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INNOVATION MANAGEMENT IN TRANSPORT – AN ECONOMIC PERSPECTIVE IN THE ERA OF CLIMATE TRANSFORMATION

Summary. An important element of a zero-emission economy is technological innovation and the economic aspects of the transformation, which enable effective and cost-effective emission reductions. A zero-emission economy aims to completely eliminate greenhouse gas emissions, which requires the transformation of the energy, transport, and industry sectors, among others. A particular challenge is reducing emissions in transport, which is responsible for approximately 25% of global carbon dioxide emissions resulting from energy consumption, primarily from fossil fuels. In the face of growing climate requirements and commitments resulting from the Paris Agreement, the transformation of this sector is becoming a priority for environmental policy at all levels. This article aims to demonstrate the role of innovative management strategies implemented by energy companies in the decarbonization process of transport, with a particular emphasis on economic aspects. By providing clean energy, developing infrastructure, and investing in modern technologies and services, these companies play a key role in the transformation of the transport sector. The costs of investing in modern technologies, such as electromobility, hydrogen, or intelligent transport systems, must be considered, as they require significant financial outlays for the development and implementation of solutions. Additionally, expenditures related to the adaptation of infrastructure, including the construction of charging stations and the modernization of the railway network, are significant and pose a challenge to public and private budgets. The scientific novelty of the present article lies in the interdisciplinary economic and technological analysis, which integrates innovation management, energy sector development, and transport transformation in the context of global climate challenges. It highlights strategic mechanisms and management tools that have been insufficiently explored so far, enabling a better understanding of how to effectively support transport decarbonization while considering economic aspects and infrastructure challenges.

1. INTRODUCTION

Innovation management in the transport sector involves the strategic planning, development, and implementation of new technologies, processes, and business models to improve efficiency, sustainability, and competitiveness. This is done in close cooperation with the energy sector, which provides essential solutions related to low-carbon energy sources, infrastructure, and system integration [1, 2]. This research analyzes innovative solutions in the transport sector, the costs of their implementation, and their impact on the development of environmentally friendly mobility systems. This involves the coordinated efforts of public and private stakeholders to drive transformational change, adapt the sector to emerging trends, and meet changing social and environmental expectations. In the context of accelerating climate transformation, the need for innovation in transport has become more urgent than ever. The sector is one of the largest emitters of greenhouse gases in the world and,

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together with fuel combustion, is responsible for a quarter of global CO_2 emissions [3, 4]. The breakdown of carbon dioxide emitters by sector is presented in Fig. 1.

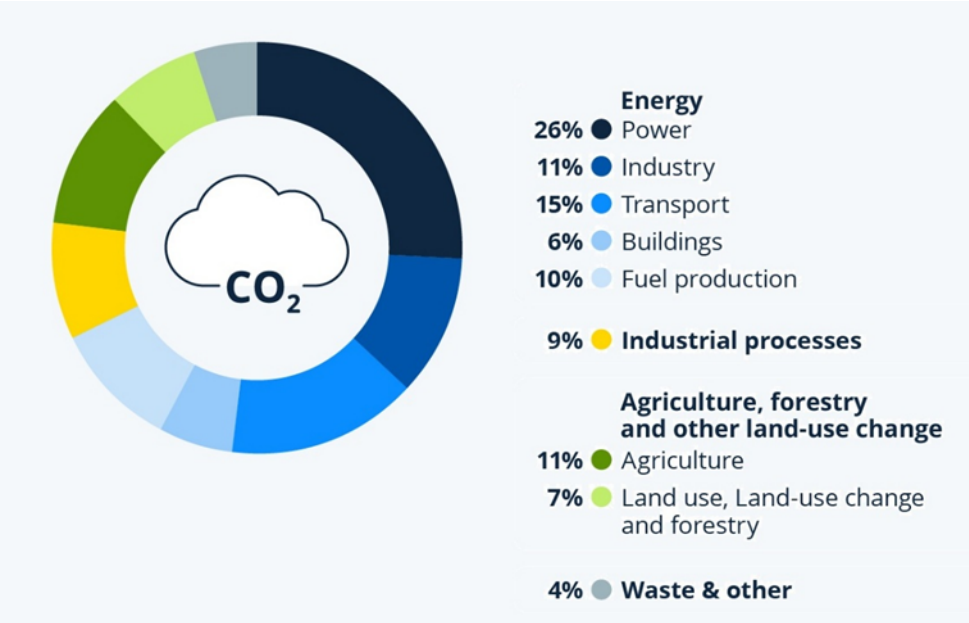

Fig. 1. CO_2 Emissions by Sector in 2024. Source [5]

