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Sustainable Logistics Through Waterways: Balancing Cost, Efficiency, and Environmental Impact

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***Abstract* -The use of various modes of transportation in transporting goods and passengers certainly presents each advantage. However, transporting logistics by land has various negative impacts such as pollution, congestion, and excessive dependence on land transportation [19]. The use of land transportation modes also has an impact on the high cost per kilometer with the same distance traveled. The use of inland waterways as a mode of logistics transportation has increased in recent years especially in Europe and Asia, of course this is driven by the benefits offered. The main objective of this study is to analyze and compare the effectiveness of sustainable logistics using inland waterway modes, especially in the context of cost, operational efficiency, and environmental impact. This research aims to provide an in-depth insight into the potential benefits and challenges faced in implementing an inland waterway-based logistics system. The method used to find data and information is to use the literature study method that discusses the use of inland waterways. From the results of the studies collected and analyzed, it was found that Inland Waterway has many positive impacts and greater benefits when compared to using other transportation routes. In addition, the application of Inland Waterway has succeeded in reducing air pollution levels, reducing shipping costs, and as the most environmentally friendly branch of water transportation.**

Keywords: Congestion Reduction, Cost Efficiency, Inland Waterway

I. INTRODUCTION

In the world of logistics, of course, it cannot be separated from the increasingly complex global challenges that are more than just ensuring that goods arrive safely and securely, but these challenges continue to change along with technological advances and the rapid pace of logistics activities around the world, so this requires business stakeholders to respond strategically. some of these challenges such as increasing transportation costs, environmental issues that are increasingly echoed, and slow delivery. The mode of transportation through which goods and passengers are delivered is key to the success and smoothness of the delivery process, which in turn will impact the level of cost efficiency and delivery time.

The use of various modes of transportation in the transportation of goods and passengers certainly presents each advantage. However, transporting logistics by land has various negative impacts such as increased air pollution, congestion, and excessive dependence on land transportation [19]. Congestion, air pollution, climate change, accidents, noise, and inadequate infrastructure are examples of transportation-related impacts that generate costs, which are not fully borne by transportation users. These external costs will continue to increase without appropriate policy intervention, as they are not factored into the selection of the appropriate freight transportation mode. In addition to the above impacts, the use of land transportation modes also has an impact on the high cost per kilometer with the same mileage when compared to using sea transportation modes. Comparison between land and sea in transportation costs, then using sea transportation is much cheaper. Transportation Observer, Bambang Haryo Soekartono said, that sea transportation costs only 27 percent of the total logistics transportation costs where 73 percent is land transportation both on the Hinterland and Foreland sides [20]. Of course, in the world of logistics, logistics distribution operational activities are very concerned, such as aspects of timeliness of delivery, security and small operational costs.

Inland Waterway Transportation (IWT), is a mode of transportation and an essential element of modern transportation and logistics systems. As the world strives to find more sustainable and efficient ways of transportation, inland waterway has seen a significant increase. This environmentally friendly mode of transportation utilizes rivers, canals, lakes and other water

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bodies as a sailing medium. This mode of inland waterway transportation offers a promising alternative to roads and railways. The use of inland waterways as a mode of logistics transportation has increased in recent years, especially in Europe and Asia. In 2021 there was an increase in transportation activities using inland waterways in major European ports, such as the port of Rotterdam which experienced an increase in loading and unloading volumes of 6%, the Port of Antwerp experienced an increase in freight transportation of 7.5%, in Constanta transportation via inland waterways increased by 6.7% to reach 15.86 million tons compared to 2020 [21]. Furthermore, in 2018 China handled the largest volume of inland waterways in the world, totaling 3.74 billion tons. (INTERNATIONAL DEVELOPMENT IN FOCUS, 2020). Inland waterways also offer a variety of benefits to various aspects such as economic benefits, environmental benefits, social benefits and multimodal benefits. Inland waterway is the most economical mode of transportation, where the external costs and infrastructure required are much lower when compared to road and rail transportation, making it an economical choice for freight transportation. Inland waterways consume significantly less energy, requiring only about 17% of the energy per ton transported, whereas road and rail transport require 50% of the energy.(European Commission) This suggests that the low energy used translates into low operating costs. Inland waterways also offer social benefits, as their carbon emissions per ton and ton-kilometer are lower than other alternative modes. Recent European data shows that inland waterway transport (IWT) environmental performance per ton kilometer for bulk carriers uses only 10 percent of trucks for carbon dioxide (CO2) emissions, 13 percent of trucks for nitrogen oxides (NOx), and 50 percent of trucks for particulate matter (PM) (CE Delft 2017). In addition, accident and noise levels are much lower compared to other modes of transportation. (BLUE ROUTES FOR A NEW ERA, 2020).

Considering the many and extensive benefits offered by using inland waterways as a mode of logistics and passenger transportation, it is necessary to take advantage of the use of inland waterways as an effective solution to the problems of congestion, pollution generated by carbon emissions, noise and high operational costs and limited cargo transported when using inland transportation modes. Therefore, the main objective of this study is to analyze and compare the effectiveness of sustainable logistics using inland waterway modes, especially in the context of cost, operational efficiency, and environmental impact. This research aims to provide an in-depth insight into the potential benefits and challenges faced in implementing an inland waterway-based logistics system. In addition, this research also provides insights for the government, private sector, and local communities, in developing policies that support and encourage the use of inland waterways as a more environmentally friendly mode of transportation.

II. Method

The analysis we use is the literature study method, According to Rosyidhana (2014: 3) in (Rusmawan 2019: 104) Literature study is a data and information collection approach that involves searching and reading written sources, such as literature or books that provide an explanation of the theoretical basis. This approach is also similar to collecting knowledge or knowledge from sources such as books and papers, as well as other sources related to the research subject. (Dewi in Rusmawan, 2019: 104).

