem for the EU. The most significant differences are observed in the eastern and western regions. In the eastern part of

the EU (states that joined the EU later than others), countries have a lower level of economic development, which has negatively affected the level of water transport. Insufficient technical equipment, often unsuitable for modern transport methods (for example, intermodal), as well as the presence of bottlenecks, characterize the waterways of the eastern part of the EU, outdated infrastructure, and fleet, because of insufficient funding for the sector over many years. In recent years, the situation in the industry has begun to improve.

This comes as pressure grows to reduce road freight transport to comply with EU rules on decarbonization, reducing air pollution, preventing congestion, and improving road safety. In addition, strong political support, both at the European and national levels, will allow for the receipt of money from special European funds (such as The Connecting Europe Facility) and ensure the allocation of a special budget for maintaining the necessary depths for navigation and improving inland waterway transport infrastructure in general. Thus, this moment may become a turning point in the development of the inland waterway transport industry, allowing for more active use of rivers for environmentally friendly transportation of goods.

2.3. Modelling and calculation of the modal shift from road to river

2.3.1. Case study

Lithuania was chosen as a selected study area because it is an Eastern European country whose future advancements in inland waterway transport can serve as a model for application in other countries. The selection was predicated upon Lithuania's advantageous geographical location within the Baltic Sea region, strategically positioned between Western and Eastern European markets, thereby delineating the Republic of Lithuania as a pivotal hub for transit and logistical services. Endowed with a central position, Lithuania is positioned to cater to expansive markets, encompassing the Baltic region, Eastern Europe, the Commonwealth of Independent States, and Western Europe, collectively comprising a populace of 689 million individuals. The transportation sector assumes a paramount role within the national economy. The transport sector is one of the most important sectors in the country, so in 2020, the transport and storage sector accounted for 13% of the country's GDP.

Currently, road transport is the dominant transport mode in Lithuania, followed by rail transport. Inland water transport is underdeveloped (see *Figure 4*).

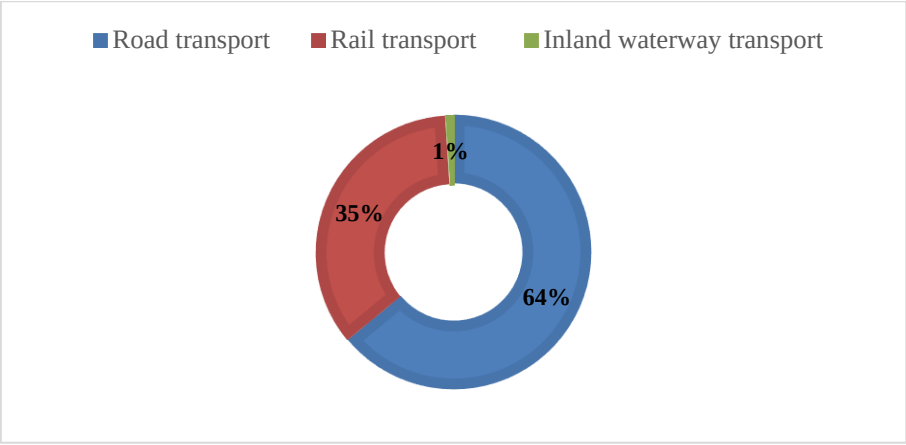

Figure 4. Modal split of interland transport in Lithuania
Source: *own data*

The potential of the inland waterway sector is very underutilized in Lithuania. The country is rich in natural waterways. Before 1990, up to 800,000 tonnes of freight were transported only via Neman between Kaunas and Klaipeda. After 1990, inland waterway transport started to decline, and this freight is now largely transported by road.

Neman is the most promising waterway in Lithuania in terms of navigation and is a vital component of the TEN-T network. It traverses two key Lithuanian centres, namely, Kaunas—the second largest city in Lithuania, a major industrial and transportation hub - and Klaipeda - one of the largest ports in the Baltic region. This fact served as the basis for choosing the Kaunas-Klaipeda route for research. It should be noted that in the southern part of Lithuania (where the main waterways are located), there is no railway connection, so inland waterway transport can become an important alternative to road transport (*Figure* 5).

