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Barriers to Green Technology Adoption in Inland Waterway Transport: A Narrative Review

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Abstract

This article reviews the challenges affecting the adoption of green technologies in inland waterway transport (IWT). While technologies such as LNG, biofuels, hydrogen, electrification, and emission abatement offer environmental benefits, their implementation faces barriers including high costs, technical limitations, inadequate infrastructure, and fragmented regulations. The study categorizes these challenges through a narrative literature review, emphasizing the need for coordinated policies, financial incentives, and infrastructure investment. It also highlights the role of institutional support and stakeholder engagement in enabling a green transition. Future research should explore the effectiveness of policies, the scalability of technology, and the socio-economic impact on IWT stakeholders.

Keywords: Green Technologies; Inland Waterway Transport (IWT); Technology Adoption Barriers

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Introduction

Inland waterway transport (IWT) is one of the most sustainable modes, considering its CO2 emissions per ton of cargo (Jacobs, 2022). It requires only a small proportion of energy compared with other transport modes. It can reduce externality costs by up to 25% compared to truck transport (Plotnikova et al., 2022). It also provides significant economic benefits. Reports indicate that farmers in the U.S. can reduce their expenses by up to seven billion USD per year (Niu et al., 2025). Additionally, IWT offers numerous job opportunities for the community. For instance, various parties, such as energy suppliers, freight companies, and port operators, require substantial labor for their operations (Vilarinho et al., 2024).

IWT has become a prominent mode of transport in many regions. In the U.S., it covers approximately 25,000 miles of countrywide waterways and serves up to 250 billion ton-miles of freight transport (Niu et al., 2025). In the European Union (EU), the IWT network spans 25,000 miles across 25 Member States, handling 81 billion ton-miles of freight (Jacobs, 2022). A similar situation also occurs in Asia. Many Asian countries have established IWT networks for over a decade, particularly in rapidly growing countries like India and China (Asian Development Bank, 2013). Furthermore, this sector continues to expand in all regions.

Although IWT is an environmentally friendly mode of transportation, it inevitably has environmental impacts. For example, it produces several greenhouse gases (GHGs), including carbon dioxide (CO2), sulfur dioxide (SO2), nitrogen oxides (NOx), and volatile organic compounds (VOCs) (Christodoulou Raftis et al., 2023). The amount of GHG emissions is considerably small; however, the industry is still growing, leading to an increase in GHG emissions in the future.

Therefore, there is a global effort to mitigate the environmental impacts of IWT through the implementation of green technologies. Unfortunately, the successful adoption of these technologies relies heavily on several factors, including financial resources, government policies, and technological development, which can be significantly challenging. As a result, many attempts are not entirely successful (Niu et al., 2025; Vilarinho et al., 2024).

This paper aims to provide a comprehensive overview of the current state of green technologies in inland waterway transport, highlighting the multifaceted challenges hindering their widespread adoption. Employing a narrative literature review approach, the authors critically assess existing studies to synthesize key insights, identify gaps, and provide informed recommendations for overcoming the barriers to implementing green technology in this critical transportation sector.

Green Technologies in Transport

The transportation sector accounts for 29-33% of total global CO2 emissions (U. S. Environmental Protection Agency, 2025). Therefore, reducing emissions from transport can yield a tremendous positive impact on the environment. Implementing green technologies has the potential to reduce emissions from the transport sector significantly.

Despite the different characteristics of various modes of transport, namely road, air, and sea, the implementation and development of green technology are similar across these modes (Banister, 2008; Shah et al., 2021; Wang et al., 2025). To provide a background for this study, the authors summarized four main categories of green technologies.

The propulsion system of any vehicle has greatly relied on the internal combustion process. This combustion process is a significant source of CO2 emissions. To reduce emissions, innovative propulsion systems that place less reliance on the combustion process or even eliminate it are suitable alternatives. For example, a hybrid engine that combines an electric motor with a combustion engine can significantly reduce energy use and emissions. This type of engine has been widely adopted in cars, trucks, and marine vessels. In addition, an advanced electric engine has become feasible, especially for personal vehicles, so they no longer need an internal combustion engine.

Sustainable fuels are another essential technology. These fuels are primarily produced from renewable sources, including biomass such as crops, fats, algae, and food waste. The air transport sector aims to increase the ratio of sustainable aviation fuels (SAFs) usage to 30% by 2030, which is expected to help limit CO2 emissions from air travel (Aksoy et al., 2025; ICAO, 2024; Raihan, 2025).