This analysis uses a literature study analysis technique, where all the results of the literature found are collected with criteria determined by the author and then evaluated to strengthen the theoretical basis of the analysis and compare the successful use of inland waterways from each literature study. According to (Ramdhani et al., 2014) describes four stages in making a literature review, namely:

1. Selecting the topic to be reviewed
2. Search for and select articles that are suitable/relevant to the title
3. Conducting literature analysis and synthesis of the selected journals.
4. Arrange and organize the structure of the review writing

The data collection technique carried out is by using the PRISMA diagram stage which has several criteria in sampling in the form of journals or articles. The determination of the criteria for the results of the analysis collected in this analysis are:

1. articles published in journals that have been published
2. articles published in Google scholar indexed journals
3. the subject of the research is the use of waterways to minimize costs and reduce the impact on the environment.
4. the keywords in the article search are waterway use, waterway utilization, waterway interaction on cost and environment, waterway analysis results, success in waterway use.

III. Results and Discussion

When compared with other line transportation methods, Inland Waterway can make logistics transportation more efficient and effective in the countries that implement it. The study results we collected and analyzed show that Inland Waterway has many greater benefits. Customer satisfaction can be increased by saving time. In addition, Inland Waterway has become the most environmentally friendly means of water transportation, has lowered air pollution levels and lowered shipping costs, so companies can build a good reputation if they use it.

Number	Researcher's Name	Research Title	Country	Results	Findings
1.	Nadia Pourmohammad-Zia, Mark van Koningsveld	Suistanable Urban Logistics: A Case Study Of Waterway Integration In Amsterdam.	Netherlands	The analysis shows that the *inland waterway-based* food distribution chain provides important advantages in terms of total cost, leading to cost savings of approximately 28% compared to the truck-based system. In addition, the waterway-based food distribution chain shows a significant average distance reduction of 80% in the city center to serve HoReCa points compared to the truck-based system. This reduction in travel distance has the potential to reduce traffic congestion, improve efficiency in terms of time and fuel consumption, and contribute to emission reduction.	In Amsterdam it was found that *inland waterway* transportation made cost savings of about 28% compared to truck-based systems and a reduction in average mileage.
2.	Antonio Felipe Gomes Teixeira, Andrej David	The water transport scenario in south america	Brazil	The country has about 3000 kilometers of navigable rivers, on a waterway called Paraguay-Paraná. According to Fleitas (13), 80% of Argentina's total production is transported via this route. To further encourage inland waterway transportation, the country has reduced the applicable tariffs by 20% in 2016. The rivers of this waterway have been used to transport goods since the colonization of the region. One of the most important ports on the Argentine section of the waterway is the Port of Rosario, located in the northern region of the country. It is a multipurpose port, operating from containers to grain and liquid cargoes.	In South America the utilization of rivers and *inland waterways* can reduce tariffs.
3.	Krystyna Wojewódzka-Król, Ryszard Rolbiecki	The role of inland waterway transport in city logistics	Poland	It is estimated that the transport of wastewater in Lille during the year displaces almost 12,000 trucks and reduces CO2 emissions by 1,500 tons. In the Netherlands, in the Amsterdam area, the transport of 140,000 tons of waste to the landfill in Alkmaar via waterways removes 5,500 trucks from the roads each year. In the UK, waste barges replace 100,000 trucks annually. (INE, 2008).	*In* the Netherlands (Amsterdam), France (Lille), UK, the use of *Inland Waterways* reduces CO2 emissions and makes vehicles more efficient. .
4.	Dr. Dalia Hosni El-deasty, Dr. Mostafa Mohamed Saber, Mr. Omar Mostafa Mohamed Ahmed, Mr. Ahmed Mohamed Omar Ibrahim	The efficiency of river logistics and its role in improving inland water transport operations in egypt	Egypt	The most prominent of these countries is the People's Republic of China, which has seven major rivers, the most prominent of which is the Yangtze River, as it plays a huge role in China's Belt and Road Initiative. The length of this river is about 6,300 kilometers, including 2,800 kilometers. Kilometers suitable for navigation by cargo ships there are also about 20 river ports along the river. Thus, inland water transportation covers about 70% of the distance across the Yangtze River. The efficiency of river logistics services, the improvement of river transportation operations, and the efficient implementation of logistics activities depend on the implementation of an effective river information service system (RIS) in all countries connected by a single river, which achieves a number of benefits, the most important of which is the safe and efficient transportation of goods and passengers across waterways (rivers).	In China, the utilization of rivers for logistics channels is beneficial to river logistics services, the improvement of river transportation operations, and the efficient implementation of logistics activities depends on the effective implementation of the river information service system (RIS) and helps improve *Inland Waterway*.
5.	N. Calderon-Rivera, Bartuseviciene, F. Ballini	Sustainable development of inland waterways transport: a review	Sweden	Currently, the inland transportation sector consumes large amounts of energy; however, when comparing different modes, IWT is the best performing mode (Rohács and Simongáti 2007). when comparing different modes, IWT is the best performing mode (Rohács and Simongáti 2007). Among all internal transportation modes, IWT is considered the most environmentally friendly due to its performance in terms of CO2 release	The*Inland Waterway* is the most environmentally friendly in CO2 release and produces the least air pollution compared to other routes.