Figure 5. Road, railway, and inland waterway transport system in Lithuania.The Kaunas-Klaipeda route.
Source: https://i.redd.it/y5enq4318lh31.jpg

The active use of inland waterway transport on the Kaunas-Klaipeda route relieves congestion on busy highways and, as a result, not only improves the environment, but also reduces the number of accidents on the road.

Currently, the administrator of inland waterways of national importance is the "Lithuanian Inland Waterways Authority" (LIWA). The LIWA is starting to implement and develop several important projects that will improve navigability in Lithuania, will allow inland navigation on a larger scale and will offer the potential to shift part of the freight transported by road to inland waterway transport and to increase the number and popularity of recreational and passenger journeys. *Table 4* shows the main projects/ key initiatives implemented in the Republic of Lithuania in recent years, aimed at improving navigation conditions.

Table 4. Main projects implemented in the Republic of Lithuania in recent years aimed at improving navigation conditions

Project / implementation timeline	Financing	Description
Kaunas Marvele port. Kaunas Marvele cargo berth is built in 2015 in a convenient geographical location near highway Via Baltica.	European Regional Development Fund, State budget. Several more stages are planned to expand the port.	It was used when oversized cargo was delivered from Kaunas to Klaipeda and vice-versa. Pilot trips upstream and downstream on Neman River have been conducted in the context of the EU co-funded EMMA project and revealed a first interest of entrepreneurs in exploiting the potential of inland navigation.
TEN-T network road E41 modernization. The start of the project is 2020, IV quarter, end - 2023 IV quarter.	The project is funded by the European Union, allocated funding – 23 mln EUR. It is planned to adapt this way for intensive freight, pleasure and passenger traffic.	The goal of the project is to improve navigation conditions, ensure compliance with guaranteed dimensions, reduce erosion of the banks and the riverbed. To achieve the goal of the project at least 500 new groynes will be built or renovated.
Opening of new waterways for navigation. Until 2030, it's planned to actively use for navigation not only Neman River, but also, Neris and Nevezis Rivers, which are now no navigable.	It is planned to use both local funds and the attraction of European funds.	It is planned to include the section of Neris River from Kaunas to Vilnius to the global TEN-T network. The upper section of Neman River from Kaunas to the border with the Republic of Belarus is included in the TEN T global network. Include the E70 road (its part in Lithuania) in the TEN-T main road network.
Launch event of the Baltic Supply Chains. Hamburg, 2023	Leading partner is the Port of Hamburg. "Lithuanian Inland Waterways Authority" represents Lithuania in this project and works together with the Klaipeda Science and Technology Park.	The project brings together up to 20 partners from 8 different countries of the Baltic Sea. The goal of the project is to create advanced infrastructure and improve processes that are needed in Lithuania to create a green corridor of inland waterways connecting the port of Klaipeda with other cities or logistics centers, waterways.

Source: *Lithuanian Inland Waterways Authority Homepage* https://vvkd.lt/en/projects/

Moreover, in the future, the "Lithuanian Inland Waterways Authority" plans to submit a range of project applications under the Connecting Europe for Transport Facility for Funding Industry Projects European Executive Agency for Climate, Infrastructure and Environment program. Among them:

- for the purchase of an electric crane in the port of Kaunas Marvele;
- for environmental impact assessment and preparation of technical documentation for the port of Jurbarkas;
- for the purchase of electric ships and charging of electric containers.

Currently, ongoing modernization efforts to improve navigability in Lithuania will allow inland navigation on a larger scale and will offer the potential to shift part of the freight transported by road to inland waterway transport.

A semi structured interview was conducted to find out the potential service users' opinion regarding the attractiveness of river transport in the context of sustainability. Participants of research were companies operating in different fields of activity. The main ones

among them: agricultural (agricultural and food production, agricultural commodities and agricultural machinery trade), trade and manufacturing companies.

Considering the large amount of information received during conducting interviews with participants, only the summarized results of the interviews are presented in this article (see *Table 5*).

According to the results obtained during the market scan it can be concluded, that in general Kaunas-Klaipeda region shippers are positive towards the idea of river transportation as an additional option for cargo delivery. We have not received any negative attitude expressed. Among the interviewers' arguments for positive attitude and benefits of inland waterway transport: favourable geographical location; lack of trucks and truck drivers in the country; lack of capacity by road or train, especially during the peak season; lower cost; CO_2 reductions.