As temperatures rise, extreme weather events become more frequent, and ecosystems face increasing pressure, international frameworks such as the Paris Agreement have set an ambitious target to limit global warming to well below 2 °C. Achieving this target requires a fundamental change in the way transport systems are designed, operated, and managed. From an economic perspective, innovation in transport is a key aspect of sustainable growth. It not only enables emission reductions and energy efficiency but also stimulates new industries, creates jobs, and increases long-term competitiveness. Strategic investments in low-emission transport solutions—such as electric mobility, smart logistics, and multimodal integration—can generate significant economic benefits while supporting global decarbonization efforts. Therefore, effective innovation management is crucial to reconciling economic development with climate resilience [6].

2. MATERIALS AND METHODS

The research method employed in this study was based on a comprehensive analysis of secondary data, supplemented by observations and calculations, which enabled reliable conclusions regarding innovation management in the transport sector.

Secondary data analysis involved a systematic review and interpretation of existing sources of information, including industry reports (such as those in the transport and energy industries), government statistics, scientific publications, data from international institutions, and climate and energy policy documents. This allowed us to collect a wide spectrum of knowledge about the current state of the transport sector, its environmental impact, and the decarbonization strategies that have been implemented. The use of secondary data also allowed us to compare different approaches and identify best practices in the field of innovation and management.

We carried out calculations based on the collected data to make a detailed assessment of the economic aspects of transport transformation. These allowed us to calculate investment costs in new technologies, analyze energy efficiency, forecast changes in CO_2 emissions, and simulate the impact of implemented innovations on the competitiveness of enterprises. Combining secondary data analysis with our

calculations ensured the reliability and objectivity of the research, enabling the presentation of a comprehensive picture of the challenges and opportunities related to the decarbonization of the transport sector and the role of energy companies in this process. The research method also helped us identify research gaps and formulate recommendations for management practice and public policy.

3. RESULTS AND DISCUSSION

3.1. Investments in the transport sector

Investments in the transport sector play a key role in shaping modern, efficient, and sustainable mobility. They include not only the expansion and modernization of road, rail, tram, and air infrastructure but also the development of intelligent traffic management systems and digital logistics solutions. Investments in low-emission technologies, such as electromobility, hydrogen transport, and the integration of various means of transport within multimodal systems, are of particular importance.

At the same time, accompanying infrastructure is being developed in the form of charging stations for electric vehicles, transfer hubs, bicycle paths, and passenger information systems, which support the comfort and environmental friendliness of travel. Investments in the digitalization of the sector are also playing an increasingly important role; these investments range from fleet management to the automation of logistics processes to real-time public transport planning [7].

In the context of climate transformation, these investments are essential for reducing emissions, increasing energy efficiency, and adapting the transport sector to the requirements of the green economy. They make it possible not only to improve the quality of transport services but also to support the goals of the country's climate and economic policy. Table 1 presents investments from the state budget earmarked for investments in the transport sector in Poland in 2023 and 2024.

Table 1

Overview of Investment Expenditures in Poland's Transport Sector in 2023 and 2024

Investment Category	2023 (million PLN)	2024 (million PLN)	Change (%)
Road infrastructure	14,230	33,169	+132.8%
Rail infrastructure	9,810	24,952	+153.2%
Air transport	1,650	1,665	+0.9%
Maritime and inland waterways transport	700	1,665	+138.6%
Public transport (bus)	800	1,000	+25.0%
Waterway construction program	292	143	-51.0%
Bus transport development fund	800	1,000	+25.0%

3.2. Investments in tram infrastructure

Reducing emissions in the transport sector is an integral part of global efforts to achieve a zero-emission economy. Electrification, the adoption of hydrogen, the development of public transport, and low-emission logistics are key solutions for a sustainable future. However, the effective implementation of these measures to minimize emissions and reduce the environmental impact of transport requires coordinated support from governments, industry, and consumers. Public transport plays a key role in this transformation, and further promoting its use is essential. Expanding and modernizing systems such as buses, trams, and metro networks can significantly reduce the dependence on private vehicles. Trams, in particular, offer a highly efficient zero-emission transport option that can be powered by renewable electricity. Cities that invest in tram systems often experience not only lower emissions but also reduced congestion and improved air quality, making urban spaces more liveable. Figs. 2 and 3 show the

implementation of a new tram line connecting the center of Warsaw with the dynamically developing residential district of Wilanów. Fig. 2 shows the construction works of the tram line in 2024, including details such as track laying and infrastructure development, while Fig. 3 shows the final works related to the road infrastructure.