Information and communication technologies (ICTs) play a crucial role in sustainable transport (Chatti, 2021). Due to advancements in artificial intelligence and computing power, the transport sector can manage big data, which provides more information and insight. These technologies can also support informed decision-making, leading to improved operational efficiency and reduced communication errors.

The final category is infrastructure development, which provides the crucial physical and digital foundation necessary for all other green transport technologies to operate, grow, and function sustainably. This focuses on two primary support systems. Physical support networks involve installing key assets like EV charging stations and hydrogen refueling points to lower barriers to zero-emission vehicle adoption, along with creating dedicated green infrastructure, such as bike lanes and bus rapid transit corridors, to encourage shifts toward more efficient transportation modes. Meanwhile, digital and enabling infrastructure are vital for operational efficiency, encompassing hardware and software updates for Intelligent Transport Systems (ITS) and, critically, Smart Grid integration features like Vehicle-to-Grid (V2G). This digital infrastructure helps optimize energy use, ensuring large-scale electric vehicle adoption does not overwhelm the electrical grid, while enhancing renewable energy utilization.

Methodology

This study employed the narrative literature review process suggested by Siddaway et al. (2019) and Pautasso (2019). The narrative review approach was selected over other types of literature review approaches because it is more suitable for providing an overview of a specific topic, which is the aim of this article. As Greenhalgh et al. (2018) noted, narrative reviews are particularly useful for identifying themes, guiding future research, and placing emerging issues within broader theoretical and practical contexts. The authors began by proposing two research questions:

1) What green technologies has IWT adopted or potentially adopted?
2) What are the barriers or challenges to adopting such technologies?

To answer these questions, the authors searched for related literature using the Google Scholar search engine. Using Google Scholar helps ensure that search results include a comprehensive range of sources, including Scopus and Web of Science (Davis et al., 2025; Martín-Martín et al., 2019). Two specific search queries were developed: "inland waterway*" AND "green technology" and "barrier*" OR "challenge*" AND "green technology" AND "inland waterway*". Initially, article titles were screened for relevance, resulting in 44 potentially relevant articles. The authors then established the inclusion and exclusion criteria, as outlined in Table 1.

Table 1: Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Published in peer-review journal.	Published before 2015
Published between 2015 and 2025	Duplicate publications
Explicitly discusses green technology in IWT	Articles not discussing green technologies, or barriers/challenges specifically related to green technologies in IWT

After the second screening, the authors excluded seven articles under the exclusion criteria, leaving 37 remaining. Each article was then carefully reviewed, with particular attention to the characteristics and functions of green technologies, their developmental trajectory, and associated barriers and challenges in their adoption within inland waterways. To organize the information gathered from the articles, the author employed the content analysis technique, a widely adopted method for interpreting and analyzing textual data (Krippendorff, 2018). The authors followed the content analysis guidelines provided by Bengtsson (2016); Erlingsson and Brysiewicz (2017) including:

1) Familiarization: All documents were repeatedly read to understand the material. Passages on barriers and enablers of green technology adoption in inland waterway transport were identified as meaning units.
2) Condensation and Coding: The meaning units were condensed into precise statements, each assigned a code like financial, technological, regulatory, or stakeholder barriers, to retain their essential meaning.
3) Recontextualization: The codes were re-examined against the original documents to ensure no data was overlooked and the analysis remained aligned with the study aim. Irrelevant or redundant information was excluded.
4) Categorization: Related codes were grouped into broader categories that represented distinct dimensions of barriers (e.g., economic, institutional, operational). This process ensured that categories were internally coherent and externally distinct.
5) Thematization and Synthesis: Finally, categories were abstracted into overarching themes that captured deeper patterns and relationships across the literature, such as “structural constraints,” “policy–practice gaps,” and “stakeholder readiness.” These themes formed the basis for the results and discussion.

Results and Discussion

The results of the intensive literature review reveal four leading technology categories and nine types of technologies. The authors present these technologies along with their corresponding challenges in Table 2.

Table 2: Green Technologies and Challenges.