Table 5**.** Findings of interviews results regarding the attractiveness of river transport in the context of sustainability

Subthemes	Representatives' statements		
	Agricultural companies	Trade companies	Manufacturing companies
Attitude towards utilising inland waterway transport	positive (I2-I4); neutral (I1)	positive (I5-I7)	positive (I8-I10)
Type of cargo	bulk (I1, I3); containers (I2, I4)	containers (I5-I7)	oversized cargo (I9-I10); heavy containers (I8-I10)
Demand peaks	end of summer (I1); end of summer and beginning of spring (I2-I4)	April-May (I5, I6); September-October (I5-I7)	no demand peaks (I8-I10)
Necessary regularity of the service	once a week (I1); twice a week (I2-I4)	3 times a week (I5-I7); during peaks every day (I6)	twice a week (I8-I10)
Condition for switching to inland waterway transport	cheaper than road transport (I1-I4)	cheaper than road transport (I5-I7)	cheaper than road transport (I8-I10)
Attitude towards use of zero emission inland waterway transport	positive (I1-I4)	positive (I5-I7)	positive (I8-I10)
Condition for switching to zero emission inland waterway transport	willingness to pay more than for regular river transport, but less than for transportation by road on the same route (I2-I4); if there is a lower pollution tax (I1)	willingness to pay more, but less than for transportation by road on the same route (15-I7); if the state compensates price difference (I6)	agree to pay more than for regular river transport due to green certificate (I8-I10); but no more than for transportation by road on the same route (I9)

Source: *own data*

Demand for the transportation of different types of cargo was discovered: containers, bulk, oversized cargo. The presence of demand for the transportation of various types of cargo can provide volumes during a year with the presence of several peaks that do not coincide in time. Participants of interview noted that for successful implementation of river transportation

service, it is important to ensure stability and regularity of the service. The best option for starting the service is transportation organized 2 times a week. All interviewers emphasised the service price as the main incentive for the modal shift. Market parties understand that inland waterway does not offer only benefits. Some participants noted that transportation time for the river transport is longer, it does not provide door-to-door delivery, so this type of transport is interested for potential users only in the case it is cheaper than road transport.

The representatives of the companies that took part in the interview have a clearly positive attitude to the advent of zero emission inland waterway transport. But even in this case, price remains the decisive factor. Participants are generally willing to pay more for "green" than for usual inland waterway transport. At the same time, in their opinion, the price should remain lower than the cost of transportation by trucks.

2.3.2. Substantiation of external costs reduction after the cargo shift from road to river

Elaborate computations were conducted to assess the external costs, contrasting the bustling A1 highway (Kaunas-Klaipeda section) with the Neman River route, an inland waterway of international significance (E41). This analysis assumed optimal conditions for consistent navigation in the specified area.

The climate change cost calculations were made based on a cost factor of € 100 per t CO_2 equivalent, the central value for short- and medium-term estimations. Environmental pollution costs were calculated using the following values: 0.6 €/kg CO and HC emissions, 7.1 €/kg NOx emissions and 38 €/kg PM (Handbook on the external costs of transport, 2020). When assessing the emission of harmful pollutants (NOx, CO, CH and particulate matter emissions), the limit values specified in the regulatory documents (Official Journal of the European Union, 2016) were used. A comparison of the external costs of road freight and inland waterway transport on the Kaunas-Klaipeda route shows that the total external costs of freight transport by rivers are lower (even using currently available diesel vessels) and can be reduced by 0.671 €-cents/tkm (*Table 6*).

Table 6. Reduction of average external costs in Lithuania after the cargo shift from road to inland waterway transport (€-cent per tkm)

External costs category	Reduction of external costs after the cargo shift from road to inland waterway transport
Accident	0,4 - 0,031=0,369
Air pollution	0,675 - 1,149= -0,474
Climate change	0,528 - 0,267= 0,261
Noise	0,465- 0 (the cost of inland waterway transport noise is considered insignificant) =0,465
Habitat damage	0,2 - 0,2=0
Congestion	0,05 – 0 (the cost of inland waterway transport noise is considered insignificant) = 0,05
Total	2,318 - 1,647=0,671

Source: *own calculations*

The analysis shows that the greatest effects are due to very low noise levels, a low number of accidents and climate change indicators for inland waterway transport. The reason for the higher air pollution compared to road transport is that the compared truck fleet is renewed faster and meets more strict emission requirements.

