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ENVIRONMENTAL ASPECTS OF TRANSPORT SYSTEM DEVELOPMENT: FROM CONCEPT TO IMPLEMENTATION

The article examines the environmental aspects of developing modern transport systems, focusing on sustainable development and the integration of eco-friendly technologies. Transportation is a major contributor to environmental pollution, making the reduction of emissions, improvement of energy efficiency, and minimization of climate impact critical tasks. The study aims to analyze the main approaches to creating environmentally efficient transport systems and identify the key factors influencing their implementation.

The article provides a detailed overview of international initiatives aimed at utilizing green technologies in transportation, including the development of electric transport, the use of renewable energy sources, the creation of intelligent transport networks, and the promotion of cycling and pedestrian mobility. Successful project examples from Germany, the Netherlands, China, Sweden, and Ukraine are presented, offering potential models for other countries.

Additionally, the article analyzes the economic, social, and institutional challenges encountered in the process of implementing sustainable transport, including the lack of appropriate legislative initiatives, high costs for new technologies, and insufficient environmental awareness among the population. Special attention is given to the importance of cross-sectoral cooperation in achieving global decarbonization goals for transport. The article concludes with a forecast of the future development of eco-friendly transport and suggestions for future research and practical initiatives in this field.

Keywords: transport systems, sustainable development, green technologies, electric transport, renewable energy sources, intelligent transport systems (ITS)

INTRODUCTION

In the modern world, the transport system is a critical component of infrastructure that ensures mobility, supports economic activity, and creates conditions for sustainable regional development. At the same time, transportation is one of the primary sources of anthropogenic environmental pressure. According to the International Energy Agency (IEA), the transport sector is responsible for approximately 23% of global carbon dioxide emissions related to energy use. The growth of automobile use, intensive fossil fuel consumption, and the spatial expansion of urbanized areas lead to increased noise levels, air pollution, landscape fragmentation, and the reduction of green spaces.

In response to the challenges posed by climate change and environmental degradation, there has been a shift in the development concepts of transport systems in recent decades. Emphasis is placed not only on the functionality and efficiency of transportation but also on the need to minimize ecological impacts, implement sustainability principles, and integrate with the natural environment. In this context, there is a growing need to analyze and implement ecological approaches to planning, designing, and operating transport infrastructure.

LITERATURE REVIEW AND PROBLEM STATEMENT

The concept of greening the transport system emerges at the intersection of ecology, urban planning, transport logistics, and systems management. The primary goal of this approach is to harmonize the interaction between transport infrastructure and the natural environment by minimizing the negative impacts of its operation. In academic discourse, an ecological transport system is viewed as a set of technical, organizational, and social solutions aimed at reducing pollutant emissions, conserving natural resources, decreasing noise pollution, and ensuring rational land use.

One of the key concepts underlying greening is sustainable transport, which, according to the European Conference of Ministers of Transport (ECMT), ensures the accessibility of mobility without harming the environment, public health, or the needs of future generations. This approach involves a paradigm shift—from automobile-centric solutions to supporting eco-friendly and energy-efficient transport modes such as public transport, cycling, and walking.

Another important concept is the eco-design of transport infrastructure, which includes principles of environmental planning: preserving natural landscapes, integrating green spaces into transport corridors, creating noise barriers, and using environmentally safe construction materials. Designing eco-friendly

transport systems requires an integrated approach that involves interaction between transport policy and policies in the areas of environmental protection, energy, land use, and health.

An essential tool in this context is Environmental Impact Assessment (EIA), which identifies potential risks associated with the construction or reconstruction of transport infrastructure and helps develop compensatory or preventive measures. In many countries (especially within the EU), the EIA procedure is a mandatory stage in implementing transport projects.

Moreover, the ecological approach requires considering the life cycle of transport vehicles—from production and operation to disposal. The life-cycle thinking concept is used to calculate the full environmental footprint of transportation, enabling a more informed choice between alternative technologies (e.g., electric vehicles, hydrogen transport, or biofuels).

Thus, the theoretical foundations of greening the transport system are based on a systematic, interdisciplinary approach that combines environmental requirements with functionality, efficiency, and social acceptability.

PURPOSE AND OBJECTIVES OF THE STUDY

The aim of this research is to analyze the environmental aspects of building modern transport systems, with a focus on sustainable development, the implementation of innovative technologies, and reducing the negative impact of transportation on the environment. Specifically, the study aims to identify effective approaches for reducing emissions, improving energy efficiency, and integrating eco-friendly solutions into transport systems.