Technology Category	Technology	Adoption Challenges and Barriers
Alternative Fuels	Liquefied Natural Gas (LNG)	High retrofit and infrastructure costs, limited bunkering facilities; regulatory misalignment, public perception of 'non-renewable'
	Biofuels (e.g., HVO, FAME, Biogas)	Fuel stability, blend compatibility, supply chain constraints, lack of incentive policies
	Hydrogen	Infrastructure gaps (refuelling), high cost, safety standards undefined, limited operational data
Electrification	Battery-Electric Propulsion	Limited range, battery cost and weight, charging infrastructure, lifecycle emissions of batteries
	Hybrid-Electric Systems	Integration complexity, maintenance skills, cost-benefit ratio vs. diesel
	Fuel Cells (Hydrogen)	Technology maturity, hydrogen supply chain, vessel design constraints
Emission Abatement	Selective Catalytic Reduction (SCR)	Space requirements, retrofit cost, urea logistics, certification issues
Structural and Material Innovations	Optimized Hull Forms for Shallow Water	Limited to new builds, lack of retrofitting potential, hydrodynamic modeling expertise needed
	Composite Materials (FRP hulls)	Fire safety regulations, structural standards, material cost, repair complexity

Green Technologies in Inland Waterway Transport

Alternative fuels

Alternative fuels refer to any substitute fuel for conventional diesel. The literature lists three primary alternative fuels: liquefied natural gas (LNG), biofuel, and hydrogen, each of which has advantages and challenges.

Liquefied natural gas (LNG) is natural gas that has been cooled into a liquid form for easier storage or transportation. Due to its availability and compatibility, it is arguably the most promising alternative fuel for inland waterway vessels (Calderón-Rivera et al., 2024b). It has less negative impact on the environment (Perčić, Vladimir, & Fan, 2021). Many studies indicate that LNG combustion releases fewer greenhouse gases compared to conventional fuel (Calderón-Rivera et al., 2024b; Perčić, Vladimir, & Fan, 2021; Ursavas et al., 2020). Another major benefit is the reduction in operational costs. Although the initial investment for LNG is high, it becomes more cost-effective over time due to its energy efficiency (Simmer et al., 2015). It has been observed that more inland transport vessels are using liquefied natural gas (LNG) than those in maritime contexts (Gómez Vilchez et al., 2022).

Biofuel is typically produced from plants, animal waste, and algae biomass. Depending on the raw materials, various types of biofuel (Tan et al., 2022). Biodiesel (FAME), made from waste oils like used cooking oil, is often blended with diesel in IWT, usually in low proportions (up to 20%) due to regulatory limits. Hydrotreated Vegetable Oil (HVO), also derived from waste oils, is a cleaner diesel substitute with improved cold flow and reduced emissions. Although bioethanol is widely used in road transport, it remains incompatible with most IWT engines. One of the key features of biofuel is that it can be used with most vessel engines with little to no adjustment, leading to a low initial cost. Furthermore, the environmental benefits of biofuels extend beyond lower CO2 emissions; they also include reduced environmental impacts throughout their life cycle (Perčić, Vladimir, & Fan, 2021). For instance, CO2 emissions are offset by the CO2 absorbed during crop cultivation.

Hydrogen fuel is an energy source that can be used in several forms. In IWT, it is often used as compressed hydrogen or converted into liquid hydrogen for easier storage and transport. Hydrogen can also be processed into ammonia, another viable energy carrier. These forms facilitate the integration of hydrogen into maritime propulsion and storage systems (Christodoulou Raftis et al., 2023). It is arguably the cleanest energy for the vessel as it emits zero greenhouse gases (El Gohary et al., 2014). In addition, hydrogen can be fully produced from renewable sources, such as a solar hydrogen plant, which generates hydrogen through electrolysis (El Gohary et al., 2014). However, it remains preliminary, necessitating significantly more research and development before it can be widely used (Calderón-Rivera et al., 2024a).

Electrification

Several studies have highlighted the benefits and potential of replacing conventional propulsion systems with electric propulsion. The significant advantage of electric propulsion is that it does not involve combustion, hence no emissions.

An entirely electric system depends solely on the onboard battery for propulsion energy, representing the pinnacle of advancement. This system typically utilizes a lithium-ion battery due to its high energy density, which enables it to store more electricity than other types of batteries (Perčić, Vladimir, & Fan, 2021). In addition, lithium-ion batteries have been used in the transportation industry for over a decade, so support facilities such as charging stations and maintenance services are more readily available (Christodoulou Raftis et al., 2023). However, one needs to consider the environmental impact of the battery throughout its life cycle, from material acquisition to disposal. A life cycle analysis conducted by Moon et al. (2025) found that battery-powered vessels are significantly more environmentally friendly than conventional diesel-powered vessels. Despite their environmental advantages, fully electric vessels remain limited due to high initial costs and operational complexities. Nevertheless, several such vessels are already in service in countries like the United States, Croatia, and China (Moon et al., 2025; Perčić, Vladimir, & Fan, 2021).