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				(Jonkeren et al. 2019). In this regard, energy consumption is about 75% lower than road; in addition, noise pollution and land use are lower compared to other modes of inland transportation (Gołębiowski 2016; Mihic et al. 2011).	
6.	Obioma Reuben Nwaogbe, Priscillia Ogorode	Assessment of operational performance and service quality in inland waterway transport: A case study of Warri Southwest, Nigeria	Nigerian	researched inland water transportation in Poland and concluded that it is the most energy-efficient mode of transportation. Inland canal transport uses fewer diesel engines per 100 tons per kilometer compared to rail or road transport. The findings show that each variable has a significant (p=0.05) and positive correlation with the efficiency of inland canal transportation.	In Poland, *inland waterway* use is most energy efficient and diesel engines are used less than in rail or road transportation.
7.	Agnieszka Nowy, Kinga Łazuga, Lucjan Gucma,Andrej Androjna, Marko Perkovic, Jure Srše	Modeling of vessel traffic Flow for waterway Design-Port of Swinoujscie Case Study	Slovenia	The study used Automatic Identification System (AIS) data to model vessel traffic flow in the port of Świnoujście. The spatial distribution of vessel positions was affected by vessel type, size, and distance from hazards. The average speed varies, where passenger vessels (PAS) are faster compared to OPT and GC. This is because PAS vessels have good maneuverability and are often controlled by skippers who are experienced in local conditions.	Energy Use Efficiency: Optimal speed guidelines based on vessel type (such as faster passenger vessels) help reduce fuel consumption and carbon emissions, supporting environmental sustainability. Guiandce on Long Routes: Installation of additional guiandce on longer routes helps reduce vessel deviation from the main track, maintaining smooth traffic flow and reducing the risk of environmental accidents.
8.	Xia, Z., Feng, T., Guo, Z., Jiang, Y., & Wang, W.	Research on safety and efficiency warranted vessel scheduling in unidirectional multi-junction waterways of port waters	China	Compared to the First-Come-First-Served (FCFS) scheduling method, IVSA is more efficient by reducing the number of vessel speed changes and minimizing the delay due to safety constraints. The improved adaptive genetic algorithm (IERAGA) shows faster convergence and produces more efficient scheduling solutions than the standard genetic algorithm (SGA).	The IVSA approach improves traffic efficiency by reducing unnecessary vessel speed changes and decreasing waiting time. The KCAPM model is helpful in maintaining vessel traffic safety, especially in congested unidirectional multi-junction lanes.
9.	Sara S. Fouad, Essam Heggy, Udo Weilacher	Waterways transformation in the vulnerable port city of Alexandria	Germany	New Economic Opportunities: The transformation opens up space for the construction of commercial and logistics facilities along the new route, which boosts local economic activity and creates jobs in the inland logistics sector. Reduced Dredging Needs in Ports: The closure of the canal stops sediment from previously flowing into the harbor area, reducing the frequency and cost of dredging required to maintain harbor depth.	The construction of commercial and logistics facilities along the new line opens up opportunities for Alexandria to develop as a regional economic and logistics hub, attracting more investment. The improved accessibility and new facilities around the roadway provide economic benefits to the local population by creating new jobs in the logistics sector and other related services.
10.	Nguyen, Thi Minh Hoa; van Binsbergen, Arjan; Dinh, Cuong Thinh	Dry port location selection for integration with inland waterway transport in developing countries A case study in Northern Vietnam	Vietnam	Cost Efficiency: Water transportation shows better cost efficiency than other modes of transportation, especially for long-distance freight transport. It is considered to be more fuel-efficient and cheaper than road and rail transportation, resulting in lower overall logistics costs. Lower Environmental Impact: The use of water transportation reduces carbon emissions and other negative environmental impacts. This mode of transportation produces lower emissions than road and air transportation, making it a more environmentally friendly option environment in reducing air pollution and road congestion.	The Potential of Water Transportation Integration in Developing Countries' Supply Chains: The findings of this study show that the integration of water transportation with inland ports has great potential to improve logistics efficiency in developing countries. For example, in Vietnam, improved connectivity of inland ports with river networks can expand the range of logistics services more efficiently. The Role of Economy and Environment as Determinants of Inland Port Location: Other findings highlight that economic factors, such as reduced transportation costs, and environmental factors, such as reduced

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					emissions, are key criteria in the selection of locations for inland ports integrated with waterways. These results indicate that water transportation is not only a low-cost solution, but also supports environmental sustainability targets for developing countries that adopt this approach.
11.	Behzad Behandi, Yun Fan and Bart Wiegmans.	Inland Waterway Transport and Inland Ports: An Overview of Synchromodal Concepts, Drivers, and Success Cases in the IWW Sector	Netherlands	As a result, the successful implementation of synchromodal transportation such as the European Gateway Services (EGS), which transports containers between the ports of Rotterdam and Antwerp and several inland terminals in the Netherlands, Germany and Belgium using more than 30 weekly barge services and 40 weekly rail services, was demonstrated.	Inland Waterway Transport is an environmentally friendly mode of transportation, efficient in the use of fuel and capable of transporting large volumes at relatively low costs. This is evidenced by the increasing output of container use around the world, seeing that the inland waterway infrastructure network in Europe is very extensive reaching 40,000 km with most of it spread across Germany, Belgium, France, Austria and the Netherlands.
12.	Fan Bu and Heather Nachtmann	Literature review and comparative analysis of inland waterways transport: "Container on Barge"	America	The results of this study show that the development of inland waterway transportation is influenced by the growth of market demand, government policy support, investment in infrastructure and has the potential to provide significant environmental benefits.	Di Eropa sendiri, pertumbuhan kapal tongkang mengalami pertumbuhan rata rata 15% selama dua dekade terakhir, dengan total TEU yang ditangani oleh kapal tongkang ini meningkat 37% dalam periode 10 tahun (2007 - 2017). ini karena dengan menggunakan moda transportasi inland waterway dapat berpotensi mengurangi emisi, kemacetan dalam jaringan transportasi hal ini lah yang membuat inland waterway alternatif yang lebih ramah lingkungan dibanding dengan yang lain.
13.	Elena Plotnikova, Milita Vienazindiene and Stasys Slavinskas	Development of Inland Waterway Transport as a Key to Ensure Sustainability: A Case Study of Lithuania	Lithuania	The results of this study show that the use of inland waterway transportation modes has economic and environmental benefits, can reduce external costs, then this study also models what types of fuels can be used in inland waterway transportation that aims to reduce environmental impacts.	The use of inland waterway transportation modes on the Klaunas - Klaipeda route is a cheaper, efficient and environmentally friendly alternative to road transportation. Furthermore, this study also proves that the development of inland waterway transportation can reduce external costs, which include the environmental and social impacts of transportation.
14.	Oleg Bazaluk, Valerii Havrysh and Vitalii Nitsenko	Energy Efficiency of Inland Waterways Transport for Agriculture: The Ukraine Case Study	Ukraine	The results of this study show that using inland waterway transportation modes such as the Dnieper River inland route has great potential for the transportation of agricultural products such as grains and sunflower oil. It offers lower logistics costs and little environmental impact, and has a high export potential, so along the Dnieper River region accounts for about 35% to 51% of the national production of grains, which will certainly have an impact on the use of inland waterway transportation modes for cost efficiency.	The findings of this study are that the use of inland waterway transportation modes has economic advantages, where waterway transportation has lower infrastructure and external costs of (EUR 24/1000 tkm) compared to roads (EUR 40/1000 tkm) or railways (EUR 68-71/1000 tkm).
15.	Natalia Calderón-Rivera Inga Bartusevičiene, Fabio Ballini	BARRIERS AND SOLUTIONS FOR SUSTAINABLE DEVELOPMENT OF INLAND	Sweden	Inland Waterways, like any other means of transportation, also incur a number of external costs associated with accidents, noise, congestion, habitat destruction, air pollution, climate change and emissions.	The use of Inland Waterways, which can transport larger volumes of goods than land transportation, can lower operating costs compared to

