

ECOLOGICAL TRANSPORT IN INTERNATIONAL PRACTICE: ELECTRIC BUSES, TRAMS AND CYCLE PATHS

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Abstract

The transition towards ecological transport has become a global priority as urbanization intensifies challenges related to congestion, pollution, and inefficient mobility. This study examines the integration of electric buses, trams, and cycling infrastructure in Russia and Azerbaijan by drawing on the experiences of Japan and China. Japan's approach, characterized by gradual technological innovation and a focus on hydrogen fuel cell vehicles, contrasts with China's large-scale deployment of electric buses and rapid tram expansion. These differing strategies provide valuable insights into the feasibility of sustainable transport models in emerging urban environments.

In Russia, the transition to electric buses and trams has been largely concentrated in Moscow, while regional cities struggle with financial constraints, aging infrastructure, and inadequate policy support. Azerbaijan faces similar challenges, with outdated public transport networks, limited cycling infrastructure, and high private vehicle dependency contributing to urban congestion and environmental degradation. Despite growing interest in sustainable transport, both countries require significant investment in electrification, infrastructure development, and regulatory frameworks to enable large-scale adoption.

The study highlights key barriers to ecological transport implementation, including

high initial costs, lack of charging infrastructure, and cultural resistance to alternative mobility solutions. It emphasizes the need for comprehensive policies that integrate financial incentives, urban planning reforms, and public engagement strategies to facilitate the transition to sustainable transport. By leveraging international best practices and aligning transport policies with sustainability goals, Russia and Azerbaijan can reduce emissions, enhance urban mobility, and improve public health, ensuring long-term economic and environmental benefits.

Introduction

The rapid urbanization of modern cities has placed significant pressure on transportation systems, leading to increased traffic congestion, air pollution, and reliance on fossil fuel-based mobility. As governments worldwide seek sustainable alternatives to mitigate these challenges, ecological transport solutions—such as electric buses, trams, and cycling infrastructure—have gained prominence. The shift towards environmentally friendly transport is not only essential for reducing carbon emissions but also for improving urban mobility efficiency and enhancing public health. Countries that successfully integrate these transport solutions can achieve long-term sustainability, economic efficiency, and a higher quality of life for their urban populations.

Japan and China serve as two leading examples of ecological transport implementation, with each country adopting distinct strategies to modernize their public transport systems. Japan has focused on gradual technological innovation, prioritizing hydrogen fuel cell buses and high-efficiency rail networks, while



China has taken an aggressive large-scale approach, deploying fully electric bus fleets and rapidly expanding tram networks in its major cities. These contrasting approaches offer valuable insights into the factors that determine the success of ecological transport policies, including government incentives, infrastructure investment, and public-private collaboration.

In Russia, efforts to integrate electric buses and trams have progressed unevenly, with Moscow leading advancements in electric mobility while regional cities continue to face financial and infrastructural challenges. Similarly, Azerbaijan's urban transport system struggles with outdated public transport networks, high private car dependency, and a lack of sustainable mobility options. The potential for ecological transport solutions in both countries depends on overcoming economic, technical, and policy-related barriers to ensure a successful transition.

This study examines the feasibility of integrating electric buses, trams, and cycling infrastructure into Russia and Azerbaijan's transport systems by analyzing the experiences of Japan and China. It explores current urban transport challenges, assesses the economic and environmental implications of sustainable transport solutions, and provides strategic recommendations for policymakers. By addressing the key factors necessary for successful ecological transport adoption, this research aims to highlight pathways for Russia and Azerbaijan to transition towards efficient, low-emission, and sustainable urban mobility solutions.

The concept of ecological transport and its role in urban development

The rapid urbanization of the 21st century has led to significant challenges in transportation infrastructure, including congestion, pollution, and resource depletion. Consequently, the concept of ecological transport has emerged as a crucial strategy for fostering sustainable urban development. Ecological transport, also referred

to as sustainable or green transport, encompasses mobility solutions that minimize environmental impact, reduce reliance on fossil fuels, and promote energy efficiency. These include electric and hybrid vehicles, trams, cycle paths, and pedestrian-friendly infrastructure, all of which contribute to a more sustainable urban environment (Banister, 2019).