The research objectives are as follows: to assess the current state of environmental aspects in transport systems across different countries; to examine key technologies and innovations aimed at reducing emissions and enhancing energy efficiency in transport; to analyze international experience and successful examples of implementing eco-friendly technologies in transportation; to identify economic and technical barriers hindering the widespread adoption of environmentally clean transport solutions; to evaluate the role of government bodies and international organizations in the development of sustainable transport systems; to explore the social factors influencing the adoption of green transport solutions, and to consider ways to increase environmental awareness among the public; and to outline the prospects for the development of eco-friendly transport systems and their integration into the global context of sustainable development.

RESEARCH RESULTS

In the process of greening the transport system, the implementation of innovative technologies and practical tools plays a crucial role in ensuring the reduction of emissions, improving energy efficiency, and minimizing the overall environmental footprint of transport. Among these, key technologies include alternative energy sources, intelligent transport systems, environmental monitoring, and digital platforms for optimizing transportation.

Alternative Energy Sources

One of the main directions is the transition to environmentally friendly fuels. The most widespread today are: electric transport, which generates no local emissions and has a high efficiency coefficient, hydrogen technologies, providing long-range autonomous operation with no CO_2 emissions, next-generation biofuels, renewable resources with a smaller carbon footprint compared to traditional fuels, these energy sources not only reduce the environmental burden but also promote energy decentralization, which is essential for ecologically vulnerable regions.

To clearly demonstrate the advantages of transitioning to electric transportation, let us examine the change in CO_2 emissions per kilometer traveled. Figure 1 presents a comparison of emissions from internal combustion engine (ICE) vehicles and electric vehicles.

As shown in the graph, the average emissions from ICE vehicles are approximately 180 g/km, whereas electric vehicles, considering the average emissions from electricity generation, produce only around 40 g/km. This indicates a reduction in emissions by nearly a factor of 4.5 when switching to electric propulsion.

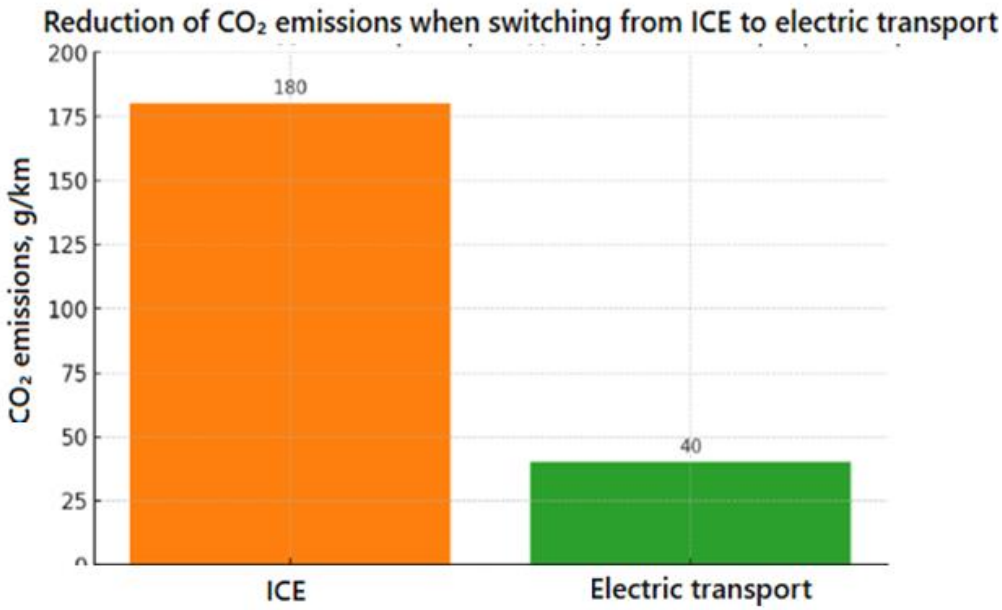

Figure 1 — Reduction of CO_2 emissions when transitioning from internal combustion engines (ICE) to electric transportation.

Such a reduction is of critical importance for large cities, where the density of traffic flows is high, and the issue of air pollution becomes particularly acute. The adoption of electric transportation not only reduces greenhouse gas emissions but also enhances the quality of life for residents, lowers healthcare costs, and aids in ecological restoration.

These energy sources not only alleviate pressure on the atmosphere but also promote the decentralization of energy systems, which is crucial for ecologically vulnerable regions.

Intelligent Transport Systems (ITS)

Intelligent transport systems optimize traffic flows, reduce congestion, save fuel, and improve the environmental situation in cities. The key components of ITS are: adaptive traffic control systems, digital platforms for monitoring road and air quality, GPS and big data technologies for predicting traffic load and optimizing transport routing, information systems are also actively used in logistics to create routes with minimal CO_2 emissions—so-called green routes.