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		WATERWAY TRANSPORT: A LIERATURE REVIEW		However, the costs are lower than road and rail transportation, making Inland Waterway a more sustainable transportation option.	trucks and trains. Transporting far more goods in one trip than other modes of transportation can reduce the frequency of trips required and the emissions generated. With Inland Waterway, inland areas can be connected to ports and support local and regional economies, so choosing Inland Waterway is a more sustainable transportation option.
16.	Jun Huang, Haiyuan Yao, and Zhengyong Chen	Exploration of Digitalization System and Technical Solutions for Inland Waterway.	China	Given the important role of Inland Waterway in developing inland areas, China has made the development of inland waterway shipping as a strategic priority in building an integrated transportation system. Technological innovation is the key to achieving relevant policy objectives. These policies are important for exploiting the comparative advantages of Inland Waterway lines, building an integrated transportation network, and building national strength in transportation.	The increasing scale of Inland Waterway development in China and its significant contribution to economic growth, with waterways such as the Yangtze River supporting 40% of the country's total GDP makes China prioritize to develop Inland Waterway to develop with the times.
17.	João Pratas, Susana Garrido, Carina Pimentel	Sustainable Inland Waterway Transportation System: Framework Proposal	Portugal	Inland waterways are a promising solution for urban logistics in the country, contributing to reducing road congestion, noise levels and environmental pollution, and CO2 emissions as well as road congestion, creating a positive impact on sustainable development.	The integration of Inland Waterways with other modes of transportation (such as road and rail) is crucial to creating an efficient and sustainable transportation system. This enables smoother movement of goods and reduces congestion on roads. It can also improve accessibility to remote areas, support social inclusion, and provide economic benefits through reduced transportation costs and increased trade. Inland Waterway is considered as a more environmentally friendly solution compared to traditional modes of transportation that emit high carbon emissions, thus helping to mitigate the effects of climate change.
18.	Vytautas Paulaus kas, Lawrence Henesey, Birute Plačiene, Martynas Jonkus, Donatas Paulauskas, Raimondas Barzdžiukas, Artur Kaulitzky, and Martynas Simutis	Optimizing Transportation Between Sea Ports And Regions By Road Transport And Rail And Inland Waterway Transport Means Including:"Last Mile" Solutions	Lithuania	In many countries, Inland Waterway connects regions and ports with inland industrial areas and population concentration areas and can be used for inter-regional cargo delivery, from ports to destination areas and from sending areas to ports. Inland waterway transportation (barges and inland waterway cargo ships) in most cases uses less energy (fuel) consumption for the transportation of the same volume of cargo. The obtained results show that container transportation between Klaipeda container terminal and Kaunas FEZ is the most acceptable using water or rail transportation (relative difference (ΔKi) up to 35-47%).	This study shows that container transportation between the Klaipeda port container terminal and Kaunas Free Economic Zone is more efficient using rail or inland waterway transportation, with the difference in relative index (ΔK_i) reaching 35-47% compared to road transportation. Inland Waterway has lower fuel consumption compared to other modes of transportation with the average fuel consumption for Inland Waterway being around 8-10 g/t km, much more efficient compared to road (55-65 g/t km) and rail (30-35 g/t km) transportation.
19.	Xuan-Kien Andg, Tien-Dat Tran , Mai-Huong Tran , and Thi Duyen-Anh Pham	Inland Waterway Transport In Vietnam: Strategies To Improve Transportation Efficiency During Covid – 19 Pandemic	Vietnam	Vietnam's water transportation network has great potential as an efficient and environmentally friendly mode of transportation. However, outdated infrastructure, such as poorly maintained waterways and ports with limited capacity, are major obstacles to maximizing its use. The COVID-19 pandemic exacerbated the situation by disrupting workforce and port operations, while restrictions on other	There is a need to modernize existing water transport infrastructure, such as dredging channels and updating port facilities. With these measures, the water transportation sector will become more efficient, reducing logistics costs and increasing freight capacity.