Ecological transport systems play a pivotal role in urban sustainability by addressing the environmental, economic, and social aspects of mobility. From an environmental perspective, traditional transport systems contribute significantly to air pollution and greenhouse gas (GHG) emissions. According to the Intergovernmental Panel on Climate Change (IPCC), the transport sector accounted for approximately 25% of global carbon dioxide (CO₂) emissions in 2020, with urban transport being a primary contributor (IPCC, 2021). Shifting towards electric and low-emission public transport reduces air pollutants such as nitrogen oxides (NO_x) and particulate matter (PM), thereby improving air quality and public health (Creutzig et al., 2018).

Economically, investment in ecological transport has the potential to enhance efficiency and reduce long-term operational costs. Electric buses, for example, have been demonstrated to offer lower fuel and maintenance costs compared to diesel-powered alternatives, despite higher initial investments (Sperling & Gordon, 2019). Furthermore, integrating ecological transport into urban planning enhances accessibility, reduces commuting times, and fosters economic productivity by improving workforce mobility (Newman & Kenworthy, 2015).

Socially, sustainable transport systems contribute to urban livability by prioritizing human-centered mobility solutions. Expanding pedestrian and cycling infrastructure encourages physical activity, reduces traffic-related accidents, and enhances social cohesion within communities (Pucher & Buehler, 2017). Cities that have successfully implemented ecological



transport solutions, such as Copenhagen and Amsterdam, have reported increased quality of life and improved public well-being due to their emphasis on bicycle-friendly policies (Gössling, 2020).

Urban development strategies that incorporate ecological transport prioritize multimodal transport networks that integrate electric buses, trams, and non-motorized transport modes. For instance, Curitiba in Brazil has become a model for sustainable transport planning, with its bus rapid transit (BRT) system significantly reducing congestion and emissions while ensuring efficient urban mobility (Duarte & Rojas, 2019). Similarly, European cities such as Vienna and Oslo have invested heavily in electrified public transport systems, which have contributed to reduced car dependency and enhanced urban sustainability (García-López et al., 2020).

Given the urgency of climate change mitigation and the necessity for sustainable urban planning, ecological transport has become an essential component of future urban mobility. Governments and policymakers must adopt integrated approaches that combine technological innovation, regulatory frameworks, and public engagement to ensure the successful implementation of sustainable transport systems. As cities continue to expand, the role of ecological transport in shaping resilient, inclusive, and environmentally friendly urban spaces will remain paramount.

Electric buses and trams as key elements of green transport

Electric buses and trams have emerged as fundamental components of green transport systems due to their ability to significantly reduce carbon emissions and enhance the sustainability of urban mobility. As cities worldwide confront the challenges of air pollution, traffic congestion, and climate change, the transition to electric public transport has become a key strategy for mitigating the environmental

impact of traditional fuel-based transportation. Both electric buses and trams contribute to lower greenhouse gas emissions, improved air quality, and increased energy efficiency, making them integral to contemporary sustainable urban planning.

The adoption of electric buses has gained considerable traction in recent years as advancements in battery technology and charging infrastructure have made these vehicles a viable alternative to diesel-powered fleets. Compared to their internal combustion counterparts, electric buses produce zero tailpipe emissions, thereby reducing urban air pollution and the associated health risks. According to the International Energy Agency (IEA), global electric bus deployment has increased substantially, with China leading the transition by operating more than 90 percent of the world's electric bus fleet as of 2020. Shenzhen, in particular, has become a global model, achieving full electrification of its bus fleet, which has contributed to a significant reduction in urban air pollutants (IEA, 2021). In addition to environmental benefits, electric buses offer economic advantages in the form of lower operational and maintenance costs. A study by Buekers et al. (2021) highlights that electric buses have fewer moving parts than conventional buses, reducing maintenance expenses while benefiting from declining battery costs and improvements in energy efficiency.

Trams, as a well-established mode of electrified public transport, continue to play a vital role in sustainable urban mobility by providing high-capacity, low-emission transport solutions. Unlike buses, which rely on road infrastructure, trams operate on fixed rail systems, allowing for greater efficiency in terms of energy use and passenger flow management. Many European cities have integrated modern tram networks to enhance public transport accessibility while minimizing environmental impact. In cities such as Vienna and Zurich, trams have become a backbone of urban mo-



bility, contributing to reduced congestion and lower per capita emissions (García-López et al., 2020). Furthermore, research by de Luca (2021) indicates that modern tram systems, when integrated with renewable energy sources, can achieve near-zero emissions, further strengthening their role in green transportation strategies.