Separate calculations were carried out for indicators of air pollution external cost, specifically for the types of vessels considered. Comparison of air pollution external costs for ships with the same indicator for heavy goods vehicles reveals their significant reduction in case of switch to river transport (see *Figure 6*).

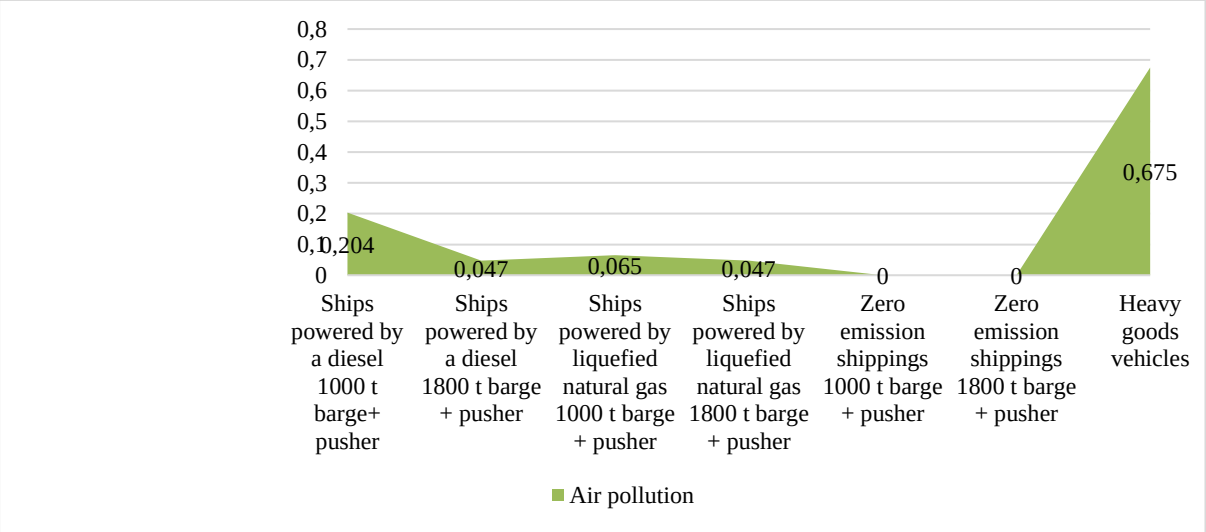

Figure 6. Inland waterway and road transport air pollution cost comparison, Eur-cent / tkm.
Source: *own calculations*

The results of the environmental impact modelling show that air pollution emissions are significantly reduced when ship tonnage increases from 1000 t to 1800 t. Using liquefied natural gas instead of diesel can reduce the external costs of air pollution to 28 %. Environmental pollution is minimized using a zero-emission option.

Table 7 further assumes a traffic volume scenario of 2 million tons per year (the most realistic volume forecast for the start of traffic) and represents the calculation of the reduction in external costs.

Table 7. Modelling of the reduction in external costs after cargo shifts from highways to inland waterways on the Kaunas - Klaipeda route, €.

External costs category	Reduction of external costs from the cargo shift from road (221 km) to inland waterway transport (260 km), €/t	Decrease in external costs for scenario 2 mln. t/year (€/year)
Accident	0,004×221-0,00031×260=0,8034	1606 800
Air pollution	0,00675×221-0,00204×260=0,96135	1922 700
Climate change	0,00528×221-0,00292×260=0,40768	815 360
Habitat damage	0,002×221-0,002×260=-0,078	-156 000
Noise	0,00465×221-0 (is considered insignificant) =1,02765	2 055 300
Congestion	0,0005×221-0 (is considered insignificant) =0,1105	221 000
Total	3,23258	6465 160

Source: *own calculations*

It has been established that when switching to river transport, savings are observed in most categories of external costs, although the road distance is shorter than that of inland waterways (221 and 260 km, respectively). Thus, the total savings in external costs when

switching from road transport to inland waterway for a scenario for transporting 2 million tons of cargo per year along the Kaunas-Klaipeda section will be almost 6.5 million Euro per year.