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				modes of transportation increased pressure on water transport.	In addition, the study also shows that more efficient water transportation can reduce pressure on roads, which are often congested by logistics vehicles, and contribute to environmental sustainability. Water transportation is more energy-efficient and produces lower carbon emissions than land transportation modes, thus playing a role in supporting Vietnam's sustainability goals.
20.	Violeta Roso, Ceren Vural , Anna Abrahamsson , Matilda Engström, Sara Rogerson , Vendela Santén	Drivers and Barriers for Inland Waterway Transportation	Sweden	Sweden's share of inland waterway transport in 2014 was only 3%, much smaller than road transport at 88% and rail at 9%. The main goods transported include liquid fuels, forest products, and mined goods. The Swedish ship fleet in 2016 was the smallest since 1970. In contrast, IWT in the Netherlands in 2017 accounted for 44.6% of total freight transportation, with bulk cargoes such as ore and sand dominating. In Rotterdam, 35% of container transportation is done via inland navigation, showing significant growth.	Findings for key drivers of Inland Waterways Transport adoption include reduced traffic congestion, logistics cost savings, and decreased environmental impact. For example, a single barge can replace up to 70-80 trucks, resulting in significantly lower cost per ton-kilometer efficiency compared to inland modes of transportation. In addition, Inland Waterways Transport has lower carbon emissions, with a smaller CO_2 contribution per ton-kilometer than trucks and trains, making it a greener logistics option.
21.	Young-Seo Choi, Gi-Tae Yeo	An analysis of research trends of inland waterway utilizing social network analysis	South Korea	Research in Europe shows a focus on "modal shift" as an effort to reduce exhaust emissions from road transportation, as well as policy support from the European Union for the development of green infrastructure. In China, there are 112 publications on inland waterways logistics, with the highest number of publications reaching 21 in 2021. The highest Degree Centrality is "inland waterway" (0.235), followed by "Inland waterway transport" (0.086) and "Yangtze River" (0.064). Research in China focuses on reducing congestion on inland waterways using AIS (Automatic Identification System) data, as well as efforts to improve maritime safety on waterways. Meanwhile, in the United States, there are 45 publications relevant to logistics on inland waterways, with the peak of publications occurring in 2020 with 10 publications. The highest Degree Centrality is "inland waterway" (0.295), followed by "maritime transportation" (0.109) and "inland waterway ports" (0.077). The problem of ship delays in the U.S. is caused by key facilities that are old and have not been updated, which affects transportation efficiency. The results of eigenvector centrality analysis show that "inland waterway" is the most important keyword in all three regions, reflecting the significance of transportation via inland waterways. This research provides insight into the characteristics and challenges faced by inland waterways in each region, and points to the need for policy support for infrastructure development and further research to improve the efficiency and sustainability of these transportation systems.	These transportation systems are playing an increasingly important role in Europe, China and the United States. Each region faces different challenges and research focuses, but overall, inland waterways offer great potential for improving transportation efficiency and reducing environmental impacts. In Europe, attention is on shifting to more environmentally friendly transportation methods, while in China, the focus is on reducing congestion and improving maritime safety. In the United States, the main challenge is modernizing aging infrastructure to overcome delays in the delivery of goods. The research revealed that the focus of research in each region varies, reflecting the specific needs and challenges faced. This demonstrates the importance of a locally tailored approach to inland waterways development and research.
22.	Totakura bangar Raju, Nilakantan Sundara raman Narasinganallur	Factors Affecting Container Shipping	India	The results identified several key factors that influence the efficiency and effectiveness of this system. Infrastructure is the most important element, with fuzzy	Container shipping via inland waterways in India is heavily influenced by several key factors, with infrastructure

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	and Syed Aqib Jalil	Through Inland Waterways		weights ranging from 0.426 to 0.503, indicating that efficient ports and terminals are necessary to support transportation. Improved infrastructure can significantly reduce shipping times and costs, making it a top priority in the development of inland waterway transport systems. In second place, economic factors, with fuzzy weights between 0.204 and 0.261, cover shipping costs, transportation time, and service reliability. The transport lead time subfactor is crucial, followed by capital investment and service convenience. Geographical factors, which include the physical condition of the waterways, come in third, with river depth as the main challenge to overcome. Although regulatory factors come fourth, their impact is still significant, as supportive government policies can increase the use of these waters. Additionally, infrastructure subfactors such as container inventory and container repositioning show the importance of container availability and management. Overall, this study emphasizes the need for special attention to infrastructure development, river depth management, and government policies to increase container shipping through inland waters, thereby contributing to sustainable economic growth.	being the most dominant element. The research revealed that while there is great potential to develop this transportation system, challenges such as inadequate river depth, lack of container inventory, and the need for more supportive government policies remain significant barriers. The implications of these findings provide a new understanding that to increase the use of inland waterways as a mode of transportation, there needs to be a comprehensive approach that includes developing better infrastructure, managing river depth through activities such as dredging, and improving container availability and management. In addition, supportive government policies, including incentives for investment in infrastructure and the development of an integrated logistics system, are essential to encourage wider adoption of container shipping via inland waterways. With these measures, it is hoped that inland waterways can serve as an efficient and sustainable alternative for freight transportation, which in turn can contribute to economic growth and the reduction of the environmental impact of the transportation sector.
23.	Piotr Durajczyk and Natalia Drop	Possibilities of Using Inland Navigation to Improve Efficiency of Urban and Interurban Freight Transport with the Use of the River Information Services (RIS) System—Case Study	Poland	RIS systems can help improve the efficiency of freight transportation, not only for longer routes, but also in urban and inter-city conditions. Shipping via waterways is much cheaper and environmentally friendly, although the transportation time is longer and sometimes impossible due to inadequate waterway infrastructure. The study also shows that the main benefits of using RIS for urban logistics are: optimization of delivery routes, better supervision and control of shipments, optimization of inter-branch transport, more efficient fleet utilization, better use of waterway technical infrastructure, incorporation of multiple receivers/shippers in a single shipment, and reduction of administrative barriers. Urban freight transportation accounts for about 10-15% of total vehicles, which contribute to 19% of energy consumption in road transportation, 25% of CO2 emissions, and 30% of NOx emissions.	This article aims to demonstrate the possibility of using this mode of transportation to transport goods within cities and between metropolitan areas as well as the role of River Information Services (RIS) to facilitate this process. The article analyzes a case study of containerized cargo transport between two industrial centers in southern Poland (Opole, Poland; Wrocław, Poland), both of which are located on the banks of the Odra Waterway, and provides a comparison between road and river transport in terms of costs, carbon dioxide emissions, and time. The article shows that the use of waterways for urban and inter-city logistics is possible but requires meeting the boundary conditions for navigability.
24.	Sándor A. Némethy, Anna Ternell, Lennart Bornmalm, Bosse Lagerqvist1and LászlóSzemethy	Environmental Viability Analysis of Connected EuropeanInland–Marine Waterways and Their Services in View ofClimate Change	Sweden	The creation of a complete pan-European network of inland waterways requires the closure of so-called missing links. But this can cause serious damage to aquatic and terrestrial ecosystems in terms of habitat loss, increased flows and erosion, ecosystem damage, and loss of ecosystem services. However, a well-planned expansion of the inland waterway network according to the modified ELOHA method and the establishment of a multimodal	The complex ELOHA method can assist in the construction of environmentally friendly inland waterway improvements. The name of the Nature Conservancy ELOHA (Ecological Limits of Hydrologic Alteration) method indicates that it seeks to explore the ecological impacts of hydrologic variability.