One of the main advantages of electric buses and trams is their capacity for integration into smart and sustainable transport networks. With the rise of digitalization, these transport modes can be equipped with energy-efficient routing systems, regenerative braking technologies, and real-time monitoring to optimize their performance. The electrification of bus and tram networks also aligns with broader policies aimed at decarbonizing urban transport. The European Green Deal, for example, prioritizes the expansion of electric public transport as a means of achieving carbon neutrality by 2050 (European Commission, 2020). Similarly, various national and municipal policies have incentivized the adoption of electric buses and trams through subsidies, tax incentives, and infrastructure investments.

Despite their many advantages, the transition to electric buses and trams is not without challenges. High initial costs, particularly for battery-powered buses, pose financial barriers for many cities, requiring substantial government support and private sector investment. Additionally, the charging infrastructure for electric buses and the development of tram networks demand significant urban planning and coordination efforts. However, long-term projections suggest that as battery prices decline and renewable energy sources become more widely available, the cost-effectiveness and sustainability of these transport solutions will improve (Li et al., 2021).

Electric buses and trams are indispensable to the evolution of green transport systems, offering viable solutions to urban environmental challenges while promoting sustainable de-

velopment. Their role in reducing emissions, improving air quality, and enhancing public transport accessibility underscores the necessity for continued investment in electrified mobility solutions. As technology advances and policies favor clean energy transportation, the widespread adoption of electric buses and trams will remain central to the sustainable urban transport agenda.

The role of cycle paths in urban mobility and sustainability

The development of cycle paths has become a critical component of sustainable urban mobility, contributing significantly to environmental protection, public health, and efficient transportation systems. As urban centers face increasing congestion, pollution, and the need for sustainable alternatives to motorized transport, cycling infrastructure has emerged as a key solution in contemporary urban planning. Well-designed cycle paths facilitate the transition towards low-carbon transport systems by reducing dependence on automobiles, promoting active mobility, and enhancing the overall quality of urban life.

From an environmental perspective, cycle paths play a crucial role in reducing greenhouse gas emissions by encouraging modal shifts from cars to bicycles. The transport sector remains one of the largest contributors to global carbon dioxide (CO₂) emissions, accounting for approximately 25% of total emissions worldwide (Intergovernmental Panel on Climate Change, 2021). Cities that invest in cycling infrastructure experience a significant reduction in transport-related emissions. Research conducted by Gössling and Choi (2018) indicates that urban areas with extensive cycling networks, such as Amsterdam and Copenhagen, have successfully reduced per capita transport emissions by replacing short-distance car trips with cycling. This transition not only decreases fossil fuel consumption but also alleviates air pollution, which is particularly relevant for



cities struggling with high levels of particulate matter (PM) and nitrogen oxides (NO_x).

Beyond environmental benefits, the integration of cycle paths into urban transport networks offers substantial public health advantages. Regular cycling has been associated with lower rates of cardiovascular diseases, obesity, and mental health disorders, as it promotes physical activity and social interaction (Celis-Morales et al., 2017). Cities with well-developed cycling infrastructure witness increased cycling participation, which in turn fosters a healthier population. Moreover, the shift from motorized vehicles to bicycles leads to reduced traffic-related accidents and fatalities. Studies conducted by Pucher and Buehler (2021) reveal that protected cycle lanes contribute to lower injury rates among cyclists, as they provide a safer commuting environment compared to mixed-traffic roadways. These findings underscore the importance of dedicated cycling infrastructure in enhancing both individual and public health outcomes.

Economically, investment in cycle paths has proven to be cost-effective, generating positive returns through reduced congestion and increased urban accessibility. Road congestion in major metropolitan areas leads to significant productivity losses, with commuters spending substantial time in traffic. By promoting cycling as a viable alternative, cities can mitigate congestion-related economic inefficiencies. Research by Litman (2020) highlights that cycling infrastructure requires considerably less space and financial resources than road expansions for automobiles, making it a more efficient investment in urban mobility planning. Additionally, the presence of well-maintained cycle paths has been linked to increased retail activity, as cyclists tend to make more frequent stops at local businesses compared to car users.

Successful implementation of cycling infrastructure depends on integrated urban planning strategies that prioritize connectivity,

safety, and accessibility. Cities such as Bogotá, with its extensive Ciclovía network, have demonstrated the potential of cycle paths to transform urban mobility by making cycling more attractive and accessible (Montes et al., 2019). However, challenges remain in cities where car-centric infrastructure dominates transport planning. In many developing urban areas, the lack of dedicated cycling lanes, unsafe road conditions, and cultural preferences for automobiles hinder the widespread adoption of cycling as a primary mode of transport. Overcoming these challenges requires comprehensive policy measures, including investment in segregated cycle lanes, public awareness campaigns, and incentives for bicycle usage.