Fig. 2. Tram line under construction in 2024. Source: author's archive

Investments in transport infrastructure play a crucial role in the development of cities and regions. They enhance residents' mobility, improve their quality of life, and stimulate economic growth by facilitating access to work, education, and services. Modernizing existing transport networks and constructing new connections, such as tram lines, contribute to sustainable development and help reduce emissions – an especially important factor in the context of climate change and environmental policy goals.

Table 2

Advantages and disadvantages of transport infrastructure investments

Advantages of Transport Infrastructure Investments	Drawbacks and Challenges of Investments
Improved mobility for residents	Delays and budget overruns
Reduced emissions and pollution	Disruptions to residents
Increased city attractiveness	Risk of overestimating demand
Spatial integration	Legal and administrative complexity
Economic benefits	High maintenance costs
Promotion of sustainable urban development	High opportunity cost
Enhanced accessibility for marginalized groups	Environmental disruption during construction
Resilience and adaptation to climate change	Risk of political and administrative changes

The above overview shows that investments in transport infrastructure bring significant social and environmental benefits as well as serious organizational and financial challenges. Their successful implementation requires careful planning, a flexible approach, and consideration of the long-term impacts on the city and its residents. While investments in transport infrastructure are essential for modern cities, their implementation requires significant financial resources, effective planning, flexible management, and the ability to respond to unforeseen difficulties. The example of the tram line to Wilanów shows that despite delays and organizational challenges, the outcome can bring meaningful benefits to both residents and the city. However, it is vital to strike a balance between infrastructure ambitions and implementation realities to ensure that such projects are not only impressive but also durable and functional.

Fig. 3. Completed tram line with unfinished road infrastructure. Source: author's archive

The construction of the tram route to Wilanów, together with the purchase of rolling stock and accompanying infrastructure, amounted to PLN 1.19 billion, with EU funding of PLN 555 million. The Warsaw budget assumed revenues of PLN 20 billion per year in 2023 and 2024 [8]. Thus, the cost of building the tram line, after taking into account EU funding, was less than 2% of the budget for the two years.

3.3. Investments in charging network infrastructure

The construction of an extensive and effective charging network, especially fast and ultra-fast charging stations, is one of the pillars of the development of electromobility and a necessary condition for the popularization of electric vehicles in public, private, and freight transport. The lack of sufficiently dense and accessible infrastructure is one of the main adaptation barriers, which is why investments in this area are gaining strategic importance at the national and EU level.

Energy companies such as Orlen, E.ON, Tauron, and Energa are actively developing charging infrastructure, treating it as a key element of the energy transformation and decarbonization of transport. These investments include the construction of new stations—especially on main communication arteries and in city centers—and the modernization of existing points in terms of their power, availability, and compatibility with various types of vehicles. Strategic locations from the point of view of users, such as park-and-ride parking lots, shopping centers, transfer hubs, and fuel stations, are becoming increasingly important. An important aspect of the development of this infrastructure is its integration with renewable energy sources, such as photovoltaic panels, wind turbines, and energy storage. This not only reduces the carbon footprint of local energy systems but also increases their flexibility and independence. These solutions support the development of distributed energy sources and enable better demand management during peak hours [9].

Significant financial outlays are also allocated to the development of digital charging infrastructure management systems, which monitor technical parameters, energy consumption, and availability, as well as user preferences. Companies are investing in dedicated mobile applications and platforms that

enable route planning with charging points, cost management, and the use of dynamic tariffs. This infrastructure is becoming an increasingly integral part of intelligent energy networks (smart grids), which allow for bidirectional energy flow and better balancing of supply and demand.

In addition, energy companies are implementing innovative solutions that support the decarbonization of transport, such as systems for managing electric vehicle fleets, dynamic charging tariffs adjusted to the network load, and billing models based on actual energy consumption. Integrating infrastructure with smart grids and mobility management systems promotes the efficient use of resources, stabilizes the network, and increases the reliability of supplies. In the long term, the development of this type of infrastructure accelerates transformation in the energy and transport sectors while building a more sustainable, flexible, and resilient urban and regional mobility system [10].

3.4. Investments in hydrogen infrastructure

The production of green hydrogen and the development of its distribution infrastructure (e.g., hydrogen refueling stations; see Fig. 4) are becoming a priority investment area for energy companies. Many of these companies view hydrogen as a key component in the future of transport decarbonization, particularly in sectors that are difficult to electrify.

Fig. 4. Hydrogen refueling station. Source [11]

Hydrogen as an energy carrier has high innovative and operational potential. It can be used in fuel cells (to power electric vehicles with a long range and short refueling time) and as an alternative fuel in modern combustion engines. Its unique feature is the ability to effectively store excess energy produced from renewable energy sources (RES), which makes it an important tool for balancing unstable electricity supplies and increasing the energy security of national systems.