Number	Researcher's Name	Research Title	Country	Results	Findings
				transport system could offer a viable compromise to the already well-developed inland waterway network in Europe.	
25.	Qiaoyu Li , Xiaoyu Wang , Zhangting Chen , Muhammad Arif	Assessing the conjunction of environmental sustainability and tourism development along Chinese waterway	China	The research emphasizes the importance of a coordinated approach between the government, local communities, and other stakeholders to achieve sustainable tourism practices. Policy recommendations include the promotion of sustainable tourism practices, community engagement, training, diversification of local income, and collaboration between the public and private sectors. The findings provide valuable insights for the development of policies that support environmental sustainability in China's tourism regions, as well as highlighting the need for effective visitor management to prevent damage to natural and cultural assets.	This research explores the relationship between tourism development and environmental sustainability along the Yangtze River and its tributaries in China, focusing on the impact of tourism development on environmental sustainability. Through a survey involving 982 stakeholders, the study found that government support and intervention had a significant positive correlation with environmental sustainability, especially in visitor management (r=0.66**).
26.	Aris Christodoulou , Panayotis Christidis , Berny Bisselink	Forecasting the impacts of climate change on inland waterways	Europe	at selected points show that in the Andube River, the number of low-water days is expected to decrease, while a similar trend is also expected in Kaub on the Rhine River, which will overall result in a positive average economic impact. More specifically, the average annual economic benefits of reduced low water levels by the end of the century for Kaub, Wildunsmauer and Hofkirchen are projected at €31 million, €6 million and €4 million, respectively. On the other hand, an average annual economic loss of €10 million is expected in Ruhrort as a result of the projected increase in the average number of low water days by the end of the century.	European inland waters appear to be one of the few sectors where climate change has negligible or even positive impacts even under the "worst case" RCP8.5 emissions scenario. Most climate models simulate increased discharge levels in the main inland waterways, namely the Rhine and Andube Rivers, which may be due to an earlier start of the ice melt season. The projected discharge levels will result in higher average water levels and - most importantly - will reduce the number of days with water levels below the minimum required for navigation.
27.	Rebecca Wehrle, Marcus Wiens, and Frank Schultmann	Evaluation of the potential of infrastructure funds: The case of inland waterways in Germany	Germany	Inland waterways (IW) are recognized as a relatively environmentally friendly mode of transport, which is expected to grow in importance and transport volume in the future. The use of IW can contribute to sustainable transportation solutions, potentially reducing costs and carbon emissions associated with other modes of transportation, such as land transportation. In addition, IW can serve a variety of functions, including flood protection, ecological benefits, and recreational value, further underscoring its positive impact on the environment and society. Furthermore, this study highlights that a well-designed infrastructure fund (IF) can mobilize public funding to support the sustainable development and maintenance of these waterways, thereby increasing their effectiveness and contribution to reducing emissions and costs.	Inland waterways (IWs) are an environmentally friendly mode of transportation that can reduce costs and emissions compared to land transportation. In addition to their transportation function, IWs also provide flood protection, ecological benefits and recreation. Appropriate infrastructure funding can support the development and maintenance of IWs, increasing their contribution to sustainable transportation.
28.	Dariusz Bernacki and Christian Lis	Sustainable gains from inland waterway investments at port-city interface	Poland	The use of inland waterways has a positive impact on reducing operating costs and carbon emissions. Water transportation operators experience reduced operating costs that contribute 0.9% of the total sustainable profit. In addition, the reduction in transit time for operators and shippers, which contributes to 23.8% of total sustainable profit, increases efficiency and can reduce shipping costs. Inland waterway transport (IWT) is also known to have better energy efficiency and lower greenhouse gas emission levels compared to other modes of transportation, contributing to the reduction of carbon dioxide (CO2) emissions. Thus, the use of	Transportasi perairan pedalaman (IWT) membantu mengurangi biaya operasional hingga 0,9% and meningkatkan efisiensi waktu transit, yang menyumbang 23,8% dari total keuntungan berkelanjutan. Selain efisien secara energi, moda ini menghasilkan emisi gas rumah kaca lebih rendah dibandingkan transportasi lainnya, sehingga mendukung pengurangan emisi karbon dioksida (CO2). Dengan demikian, IWT memberikan manfaat ekonomi sekaligus