Environmental Monitoring Systems

Effective transport system management is impossible without the systematic collection and analysis of environmental data. Environmental monitoring tools include: stationary air quality monitoring stations, mobile sensor platforms on vehicles, drones for collecting environmental information from hard-to-reach areas, decisions on adjusting traffic patterns and restricting vehicle access to high-pollution zones (e.g., Low Emission Zones in Europe) are based on this data.

Urban Solutions

Modern environmental transport policy focuses on integrating transport with the urban environment. These solutions include: infrastructure development for cycling and walking, multimodal transport development, use of environmentally safe materials in the construction of roads, stations, and bus stops.

Along with technical solutions, citizens' transport behavior is also changing under the influence of new environmental norms and digital services that simplify the choice of eco-friendly mobility options.

DISCUSSION OF RESEARCH RESULTS

Real-World Examples of Environmentally-Oriented Transport Solutions

At the global level, an increasing number of countries are incorporating environmentally sustainable approaches into their transport policies. These practices illustrate that sustainable transport development can successfully integrate functionality, energy efficiency, and environmental stewardship. The following section highlights emblematic examples of "green" transport initiatives that have set a benchmark for eco-conscious mobility.

Germany: Green Transport Transformation

Germany is at the forefront of implementing strategies aimed at decarbonizing its transport sector. The Klimaschutzprogramm 2030 outlines ambitious measures focused on sustainable mobility, including: large-scale promotion of electric vehicles (targeting 15 million EVs by 2030); expansion of cycling infrastructure,

notably through high-speed bicycle highways (e.g., Radschnellweg); significant investment in the electrification and modernization of railway networks.

In addition, several cities—such as Darmstadt—have piloted initiatives offering free public transport during peak hours, aimed at reducing reliance on private vehicles.

The Netherlands: Europe's Cycling Capital

Amsterdam and Utrecht serve as prime examples of successful integration of cycling into urban mobility systems. Key components of their approach include: over 500 km of dedicated cycling lanes; automated bicycle parking facilities; traffic signal prioritization for cyclists; active public engagement in transport planning.

Such measures have substantially alleviated road congestion and improved urban air quality.

China: Electrification of Urban Buses

China has demonstrated a large-scale shift toward electric public transport, particularly in Shenzhen, which became the first metropolis to transition its entire fleet of over 16,000 buses to electric power. This achievement is supported by: ongoing expansion of charging infrastructure; substantial investment in the development of advanced battery technologies.

This case exemplifies the feasibility of a full-scale transition to electric mobility within the public sector.

Sweden: The "15-Minute City" Concept

Stockholm is actively implementing the "15-minute city" model, an urban planning concept that ensures residents can access essential services within 15 minutes on foot or by bicycle. This model: reduces dependence on private vehicles; promotes decarbonization of the urban environment; enhances overall quality of life by fostering environmental and social balance.

Ukraine: Initial Steps Towards Sustainable Transport

Although Ukraine is only beginning to establish a systematic framework for green transport, several promising initiatives are already underway: introduction of electric buses in Kyiv, Lviv, and Dnipro; development of mobile applications for public transport planning; construction of cycling infrastructure in cities such as Poltava and Ivano-Frankivsk; implementation of smart traffic light systems.

These examples highlight the potential for adapting European best practices within the national context and advancing the ecological modernization of Ukraine's transport system.

RESEARCH RESULTS

Challenges and Opportunities in the Ecological Transformation of Transport Systems

Despite the numerous advantages of transitioning toward environmentally sustainable transport systems, this transformation entails a range of significant challenges. However, these challenges also open avenues for innovation, cross-sectoral collaboration, and a strategic rethinking of mobility approaches.

Institutional and Regulatory Barriers

In many countries, including Ukraine, the absence of a unified strategy or clearly defined regulatory frameworks for green mobility hinders the transition toward sustainable transport. Specific issues include: a lack of legislative incentives for manufacturers and users of electric vehicles; fragmentation in the implementation of emission standards; limited authority and resources at the local government level to implement innovative transport solutions.

Economic Challenges

The shift to environmentally friendly transport requires substantial financial investment in: infrastructure modernization; construction of charging stations; procurement of eco-efficient vehicles. high initial costs frequently act as a barrier to implementation, particularly under conditions of constrained public budgets or economic instability.

Technological Complexity and Uneven Access to Innovation

Access to advanced transport technologies remains unequal across regions. For instance: rural areas often face logistical difficulties in establishing charging infrastructure; larger urban centers benefit from greater levels of digitalization, enabling the use of Intelligent Transport Systems (ITS); transport models that succeed in one national context may not be directly transferable to others with differing socioeconomic realities.