This figure may increase even more when ships are powered by alternative energy sources. Possible options for the transition to zero-emission shipping using alternative fuels are presented below.

3. Discussion

Increasingly stringent emission limits will inevitably lead to increased adoption of alternative power drives for all types of transport in the future, and inland waterway transport is no exception. This study led in its multifaceted approach, encompassing specific calculations of the benefits of transferring part of the cargo flow to the river in a designated area. The study analysed the external costs of different modes of transport and the positive effect for sustainable transport after the cargo shift from road to river. The results highlight the importance of external cost calculations, which have been studied by authors such as Koba et al. (2024), Hofbauer and Putz (2020), Nowakowski et al. (2015), Otten et al. (2017) and others justification for the use of river transport to reduce external costs and meet global sustainable development goals. This was also confirmed by our calculations in case of Lithuania.

Furthermore, the study will thorough investigate potential options for transitioning to alternative power drives, as an analysis of additional actions that can be implemented to improve the results obtained. The most suitable option for the particular route will be selected.

Currently, there are various alternatives to diesel available, all of which have their individual advantages and disadvantages (Calderón-Rivera et al., 2024; Peng et al., 2024; Li & Yang, 2024; Feng et al., 2024; Gbako et al., 2024; Breuer et al., 2022). Their analysis is presented in the tables below (*Tables 8 and 9*).

Table 8. Examples of alternative power drives for inland navigation in the future

Drivetrain technology	Description
Battery electric	The advantage is that the battery systems can either be integrated into the hull of the ship or it can be installed in separate battery cabinets assembled e.g., in a container. Battery containers could then be interchangeably stored on the ship.
Hydrogen Fuel Cell	Since hydrogen does not occur naturally on earth as a single molecule, but only as a chemical compound, it must always be separated to obtain pure hydrogen. Currently, there is much active research on how this process can be made as energy-efficient and climate-neutral as possible. Being carbon-free, makes the hydrogen operation of the combustion engine at least theoretically CO2, CO and hydrocarbon-free. In real operation traces of hydrocarbons in the exhaust gas can be detected due to lubricating oil in the combustion chamber.
Methanol Fuel Cell	Methanol is produced from fossil sources (natural gas) but can also be produced regeneratively. Methanol is harmful to the environment (same water hazard class as diesel) but biodegradable. Due to the liquid property of methanol, handling is like that of diesel or petrol. In combination with the comparably high energy density this is the strongest advantage of methanol.
Liquefied natural gas (LNG)	Due to its lowest possible carbon content methane has a great potential to reduce CO_2 emissions when used as fuel. However, since methane is a very climate-impacting gas, methane slip must be kept under control when LNG is used as fuel. LNG is produced by cooling down the natural gas to minus 162°C, thus converting it to liquid state for ease of storage and transport.

Ammonia	Does not contain carbon, it is a fuel outside the carbon cycle and has (except from possible emissions of nitrous oxides) no direct effect on the climate. Today, ammonia is produced mainly using the Haber-Bosch process utilizing nitrogen and hydrogen as the basis for fertilizers, which requires approximately 3% of the electrical energy generated worldwide.
GTL (Gas-to-Liquid) *	GTL is produced with the Fischer-Tropsch synthesis. Within this process various liquid synthetic fuels such as GTL, lubricating oils and other paraffinic products for the chemical industry can be obtained from natural gas, other gasified fossil fuels or biomass.
HVO (Hydrotreated Vegetable Oil) *	The feedstock for HVO con-sists of renewable sources. These can be residual plant and animal fractions from the food industry or residues from vegetable oil processing. The fuel HVO is climate neutral in the tank-to-wake cycle. Carbon contained in biomass is eventually absorbed from the atmosphere by photosynthesis by the plants replacing the burned plants.
PTL*	The synthetic fuel produced entirely from renewable energy sources is called PTL. The output of today's PTL refineries is still very low; and therefore, an immediate switch to this fuel is unfeasible. However, as market interest in this fuel increases, it can be expected that production capacity will increase significantly.