Number	Researcher's Name	Research Title	Country	Results	Findings
				inland waterways is not only economically beneficial, but also contributes to environmental sustainability.	mendukung keberlanjutan lingkungan
29.	Ogboeli Goodluck Prince, Brown Ibama, and Onuegbu Williams	Evincing the social and economic impact of inland waterways transportation in the development of the Port Harcourt Metropolis	Nigeria	The analysis shows that the use of inland waterways transportation has a significant positive impact on reducing costs and carbon emissions. It is considered one of the most environmentally friendly options for transporting goods and services, with minimal negative impacts on the environment, such as topographical changes, low energy and resource use, and reduced noise and air pollution. In addition, these transportation systems can improve mobility and accessibility to hard-to-reach areas, which in turn supports economic growth and job creation in surrounding communities. Inland waterways also contribute to the reduction of traffic congestion on roads, which can reduce carbon emissions from motor vehicles. By utilizing the existing network of rivers, canals and lagoons, water transportation can be an efficient and sustainable alternative for the transport of goods, thereby supporting economic growth without putting additional strain on existing road infrastructure.	Inland waterways transportation has major benefits in reducing costs and carbon emissions, making it an environmentally friendly transportation option. These systems utilize rivers, canals and lagoons to transport goods efficiently with minimal impact on the environment, such as low energy use, air and noise pollution. In addition, it helps reduce road congestion, increases mobility to remote areas, and promotes economic growth and job creation. By reducing pressure on road infrastructure, water transportation is a sustainable solution to support greener development.
30.	Shekwoyemi Gbako, Dimitrios Paraskevadakis, Jun Ren, Jin Wang, and Zoran Radmilovic	A systematic literature review of technological developments and challenges for inland waterways freight transport in intermodal supply chain management	Europe, China and United States	Based on an analysis of the literature on inland waterway transportation (IWT), there has been a significant increase in academic publications indicating a growing interest in the field. However, key challenges facing the sector include limited research on sustainable development, insufficient government support and investment, and aging infrastructure issues. In addition, factors such as seasonal variations and climate change also affect the reliability and efficiency of IWT. Gaps in labor skills and regulatory complexity are additional barriers that complicate operational planning and service quality. On the other hand, technological innovations such as digitalization, automation, and the use of alternative fuels show potential to improve the efficiency and sustainability of IWTs. Research shows that fleet modernization and the application of information and communication technology (ICT) can help address some of these challenges. With a focus on environmental sustainability and capacity optimization, the IWT sector can be better integrated into the broader logistics chain. Therefore, further research is needed to explore technological innovations and cooperation mechanisms that can improve the effectiveness of IWT in the future.	While inland waterway transportation (IWT) is growing rapidly, the sector faces challenges such as lack of government support, aging infrastructure, and the impacts of climate change. Technological innovations such as digitalization and alternative fuels offer solutions to improve efficiency and sustainability. Further research is needed to foster innovation and collaboration in this area.

Inland Waterway is an alternative mode of logistics transportation through waterways. Although the use of Inland Waterway has been well developed by developed countries, in developing countries themselves this potential has not been maximized properly. This mode of transportation is also known as a more efficient mode than other modes of transportation. Fan Bu and Heather Nachtmann also point out that inland waterway transportation is increasingly in demand as a reliable and low-cost alternative mode. The Inland Waterway is expected to provide a solution to the problems faced on other routes.

The use of inland waterway transport is said to be efficient because it can reduce mileage and load a lot of cargo so that tariffs can be more efficient, this is an advantage for using inland waterway transportation modes. Inland areas that must be reached using trucks with limited capacity transport is the cause of high

operating costs, but if you maximize the use of Inland Waterway and replace trucks with ships that have more capacity and lower costs because it is more efficient. Inland Waterway Transport can facilitate transportation connectivity between regional markets and support hinterland access to ports with higher economies of scale than other modes of transportation (Konings et al., 2013; Shobayo and van Hassel, 2019). With barges capable of carrying 200 times more cargo per unit distance compared to a typical truck, the development of Inland Waterway Transport corridors contributes to helping reduce the negative impacts of freight transport, such as traffic congestion, noise, air pollutants, and accidents, which have increased in recent years (INE, 2016). (Spillover effects of inland waterway transport development: Spatial assessment of the Rhine-Alpine Corridor). Sea transport is generally considered one of the most sustainable modes of transportation (BVB, 2017). This mode of transportation is highly energy-efficient, where the high volumes transported over long distances are a contributing factor to a more sustainable performance (Mircetic et al., 2017). Due to the high capacity of ships, CO2 emissions per ton-kilometer are lower compared to other modes using fossil fuels (BVB, 2017). (Drivers and Barriers for Inland Waterways Transportation)

The statement that has been presented above, is reinforced by the findings of the literature review that we read, the data in the literature review is based on several previous literature reviews, that there are three main benefits received, the first is that transporting containers using barges can significantly reduce shipping costs due to the high fuel efficiency with inland waterway transport (IWT) per ton per mile when compared to rail and truck transportation. According to the Oklahoma Department of Transportation (2019) on average, one gallon of fuel can move a ton of cargo 576 miles by barge, 413 miles by rail and only 155 miles by truck. (cited by Fan Bu & Heather Nachtmann, 2021). Furthermore, according to research conducted by Gharehgozli and Zaerpour (2018) barge infrastructure costs are at the lowest level compared to other modes of transportation, barge infrastructure costs are 12.6 EUR per thousand ton-kilometers, where for trains it is 45.21 EUR and 48.42 EUR for trucks. This shows that barge infrastructure costs are about four times cheaper than rail and truck. Also, using barges is more environmentally friendly compared to other modes of transportation, for example the environmental cost of transporting containers using barges is 0.27 cents per tonne per kilometer, 2.01 cents using trains and 0.80 cents using trucks. (cited by Fan Bu & Heather Nachtmann, 2021) Third, the use of inland waterways can reduce port congestion based on a study conducted by Zweers at al. (2019) 40% of trucks in the Port of Rotterdam experience very severe delays, with the development of the use of barges can allow the port to divert container transportation from trucks to barges, making it easier for the port area to be accessed because it is less congested. (cited by Fan Bu & Heather Nachtmann, 2021)