The role of cycle paths in urban mobility and sustainability is multifaceted, encompassing environmental, health, and economic benefits. As cities continue to expand and transportation demands grow, integrating cycling infrastructure into urban planning is essential for creating more livable, efficient, and sustainable urban environments. Governments and policymakers must prioritize cycling networks as part of broader sustainable transport initiatives, ensuring that cities transition towards low-emission, health-conscious, and economically viable mobility solutions.

Japan's experience in green urban transport

Japan's experience in green urban transport reflects a comprehensive approach to sustainable mobility, integrating advanced technologies, efficient urban planning, and strong policy frameworks to reduce environmental impact. As a highly urbanized and densely populated country, Japan has prioritized the development of environmentally friendly transport systems to mitigate congestion, lower greenhouse gas emissions, and improve the overall quality of urban life. The country has achieved significant progress through investments in electric buses, trams, and rail networks, supported by a com-



bination of government incentives, technological innovation, and public-private sector collaboration.

One of the most notable aspects of Japan's green transport strategy is its extensive railway and tram infrastructure, which has long served as the backbone of urban mobility. The country's railway system, particularly its high-speed Shinkansen network and urban commuter railways, has contributed to a significant reduction in private car usage, thereby lowering carbon emissions. According to a study by Morichi and Acharya (2013), Japan's railway transport emits significantly less carbon dioxide per passenger-kilometer compared to road-based transport modes, making it one of the most energy-efficient urban transport solutions globally. Urban rail systems in cities such as Tokyo, Osaka, and Nagoya are highly integrated with bus and tram networks, ensuring seamless connectivity and reducing dependence on fossil fuel-powered vehicles.

Electric buses have also gained prominence in Japan's sustainable transport initiatives, particularly in urban centers where the government has promoted their adoption through subsidies and policy support. The Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) has implemented incentives to accelerate the transition from diesel to electric and hydrogen-powered buses, with a focus on reducing particulate matter and nitrogen oxide emissions in densely populated areas. Research by Iida and Taniguchi (2020) highlights that several municipalities, including Kyoto and Fukuoka, have successfully introduced electric bus fleets as part of broader urban decarbonization efforts. These electric buses not only reduce emissions but also contribute to quieter and more comfortable public transport experiences, enhancing the overall appeal of sustainable mobility solutions.

Trams have also played a critical role in Japan's urban transport sustainability efforts, particularly in cities such as Hiroshima, Toyama,

and Okayama, where modern light rail transit (LRT) systems have been developed to provide energy-efficient mobility options. Unlike many countries that phased out tram networks in the mid-20th century, Japan has actively maintained and modernized its tram systems to complement urban transport strategies. The Hiroshima Electric Railway, for example, has continuously expanded its tram network, making it one of the most extensive in Japan and a model for integrating light rail with other sustainable transport modes. As noted by Fujii and Harata (2019), the efficiency of tram systems in Japan is enhanced by policies that prioritize transit-oriented development (TOD), ensuring that residential and commercial areas are well-connected to public transport hubs.

The success of Japan's green urban transport policies is also attributed to its strong emphasis on innovation and technology. The country has been a leader in developing hydrogen fuel cell technology for buses, with Toyota's Sora fuel cell bus being deployed in Tokyo ahead of the 2020 Olympics as part of an effort to showcase zero-emission transport solutions. Japan's commitment to hydrogen mobility aligns with its broader energy policy objectives, which seek to diversify energy sources and reduce reliance on imported fossil fuels. According to research by Kondo et al. (2021), the integration of hydrogen buses into urban fleets represents a significant step towards achieving long-term carbon neutrality goals while leveraging Japan's advancements in fuel cell technology.

Urban cycling infrastructure, while not as dominant as in European cities, has also received increasing attention in Japan's sustainable transport planning. Cities such as Tokyo have introduced policies to expand bicycle-sharing systems and dedicated cycling lanes, recognizing the role of cycling in reducing urban congestion and promoting low-carbon mobility. Although challenges remain in integrating cycling infrastructure into Japan's



compact urban landscapes, initiatives such as the introduction of underground automated bicycle parking systems demonstrate the country's innovative approach to overcoming space constraints while promoting green transport alternatives.