Another considerable alternative is the hybrid system, which combines the combustion engine with electric propulsion. The two main types of hybrid systems are series hybrid and parallel hybrid (Perčić, Vladimir, & Koričan, 2021). The series hybrid uses electricity to propel the vessel. At the same time, the combustion engine is only responsible for generating electricity, which can be directly sent to the propulsion system or stored in the battery. In a parallel hybrid, the combustion engine and the electric system work together to propel the vessel. One key advantage of hybrid systems is that they offer a more seamless transition for operators from conventional propulsion technologies, requiring less operational change and technical adaptation. Current vessels can be retrofitted to fit in with the hybrid propulsion (Teske et al., 2025). It is also more flexible since it can operate on a conventional engine in case of a failure in the electric system, and it does not need a charging station (Candelo-Beccera et al., 2023). The hybrid vessel is still in pilot phase. However, many studies forecasted a growth trajectory soon (Fan et al., 2021; Teske et al., 2025).

Hydrogen fuel cells convert hydrogen gas into electricity via an electrochemical reaction, emitting only water as a by-product. The Proton Exchange Membrane Fuel Cell (PEMFC), commonly used in inland waterway transport (IWT), generates power by splitting hydrogen into protons and electrons, producing an electric current for propulsion (Christodoulou Raftis et al., 2023). These systems include hydrogen storage tanks, fuel cell stacks, and electric drives tailored to vessel requirements. It is more suitable for small vessels such as cargo or passenger ferries (Candelo-Beccera et al., 2023). It has zero tailpipe emissions, arguably one of the cleanest methods (Latapí et al., 2023). It is highly advanced and requires significant research and development before it can be implemented in real-world operations (Christodoulou Raftis et al., 2023; Latapí et al., 2023).

Emission Abatement

Emissions abatement in inland waterway transport is increasingly emphasized in Europe, particularly due to elevated nitrogen oxide (NO_x) and particulate matter levels. Stage V emission standards introduced stricter limits for non-road engines, including those on inland vessels (Jurkovič et al., 2024). Selective Catalytic Reduction (SCR) is a key technology that reduces NO_x by converting it into nitrogen and water using a urea-based reagent. Its effectiveness is well established, but performance can decline under low engine loads, common in IWT. To address this, microwave heating has been proposed to maintain optimal catalyst temperatures and ensure consistent SCR efficiency (Savu et al., 2022).

Structure and Materials Development

Several studies concentrate on enhancing vessel structure and materials, aiming for lightweight design and reduced drag. One of the promising concepts is hydrodynamic optimization, which involves designing the vessel to be most efficient with water flow (Deng et al., 2021). A study confirmed that improving vessel shape can reduce water resistance by up to 8%, resulting in a significant reduction in fuel consumption (Deng et al., 2021). Many state-of-the-art studies continue to find more efficient designs that balance energy efficiency, payload, and structural stability (Karczewski & Kunicka, 2021). Additionally, various composite materials, including combinations of carbon fiber, fiberglass, and polymer, have become available for vessel construction. These materials are lighter than metal, so the vessel requires less energy (Koci, 2022).

Challenges and Barriers

Technical and Operational Challenges

Despite the abundance of available technologies, many remain underutilized due to their technical limitations. While LNG and biofuels are the most accessible sustainable energy sources for inland vessels, hydrogen remains quite distant from this goal. The primary challenges of using hydrogen stem from the difficulty in storing it, which requires either very high pressure or very low temperature to store sufficient hydrogen for a trip (Ibrahim et al., 2024; Latapí et al., 2023). It also requires a larger and more robust tank onboard, necessitating a new ship design that may offer reduced cargo space (Latapí et al., 2023). Another problem is refueling. Transitioning from traditional fuels to hydrogen complicates the bunkering process due to hydrogen's lower energy density, necessitating more frequent refueling (Abu Bakar et al., 2023).

The electric vessel could be a practical green innovation, but it has several complexities. The battery needs sufficient capacity, which results in it being large and heavy. This heavy battery burdens the vessels to carry and can impact vessel performance (Teske et al., 2025). Additionally, electric vessels require various support infrastructures, such as charging stations and advanced power grids, which are not readily available in many regions (Feng et al., 2024).