The findings of this literature review show that the Inland Waterway provides a solution to the problems faced regarding the chosen mode of transportation with considerations of much reduced costs and little environmental impact. Although the Inland Waterway does not completely remove all the problems and challenges of other routes, it can be a better alternative to other modes. Therefore, it needs maximum utilization, continuous development so that the many shortcomings that have been corrected can create an alternative that is truly key to a sustainable system in the future. These findings add to the literature evidence by qualitatively synthesizing the magnitude of the relationship between studies, hence the need for a broader scope, given the limitations of this study. First, the subject of this research is published articles. Second, it only focuses on journals on Inland Waterways. The findings of this next literature review on Inland Waterway Transport (IWT) is one mode of transportation that utilizes inland waterways such as rivers and canals for the transportation of goods. As part of the intermodal transportation system, Inland Waterway Transport offers significant advantages, especially in terms of cost efficiency and lower environmental impact compared to other modes of transportation such as road and rail. Research by Mostert et al. (2017) shows that the use of Inland Waterway Transport can reduce logistics operational costs while reducing external costs, such as carbon emissions and air pollution. However, its implementation is still hampered by limited connectivity with other modes of transportation, especially rail, as highlighted by Notteboom (2007). Sustainability has become an important focus in the development of modern logistics systems. Research by Hofbauer and Putz (2020) suggests that Inland Waterway Transport generates significantly lower external costs than other modes of transportation, making it an ideal choice for green logistics. In this case, the integration of Inland Waterway Transport with dry ports can be a solution to create a sustainable logistics system. Caris et al. (2014) added that collaboration between inland waterways and dry ports can improve overall logistics efficiency while reducing environmental impact.

Inland waterways are vital elements of the maritime transportation system that support the efficient transport of goods. According to recent research, an in-depth understanding of vessel traffic patterns on these waterways is critical to designing safer and more efficient routes. The research used data from the Automatic Identification System (AIS) to analyze vessel navigation patterns, including position, speed, vessel type and dimensions. This analysis led to an understanding of the spatial distribution of vessels on inland waterways. It was found that the distribution of vessel positions is strongly influenced by parameters such as lane length, channel width and proximity to hazardous areas. For example, the narrower the lane, the higher the level of vessel navigation accuracy required to reduce the risk of accidents.

IV. CONCLUSION

This research aims to analyze and compare the effectiveness of sustainable logistics using inland waterway transportation modes, focusing on aspects of cost, operational efficiency, and environmental impact. This research aims to provide insight into the potential advantages and challenges of implementing an inland waterway-based logistics system and demonstrate its

greater benefits compared to other modes of transportation.

We found that countries with the highest use of inland waterway transportation modes are in the Netherlands, Germany, Belgium, France and Austria, this is evidenced by the vast network of inland waterway infrastructure in Europe reaching 40,000 km with most of them spread in Germany, Belgium, France, Austria and the Netherlands. Then, we also found that inland waterways also have an impact on Gross Domestic Product (GDP) as in China the development of inland waterways has a significant contribution to economic growth, waterways such as the Yangtze River which supports 40% of the country's total GDP makes China prioritize to develop Inland Waterway to develop with the times. Furthermore, we also found that the inland waterway mode of transportation has lower infrastructure and external costs of (EUR 24/1000 tkm) compared to road (EUR 40/1000 tkm) or rail (EUR 68-71/1000 tkm) and also Inland Waterway has lower fuel consumption compared to other modes of transportation with the average fuel consumption for Inland Waterway is about 8-10 g/t km, much more efficient than road (55-65 g/t km) and rail (30-35 g/t km), equivalent to six times that of road and three times that of rail.

In addition, this research shows that sustainable logistics via inland waterways is an effective solution to balance cost, operational efficiency, and environmental impact on the supply chain. However, the initial cost of building infrastructure and implementing new technologies may be higher compared to other transportation methods, but long-term benefits such as reduced carbon emissions, improved energy efficiency, and clean water filtration will be part of the fun. Therefore, to achieve sustainability goals and improve competitiveness in the competitive logistics industry, it is highly recommended to implement an inland waterway-based logistics strategy. Due to its cost efficiency, lower environmental impact, and large carrying capacity, inland waterwa [1]y transportation (IWT) has great potential to serve as the backbone of a sustainable logistics system. With higher fuel efficiency and utilization of existing infrastructure, IWT is an economical solution. With much lower carbon emissions, IWT also contributes to improved air quality and reduced noise pollution, and creates a more efficient logistics network through its integration with other modes of transportation. As such, IWT plays an important role in climate change mitigation. By improving accessibility and reducing transportation costs, the development of IWT infrastructure can help regional economic growth and create new jobs. But issues such as Infrastructure limitations, lack of standardization, and availability of skilled labor need to be addressed through government investment, public-private partnerships, workforce development, and promotional campaigns. If appropriate measures are taken, inland waterway transportation can contribute significantly to green econ [2] [3] [4] [5] [6] [7] [8]omic development, and further research such as life cycle analysis, integration with renewable energy, development of geographic information systems, comparative case studies, etc. are needed. Help optimize the use of waterways and identify best practice developments.

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