Scheme 1. Production of green hydrogen (electrolysis of water from RES) using electricity from photovoltaic panels or wind turbines

$$2H_2O \rightarrow 2H_2 + O_2$$

The advantages of producing green hydrogen through the electrolysis of water using renewable energy sources, such as photovoltaic panels or wind turbines, are multifaceted. First of all, this process is completely emission-free—it does not generate any greenhouse gases or pollutants, thereby reducing its negative impact on the climate. In addition, green hydrogen is produced from renewable energy sources that are inexhaustible and locally available, which increases energy security and independence from fossil fuels. The use of electrolysis enables flexible hydrogen production, adapted to the changing conditions of energy production from renewable sources, and facilitates integration with intelligent energy management and storage systems. This makes green hydrogen a key element of the transformation towards a low-emission economy and sustainable development of transport and industry.

Energy companies are also investing in new forms of hydrogen production—the so-called turquoise (based on methane pyrolysis with CO_2 capture) and pink (produced using nuclear energy) production—

which increases the flexibility of production systems and enables their adaptation to different geographical and technological conditions.

Scheme 2. Production of a turquoise hydrogen (methane pyrolysis) thermal method without CO_2 emissions—coal remains in solid form

$$CH_4 \rightarrow C + 2H_2$$

The primary advantage of producing turquoise hydrogen by methane pyrolysis is the lack of CO_2 emissions to the atmosphere because the coal produced in the process remains in solid form and can be safely stored or used industrially. This makes the process more environmentally friendly than traditional steam reforming of methane, which generates significant amounts of carbon dioxide. Additionally, methane pyrolysis is energy efficient and allows for the production of high-purity hydrogen, which makes it a promising technology for the decarbonization of the transport and industry sectors. In addition, the possibility of using solid coal as a raw material for further industrial processes increases the economic attractiveness of this method.

Scheme 3. Production of pink hydrogen (electrolysis from nuclear energy) using electricity from a nuclear power plant

$$2H_2O \rightarrow 2H_2 + O_2$$

Pink hydrogen production is considered environmentally friendly because it is based on the electrolysis of water using electricity from nuclear power plants, which do not emit greenhouse gases during operation. Unlike traditional methods based on fossil fuels, this process does not involve carbon dioxide emissions, which supports decarbonization goals. Additionally, nuclear power plants provide a stable and continuous source of energy, which allows hydrogen production in any weather conditions. Thus, pink hydrogen can play an important role in building a low-emission energy and transport system. This approach also promotes the diversification of energy sources and reduces dependence on fossil fuels.

At the same time, pilot programs are being implemented that utilize hydrogen in transportation applications, including urban and regional logistics systems. These include, among others, zero-emission hydrogen buses, fuel cell trains, and long-distance trucks. These solutions are being tested and put into operation in Europe and Asia, often with the support of public funds and EU programs. The importance of investing in green hydrogen goes beyond the transport sector itself. It is also an important component of the synergy between the energy, industrial, and infrastructure transformation while enabling the development of a new market for alternative fuels and jobs in innovative industries [12].

3.5. Examples of implementing innovative solutions

3.5.1. E.ON Drive – Comprehensive support for the development of electromobility

E.ON Drive is a modern and integrated program designed to support the shift toward sustainable transport. Its main goal is to make it easier for both individual and business customers to switch to mobility based on electric vehicles. The program offers a comprehensive ecosystem of services and solutions, covering all stages of the process, from technical consulting and infrastructure design to the installation of charging stations to ongoing management and supply of electricity, including that from RES.

E.ON Drive is not just technology—it is primarily people. The development of the program is supervised by a team of 350 specialized experts and electromobility enthusiasts, supported by a global network of 75,000 specialists from the E.ON group, one of the largest energy suppliers in Europe. This allows it to combine agility and flexibility in action with the strength and resources of a large, international energy organization.

The program is dynamically developing its charging infrastructure throughout Europe. E.ON Drive currently operates in 14 European markets and manages a network of over 420,000 public and private charging points. A significant part of this infrastructure is already being integrated with renewable energy sources, which is a significant contribution of the company to reducing CO_2 emissions and achieving climate goals.

Another important element of the program is the development of intelligent billing systems, which allow users to conveniently monitor energy consumption, manage charging costs, and optimize the entire process. As such, E.ON Drive not only increases the availability of chargers but also increases the comfort and efficiency of electric vehicles.