*Refers to drop-in fuels that are synthetic and completely interchangeable substitutes for conventional petroleum-derived hydrocarbons, meaning that they do not require significant adaptation of the engine or the fuel system. Since the type approval process is elaborate and costly compared to the small market, standardization and the future usage and availability of blends or pure drop-in fuels must be coordinated far in advance.

Source: *Dahlke-Wallat et al.,2020.*

Table 9. Indicators of emission factors/reduction potential complying with Stage V or better for alternative power drives possible for inland navigation in the future

Drivetrain technology	Emission factors/reduction potential		
	CO_2 g/kWh/%	NOX g/kWh/%	PM g/kWh/%
Battery electric	0/-100%	0/-100%	0/-100%
Hydrogen Fuel Cell	0/-100%	0/-100%	0/-100%
Methanol Fuel Cell	0/-100%	0/-100%	0/-100%
Liquefied natural gas (LNG)	637/-13%	1.8/-84%	0.015/-97%
Ammonia	new processes for ammonia production must be applied before it can be used as a climate-friendly fuel. Such processes are still in the development phase and have not yet been used commercially.		
GTL (Gas-to-Liquid)	720/-0%	1.8/-84%	0.015/-97%
HVO (Hydrotreated Vegetable Oil)	0/-100%	1.8/-84%	0.015/-97%
PTL	0/-100%	1.8/-84%	0.015/-97%

Source: *Dahlke-Wallat et al., 2020*

Thus, it became obvious that the 3 options (battery, hydrogen, and methanol) are completely zero-emission solutions, where CO_2, NOx and PM emissions equal 0. *Table 10* provides an overview and comparison of the criteria for these 3 different powertrains.

Table 10. Overview of the criteria for zero-emission solutions

	Methanol	**Hydrogen Fuel Cell**	**Battery electric**
Techno-logical readiness	Lower energy density of methanol requires larger tank.	Lower energy density of hydrogen requires larger tank. Hydrogen not widely available and costly.	High weight of batteries. Usually, application field - rather short distances.
Average Energy cost per kWh Eur/kWh*	2500	2000	750
Operational costs per kWh Eur/kWh **	0,46	0,45	0,12

* CCNR, 2021
**Dahlke-Wallat et al., 2020
Source: *own compilation*

Thus, based on the analysis, it can be concluded that battery electric ships can be considered the most favourable option, both from an economic and technical point of view, for transporting goods with zero emissions on the Kaunas-Klaipeda route. The solution to both technological difficulties (the high weight of batteries and usually application field -rather short distances) may be the need to stop and replace the battery on the way from Kaunas to Klaipeda. The solution to this problem is technically feasible since there is a port on the way from Klaipeda to Kaunas where it will be possible to make a stopover. This is the port of Jurbarkas, the development of which is planned, as noted above.

All-electric shipping is not yet commonplace in Europe, although examples exist. Therefore, Alphenaar is the first Dutch inland vessel to use interchangeable energy containers for propulsion: ZESpacks. The company Zero Emission Services (ZES) was founded in 2020 by ENGIE, ING, Wärtsilä and the Port of Rotterdam Authority, thereby taking an important step in the transition to emission-free inland shipping.

Alphenaar sails with two ZESpacks on board between Alphen aan den Rijn and Moerdijk and can be loaded and exchanged at the first charging station at the CCT terminal in Alphen aan den Rijn. There are 2 ZESpacks on board the Alphenaar. They look like standard containers but are filled with batteries that are in turn filled with green electricity. The containers consist of 45 battery modules that are good for 2 MWh in total, comparable to the capacity of 36 electric cars. During sailing towards Moerdijk, one battery is used, a trip that lasts approximately six hours. The second container is used on the way back.

The batteries can be charged at the CCT container terminal in the Alphen aan den Rijn. This charging station was designed by Engie. The containers can alternate. The charging station has a capacity of two megawatts, which means that the batteries of two energy containers can be charged at a rate of 1,000 kW each. (Port of Rotterdam; Zero emission services). The intention is for the number of ZESpacks and charging/switching stations to increase rapidly in the coming years.