Public Perception and Behavioral Factors

Even the most advanced technological solutions may lose their effectiveness if human behavior is not adequately addressed. Key issues include: persistent dependence on private vehicles; public distrust of new transport modes (e.g., e-scooters or electric buses); low levels of environmental awareness among the population.

Hence, it is essential to carry out public awareness campaigns, implement educational initiatives, and actively engage communities in shaping transport policies.

Future Prospects

Despite the existing challenges, the development of environmentally sustainable transport systems offers considerable long-term prospects: expansion of national and international funding mechanisms, such as the European Green Deal, Horizon Europe, the World Bank, and the European Bank for Reconstruction and Development, which collectively provide financial impetus for green mobility initiatives, rapid technological advancements, including the decreasing cost of battery technologies, the emergence of alternative eco-friendly fuels, and the evolution of smart infrastructure capable of supporting intelligent transport systems, a global shift towards decarbonization, reinforced by the commitments made under the Paris Climate Agreement, which continues to shape transport policies and investment strategies worldwide, changing generational values and cultural mobility patterns, particularly evident in large metropolitan areas, where younger populations increasingly favour walking, shared transport modes, and micromobility solutions over conventional car ownership.

In this context, it is essential not merely to respond to current challenges, but to actively shape a new mobility culture—one that is attuned to both environmental imperatives and the evolving social expectations of future generations.

CONCLUSIONS

The integration of environmental considerations into the design and development of transport systems is a vital component of sustainable development policy. Efforts aimed at reducing harmful emissions, enhancing energy efficiency, and improving the quality of urban life through innovative technological solutions have already demonstrated significant progress in many regions of the world.

However, the ecological transformation of transport infrastructure remains a complex and multidimensional challenge. Financial constraints, technological disparities, regulatory gaps, and socio-behavioral barriers continue to hinder the rapid transition to sustainable mobility. Overcoming these obstacles requires not only targeted investments but also systemic reforms and long-term strategic planning.

A key factor in achieving success is the effective collaboration between public authorities, private sector actors, and local communities. Their coordinated efforts can ensure the implementation of environmentally sound solutions that are economically viable and socially inclusive.

Among the most promising directions for future development are: the widespread adoption of electric transport, contributing to substantial reductions in greenhouse gas emissions; the deployment of intelligent transport systems (ITS) to optimize traffic flows and minimize environmental impact; the expansion of pedestrian and cycling infrastructure, promoting low-impact modes of transportation.

Additionally, further innovation in clean energy technologies and increased international cooperation on regulatory harmonization will facilitate the global diffusion of sustainable transport practices.

Ultimately, the ecological modernization of transport systems is not only an environmental imperative but also a driver of broader societal transformation. By reshaping mobility patterns and fostering environmental awareness, such changes contribute to building more resilient, livable, and future-oriented cities.

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Середа Б.П., Муковська Д.Я., Зюзін Є.П., Орел В.Г. **Екологічні аспекти побудови транспортної системи: від ідеї до реалізації**

У статті розглядаються екологічні аспекти побудови сучасних транспортних систем з аспектом на сталий розвиток та інтеграцію екологічно чистих технологій. Транспорт є однією з основних причин забруднення навколишнього середовища, тому важливими завданнями є скорочення викидів, підвищення енергоефективності та мінімізація впливу на клімат. Метою дослідження є аналіз основних підходів до створення екологічно ефективних транспортних систем та визначення ключових чинників, що впливають на їх впровадження.

У статті детально розглядаються міжнародні ініціативи, спрямовані на використання зелених технологій у транспорті, зокрема розвиток електричного транспорту, застосування відновлюваних джерел енергії, створення інтелектуальних транспортних мереж та підтримка велосипедної та пішохідної мобільності. Наведено приклади успішних проектів у Німеччині, Нідерландах, Китаї, Швеції та Україні, що можуть слугувати моделями для інших країн.

Також аналізуються економічні, соціальні та інституційні проблеми, які виникають у процесі впровадження сталого транспорту, включаючи відсутність відповідних законодавчих ініціатив, високі витрати на нові технології та недостатню екологічну свідомість населення. Особлива увага приділяється важливості міжсекторальної співпраці для досягнення глобальних цілей у сфері декарбонізації транспорту. Стаття завершується прогнозом подальшого розвитку екологічного транспорту та пропозиціями щодо майбутніх досліджень і практичних ініціатив у цій сфері.

Ключові слова: транспортні системи, сталий розвиток, зелені технології, електричний транспорт, відновлювані джерела енергії, розумні транспортні системи (ITS)

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