The activities undertaken within E.ON Drive constitute an important step towards the green transformation of the transport sector and are an integral element of the company's long-term strategy for sustainable development. By creating a friendly environment for e-mobility users, E.ON Drive contributes to building a future in which transport will be emission-free, modern, and accessible to everyone [13].

3.5.2. Orlen Charge – Development of electromobility infrastructure in Poland

Orlen Charge is a strategic program of the ORLEN Group, the aim of which is the dynamic development of modern charging infrastructure for electric vehicles in Poland. The project is implemented in close cooperation with local governments and public administration units, which enables the effective adjustment of infrastructure solutions to the needs of city residents and users of low-emission transport.

Currently, the Orlen Charge network includes over 400 publicly available charging points, which makes the ORLEN Group a leader in the domestic electromobility market in terms of the range and availability of charging infrastructure. The stations are located in strategic locations, both in cities and along main communication routes, which translates into real support for the development of zero-emission transport and increases the comfort of electric vehicle drivers in everyday use.

As part of cooperation with cities, Orlen plans to build 40 new publicly available charging stations in 33 cities throughout Poland. This project is being implemented using PLN 63 million in funding obtained from the National Fund for Environmental Protection and Water Management (NFOŚiGW). Financial support allows for faster project implementation, shorter investment implementation time, and improved charging availability in medium and large cities. A key element of the Orlen Charge program is also investment in ultra-fast charging stations with power from 150 kW to up to 400 kW. Such points will be installed primarily on transit routes (e.g., motorways and expressways), as well as in cities wherever there is a need for fast and efficient energy replenishment in electric vehicles. Drivers will be able to charge the battery to a significant level in just a few minutes, which brings electromobility closer to the standards of convenience offered by traditional fuels. Orlen Charge has already installed one ultra-fast Willbert Amber II charging station of Polish production belonging to the new generation of DC chargers. This station will provide ultra-fast charging with a power of up to 360 kW and excellent communication with the vehicle being charged. The device is equipped with two liquid-cooled CCS (Carbon Capture and Storage) connectors to increase charging efficiency. Owing to the dynamic power management system, two electric cars can be charged from the device at the same time, with the power adjusted to the capabilities and expectations of the vehicle being charged.

The Orlen Charge program is not only about infrastructure; it is also a step towards sustainable development and implementation of the climate goals of Poland and the European Union. Investments in electromobility are a crucial element of the ORLEN Group's energy transformation strategy, aligning with its long-term vision of developing clean technologies and achieving emission neutrality [14].

In addition to the expansion of physical infrastructure, Orlen Charge places strong emphasis on innovation, customer experience, and the integration of smart technologies. The company is actively developing digital tools, such as mobile applications and intelligent billing systems, to make the charging process more user-friendly and efficient. These solutions not only simplify access to charging services but also enable real-time monitoring of station availability and energy usage. Furthermore, by prioritizing renewable energy sources for powering its stations, Orlen Charge reduces the overall carbon footprint of the transport sector. As the network continues to grow, the program is set to play a crucial role in shaping the future of sustainable mobility in Poland.

Fig. 5. Ultra-fast charging station (360 kW). Source [15]

Innovation and adaptation to the dynamically changing requirements of the environment constitute the direction in which Orlen will follow, strengthening its position as a leader in energy and transport transformation [16, 17].

4. CONCLUSIONS

The transport sector requires substantial financial investments in infrastructure, as well as innovative technical and technological solutions to achieve climate goals and establish a sustainable mobility system. These investments include the development of electromobility, such as the expansion of the network of charging stations integrated with renewable energy sources, and the implementation of hydrogen technologies, such as green, turquoise, or pink hydrogen, to decarbonize heavy, rail, and long-distance transport.

Energy companies play a key role in this process, not only by providing clean energy but also by developing digital management systems, dynamic tariffs, and services based on flexible energy consumption. At the same time, the transformation of transport requires the modernization and construction of new infrastructure, which brings challenges related to the time-consuming nature of projects and the need for long-term planning. An example is the construction of the tram line to Wilanów. Although the main route was put into service with a delay, this investment shows the scale and complexity of the activities necessary to transform urban transport.

In light of growing climate requirements and societal needs, the effective management of transport innovations is becoming not only a challenge but also an opportunity to build a resilient, accessible, and low-emission transport system.

However, this transformation is not without limitations. Key barriers include high initial investment costs, technological uncertainties, regulatory complexity, and the uneven pace of development across regions. Future research should focus on identifying effective financing models, measuring the socio-economic impacts of low-emission transport solutions, and evaluating the scalability of innovative technologies in diverse urban and regional contexts.

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