In the future, such technology can be used on the route we are considering – Kaunas - Klaipeda. Based on the analysis of possible options for transition to zero-emission shipping using alternative fuels (Feng et al., 2024; Li & Yang 2024; Gbako et al., 2024 and others), it can be concluded that for the transportation of goods with zero emissions along the Kaunas-Klaipeda route, battery electric ships can be considered the most profitable option, both from an economic and technical point of view.

Thus, river navigation which is a more environmentally friendly mode of transport (Cavalcante de Barros et al., 2022; Bu & Nachtmann, 2023; Vega-Muñoz et al., 2021; Sihn et al., 2015) could become even cleaner. Inland shipping still has considerable capacity reserves for additional vessel performance on most waterways, which makes the desired shift of freight

traffic to relieve roads possible. This is extremely important considering the congestion of other modes of transport and forecasts for an increase in the number of cargo flows in the future.

Our analysis proves that there are already examples of electric inland waterway transport for cargo transportation in Europe, although they are not yet numerous. If zero-emission shipping occurs in Neman, Lithuania could become a unique example of the use of these modern zero-emission technologies on river vessels. Such changes lay the foundation for how the EU transport system can achieve its planned green transformation. This experience in river transport development and the transition towards zero-emissions can be used in other countries.

Conclusion

The present study has sought to make significant contributions to understanding of the benefit of inland waterway transport development, with a particular focus on the potential for reducing environmental impact. In addition, the possibility of achieving zero emissions in river transport, using the Republic of Lithuania as a case study, was analysed.

Much research is being conducted on the possibility of reducing pollution for road transport. The bibliometric analysis of this study showed that far less attention is given to inland waterway transport, although this mode of transport has great underutilized potential.

Manifest content analysis proves the relevance of the research and the chosen topic to policy initiatives in recent years aimed at solving environmental issues. However, in many Eastern European countries (such as Lithuania, the example of which we consider in the article), inland waterway transport has not received due attention in recent decades. This has led to aging infrastructure and underdevelopment of the industry. Currently, due to the special interest in providing clean transport services, this topic may become a turning point for the development of river navigation. In this regard, the results of this study may help inland waterway transport contribute to reducing environmental impacts to provide an impetus for greater use of river transport and attract investment in this type of transport.

In this study, we examined inland waterway transport contributions to reducing environmental impacts on Lithuania in the case of a modal shift in cargo traffic from the busy Kaunas-Klaipeda highway to the Neman River (an inland waterway of international importance, E41). A semi structured interview as qualitative study method was conducted to find out the potential service users' opinion regarding the attractiveness of river transport in the context of sustainability. According to the obtained results it can be concluded, that in general, interviewers are interested in the idea of river transportation as additional options for delivery cargo and have clearly positive attitude to the advent of zero emission inland waterway transport. Which proves the significance of the development of inland waterway transport. A comparison of the impacts on the main external costs for Kaunas-Klaipeda route revealed that the external costs are lower when transporting cargo via river, even though the distance of the road route is shorter. Interrelations among external costs show that the greatest effect is achieved due to a very low noise level and a low number of accidents (traffic safety) for inland waterways. Various freight transport models have been simulated. The results show that air pollution emissions may decrease when ship tonnage increases.

One of the significant differences and innovations of this article - the calculation of a specific positive effect in terms of external costs for ships using alternative fuels and various energy sources in inland waterway transport. Using liquefied natural gas instead of diesel can reduce the external costs of air pollution by up to 28%. This figure may be significantly increased using ships powered by alternative energy sources.

In this study the possibility of transitioning to zero emissions in river transport is also shown and analyzed. The novelty of this study is that we described and discussed different types of possible emission-free inland shipping. This will provide an additional impetus to increase the positive environmental impact of switching cargo from roads to rivers by using ships powered by alternative energy sources. This study provides evidence that the most suitable alternative power drive option for achieving zero emissions via this route is the use of electric ships.

This paper was designed for a specific Kaunas-Klaipeda route, but the results from this study open the door for further scientific studies of possible modal switching on other rivers, which will contribute to reducing environmental impact. Further prospective research may include a review of possible financing mechanisms in different regions of the world to promote the transition towards alternative power drives for zero-emissions in inland waterway transport.

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