Economic and Financial Challenges

Greening IWT requires significant financial resources, which is a critical barrier in the transition to green technology. Transitioning from conventional fuel to alternative energy requires retrofitting, which is very costly (Calderón-Rivera et al., 2024a). Many infrastructures are outdated and cannot be retrofitted. Therefore, operators must purchase new equipment, which is more expensive, but not all have the financial resources to afford it (Trivedi et al., 2021).

Many small and medium-sized operators lack financial liquidity or access to long-term investment credit, particularly in markets where incentives for green technology are limited. Even when funding is available, uncertainty about long-term economic returns persists. Fluctuating fuel prices, evolving regulations, and immature technologies increase financial risk. The potential for positive cash flow is unclear, particularly in the early adoption stages when economies of scale and efficiencies have not yet been realized (Latapí et al., 2023).

Policy and Regulatory Challenges

Government policies play a crucial role in fostering the development and implementation of green technologies. However, in the inland waterway transport context, the effort to advance sustainable matters is insufficient. No specific government agency is responsible for this issue, so no one genuinely drives this matter (Calderón-Rivera et al., 2025). This situation led to a delay or failure in many green projects. Many transport operators are resistant to the green transition. Their reasons are varied. Governments must consider a dual approach that combines incentives with enforcement. While supportive measures can encourage early adopters, punitive mechanisms, such as emissions-based fees or mandatory emission targets, may be necessary to overcome persistent inertia among reluctant stakeholders (Calderón-Rivera et al., 2024b; Vilarinho et al., 2024). Strong governmental commitment, policy alignment, and stakeholder engagement are essential to catalyze the systemic transformation required for sustainable inland waterway transport.

Contrasting Regional Contexts of Green Technology Adoption

The adoption of green technologies in IWT varies across different regions and countries. Several factors, including government policies, financial resources, and technology readiness, influence the levels of adoption and barriers (Wang et al., 2020). Evidence from the literature indicates that adoption patterns and related barriers differ significantly across Europe, the United States, and Asia, reflecting distinct institutional, economic, and infrastructural contexts.

In Europe, IWT green technologies are highly advanced. Several companies have adopted biofuels and successfully reduced environmental impact (Jacobs, 2022). Advanced propulsion systems, such as electric and hydrogen engines, are currently in the pilot stage. An electrification pilot project has been carried out on the Rhine River, while a hydrogen-powered vessel has been developed in Nordic countries (Latapí et al., 2023). European policies, such as the EU Green Deal support these pilot projects. The main barriers among EU countries are the high retrofit costs and the differing resources and development stages between Western and Eastern European nations.

In the USA, the focus is on electrification, especially for small to medium-sized vessels. IWT is crucial for the USA because it accounts for 14% of freight transport in the USA, so improving energy efficiency not only reduces emissions but also saves a significant amount of operational cost (Wang et al., 2020; Wang et al., 2025). In contrast, Latin America, which spans a vast area of rivers, including the Amazon and Magdalena, lags behind other regions in terms of green technology adoption. The ships operating on these rivers are relatively old, yet some of them use blended biofuels. The main challenges include weak government policy and the dominance of informal operators, which lead to low collaboration between public and private sectors (Calderón-Rivera et al., 2025; Shao et al., 2024; Vilarinho et al., 2024)

In Asia, China has significantly developed the IWT system and infrastructure. This is a result of high economic growth, which has substantially increased transportation on the Yangtze River. Similar to the USA, China focuses on electrification and LNG energy with massive support from the central government (Fan et al., 2021; Peng et al., 2025). However, other Asian countries, such as India and those in Southeast Asia, have underdeveloped IWT systems. Therefore, they have a low adoption rate of green technologies in the IWT sector. The challenges faced by these countries include weak government support and low-capacity port and river infrastructure, which are necessary for using advanced green technologies (Christodoulou Raftis et al., 2023; Trivedi et al., 2021)

Recommendation

This review emphasizes the necessity for a comprehensive policy framework to promote the adoption of green technology in inland waterway transport (IWT). Recommendations include establishing governmental bodies to coordinate sustainability initiatives, streamline policy design, and ensure regulatory coherence. Targeted economic incentives, such as subsidies, tax relief, and concessional loans, can help address financial barriers, along with public-private partnerships to mobilize investment. Harmonizing environmental and safety regulations reduces compliance uncertainty and encourages broader adoption. Enforceable mandates, like emissions caps or green technology quotas, may drive change among resistant stakeholders.