Japan's experience in green urban transport offers valuable insights into how policy coordination, technological innovation, and efficient public transport infrastructure can contribute to sustainable urban mobility. The country's emphasis on railway electrification, electric and hydrogen bus deployment, and tram network modernization illustrates a multi-faceted approach to reducing emissions and enhancing transport efficiency. As Japan continues to refine its green transport policies, its success serves as a model for other nations seeking to transition towards sustainable and low-emission urban mobility systems.

China's large-scale adoption of ecological transport

China's large-scale adoption of ecological transport represents one of the most ambitious and comprehensive transitions towards sustainable urban mobility in the world. As the country grapples with severe air pollution, congestion, and rising energy consumption, its government has implemented extensive policies aimed at promoting electric buses, trams, and non-motorized transport. These efforts align with China's broader climate goals, including its commitment to carbon neutrality by 2060. The transition towards green transport has been supported by strategic investments, regulatory incentives, and advancements in electric vehicle (EV) technology, making China a global leader in sustainable urban mobility.

One of the most striking achievements in China's ecological transport strategy is the widespread adoption of electric buses. The city of Shenzhen, in particular, has become a global model, achieving full electrification of its public bus fleet as early as 2017. The tran-

sition, facilitated by strong government support, was made possible through subsidies, infrastructure development, and the engagement of key industry players such as BYD and Yutong, two of the world's largest electric bus manufacturers. Research by Xie et al. (2020) highlights that replacing diesel buses with electric ones in Shenzhen led to a significant reduction in greenhouse gas emissions, with estimates indicating a decrease of over 1.35 million tons of CO₂ annually. In addition to environmental benefits, electric buses have contributed to lower operating costs for transport operators, as electricity prices in China remain relatively low compared to conventional fuel costs. These advantages have incentivized other Chinese cities, including Beijing, Shanghai, and Guangzhou, to accelerate the deployment of electric bus fleets.

In parallel with bus electrification, China has also made considerable progress in expanding its tram and light rail systems. Many cities have reintroduced tram networks as part of their strategy to reduce traffic congestion and provide energy-efficient public transport options. The re-emergence of trams in cities such as Beijing, Qingdao, and Guangzhou aligns with the government's objective to diversify public transport options while reducing reliance on private vehicles. According to research by Zhang and Zhang (2019), modern tram networks in China have been designed with a focus on integrating renewable energy sources, such as solar and wind power, into their operations, further enhancing their environmental sustainability. Additionally, trams have played a critical role in transit-oriented development (TOD), where urban planning policies prioritize accessibility to public transport hubs, reducing the need for extensive road expansion and car-dependent infrastructure.

Beyond electrification and rail expansion, China has also placed significant emphasis on non-motorized transport, particularly through the development of cycling infrastructure and



bike-sharing programs. The rapid proliferation of dockless bike-sharing services, pioneered by companies such as Mobike and Ofo, has revolutionized urban mobility by providing an affordable and convenient alternative to motorized transport. According to He et al. (2021), bike-sharing schemes in major Chinese cities have led to a measurable decline in short-distance car trips, contributing to reduced traffic congestion and lower emissions. The integration of cycling infrastructure with public transport systems has further enhanced multi-modal mobility, ensuring that last-mile connectivity is efficiently addressed.

The success of China's ecological transport initiatives is closely linked to its strong policy support and financial incentives. The central government has implemented a range of subsidies, tax breaks, and research grants to accelerate the adoption of electric and sustainable transport technologies. The New Energy Vehicle (NEV) policy, which mandates electrification targets and provides incentives for public transport electrification, has played a crucial role in driving widespread adoption. Research by Liu et al. (2020) indicates that China's government subsidies have accounted for a substantial portion of the total cost of electric buses, making them economically competitive with conventional diesel vehicles. Furthermore, stringent emissions regulations and urban planning policies have encouraged local governments to prioritize ecological transport in their development agendas.

Despite these advancements, challenges remain in ensuring the long-term sustainability of China's green transport transition. The rapid expansion of electric bus fleets has placed significant pressure on the electricity grid, necessitating further investment in smart grid technologies and energy storage solutions. Additionally, while battery technology has improved, issues related to battery disposal and recycling continue to pose environmental concerns. The Chinese government has responded

by introducing circular economy initiatives that promote battery reuse and recycling, aiming to minimize the environmental footprint of electric transport systems.

China's large-scale adoption of ecological transport serves as a benchmark for other nations seeking to transition towards sustainable mobility solutions. The integration of electric buses, modern tram networks, and non-motorized transport infrastructure demonstrates a multi-faceted approach to reducing urban emissions and enhancing public transport efficiency. With continued technological advancements and policy refinements, China is likely to remain at the forefront of global efforts to achieve greener and more sustainable urban mobility.