Substantial investment is needed to upgrade inland waterway transportation (IWT) infrastructure, including refueling stations for alternative fuels and charging facilities for electric vessels. Technical training and capacity-building programs are also essential to equip operators and maintenance staff to manage advanced systems. Raising public awareness and involving stakeholders, from transport operators to local communities, in the policy design process is vital for building trust, enhancing feasibility, and ensuring a long-term commitment to sustainability. A balanced approach that combines incentives, infrastructure, regulation, and engagement is crucial for a successful green transition in the IWT sector.

The literature reviews also suggest practical solutions to address the challenges. Financial support from the government or targeted loans, such as a green credit line, can help shipping operators improve their environmental performance and achieve their ecological goals. Financial incentives are particularly important for small operators and start-up companies. Additionally, collaboration between developed and developing nations will accelerate the global adoption of green technologies. Many countries have started pilot projects, including those focused on clean propulsion systems and green infrastructure. These leading nations can share their knowledge and even mentor smaller countries with fewer resources and less preparation.

Research Gap and Future Research Recommendations

Despite increasing academic and policy attention toward sustainable inland waterway transport (IWT), several critical research gaps remain. One notable gap is the lack of a systematic framework for categorizing green technologies based on their functional characteristics and technological readiness levels (TRL). Much of the existing literature discusses specific technologies in isolation, without situating them within a broader context that allows for comparative assessment of scalability, integration feasibility, and environmental effectiveness. In addition, empirical evidence on the real-world implementation of these technologies remains limited. There is a lack of analysis of their operational performance, lifecycle costs, and long-term environmental benefits, particularly in diverse IWT contexts.

Another critical gap pertains to the socio-economic dimensions of green technology adoption. Most studies focus on technological or regulatory aspects, while overlooking the challenges faced by small and medium-sized operators. These stakeholders often lack the financial and technical capacity to adopt advanced technologies and are thus at risk of exclusion from the green transition. Furthermore, while various regions such as the European Union, the United States, and parts of Asia have introduced policy initiatives to promote sustainability in IWT, cross-regional comparative research remains sparse. Little is known about how differing policy instruments, infrastructural readiness, and governance models influence adoption outcomes.

In addition, Future research should focus on the role of small-scale operators in adopting green technologies in inland waterway transport. Studies are needed to explore financing mechanisms, such as microloans or cooperative schemes, tailored to their constraints. Further work should examine how governance structures and policy frameworks can better integrate informal and fragmented operators. Comparative regional studies could highlight differences between advanced regulatory contexts and developing economies. Such research will ensure more inclusive and equitable pathways toward sustainable inland waterway transport.

Future research should address these gaps by developing analytical frameworks that integrate technological, economic, and policy dimensions of green innovation in IWT. There is a need for case-based and longitudinal studies that evaluate implementation outcomes under real operational conditions. Moreover, research should explore the effectiveness of incentive-based and regulatory policy instruments, such as subsidies, emissions pricing, and green certification schemes, in shaping adoption behavior. Particular attention should be given to the perceptions and constraints of small-scale operators to ensure that future policies are inclusive and equitable. Ultimately, comparative studies across various geographical regions can offer valuable insights into best practices and the contextual factors that facilitate or hinder the successful diffusion of technology.

Conclusion

This review examines the implementation of green technologies in inland waterway transport (IWT) and how their adoption is influenced by a complex interplay of technological, economic, regulatory, and operational barriers. While promising innovations such as LNG, hydrogen fuel, battery-electric propulsion, and structural optimization offer substantial environmental benefits, their deployment remains constrained by high costs, infrastructure deficits, and fragmented policy support. The analysis reveals that effective adoption is not solely a matter of technological availability but requires coordinated action across institutional, financial, and regulatory dimensions.

To achieve meaningful decarbonization in the IWT sector, governments must develop integrated strategies that combine supportive regulation, targeted financial incentives, infrastructure modernization, and stakeholder capacity-building. Institutional leadership and inter-agency coordination are crucial for overcoming inertia and ensuring a long-term commitment to sustainability goals. By addressing the identified barriers through a systems-oriented approach, policymakers and practitioners can enable a more inclusive and effective transition toward green inland waterway transport.

This review is subject to several limitations. First, it employs a narrative review method rather than a systematic or meta-analytic approach, which may limit the reproducibility and comprehensiveness of literature selection. Second, the analysis primarily focuses on academic sources and may overlook valuable insights from grey literature, industry reports, or unpublished policy evaluations. Third, while the study touches upon regional differences, it does not conduct a deep comparative analysis across geographical contexts, which may obscure context-specific dynamics in green technology adoption.

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