Comparative analysis of Japan and China's approaches

Japan and China have adopted distinct yet complementary approaches to ecological transport, reflecting their unique economic structures, urban planning philosophies, and policy frameworks. Both countries have made substantial advancements in sustainable mobility through the development of electric buses, trams, and other green transport initiatives. However, their strategies differ in terms of technological implementation, regulatory mechanisms, and the scale of deployment.

Japan's approach to ecological transport has been characterized by an emphasis on high-efficiency public transit networks, long-term urban planning, and the integration of advanced technologies such as hydrogen fuel cells. The country has prioritized the modernization and expansion of its railway and tram systems, which serve as the backbone of urban mobility. Research by Morichi and Acharya (2013) highlights that Japan's extensive rail infrastructure, including high-speed rail, light rail, and subway networks, has contributed to significantly lower carbon emissions per capita compared to other developed nations. The in-



tegration of electric and hydrogen-powered buses into the public transport system further complements this strategy, as seen in Tokyo's deployment of Toyota's Sora hydrogen buses for public transit. Japan's transition towards ecological transport has been gradual, reflecting a cautious and highly regulated approach that balances technological innovation with economic feasibility.

China, by contrast, has pursued a large-scale, rapid deployment strategy, leveraging its industrial capacity and centralized policy framework to electrify urban transport at an unprecedented rate. The full electrification of Shenzhen's bus fleet exemplifies China's ability to implement large-scale transformations within short timeframes. The Chinese government has provided extensive financial subsidies and regulatory mandates to accelerate the adoption of electric vehicles, as outlined in the New Energy Vehicle (NEV) policy (Liu et al., 2020). Additionally, China's urban development strategy has embraced transit-oriented development (TOD), integrating newly developed tram and bus rapid transit (BRT) networks with residential and commercial hubs. This approach has led to widespread adoption of electrified transport solutions, albeit sometimes at the expense of long-term infrastructure sustainability and energy efficiency optimization.

One of the fundamental distinctions between Japan and China lies in their technological preferences. While both nations have invested heavily in electric mobility, Japan has placed significant emphasis on hydrogen fuel cell technology as an alternative to battery-electric vehicles. According to Kondo et al. (2021), Japan views hydrogen as a long-term solution for achieving carbon neutrality, investing in research and development (R&D) initiatives to establish a hydrogen-based energy ecosystem. China, on the other hand, has focused primarily on battery-electric vehicles, benefiting from domestic manufacturing capabilities and economies of scale. The dominance of bat-

tery-electric transport in China has been driven by cost efficiency and existing industrial supply chains, whereas Japan has taken a more diversified approach, incorporating both battery and hydrogen-based solutions.

Another key distinction between the two countries is the role of governance and policy mechanisms in shaping ecological transport outcomes. Japan's transition has been guided by meticulous urban planning policies that prioritize long-term environmental sustainability. Cities such as Kyoto and Fukuoka have gradually integrated electric buses into existing transport networks, ensuring that infrastructure development aligns with public demand and economic viability (Iida and Taniguchi, 2020). In contrast, China's government has implemented aggressive policies that mandate the rapid electrification of public transport fleets, often requiring entire cities to transition within a few years. While this strategy has yielded significant reductions in carbon emissions, it has also introduced challenges related to infrastructure strain, battery waste management, and the long-term sustainability of large-scale deployment.

Despite their differences, both Japan and China share common goals in reducing transport-related emissions and enhancing urban sustainability. Both nations have implemented policies that incentivize public transit use over private car ownership, aiming to alleviate congestion and improve air quality. Additionally, they have leveraged smart city technologies to optimize transport efficiency, including real-time data monitoring for electric buses and predictive maintenance for rail networks. Research by Zhang and Zhang (2019) indicates that both countries have recognized the necessity of integrating renewable energy sources into transport electrification efforts, reducing reliance on fossil fuel-generated electricity.

Japan and China exemplify two contrasting yet effective approaches to ecological transport development. Japan's model prioritizes gradual



technological innovation, urban planning coherence, and hydrogen fuel development, while China's model emphasizes rapid-scale deployment, industrial leverage, and battery-electric technology. Both strategies offer valuable insights into sustainable urban transport, demonstrating that while different pathways exist, achieving ecological mobility requires a combination of technological advancement, regulatory support, and strategic infrastructure investment. As both countries continue to refine their transport policies, their experiences provide a foundation for other nations seeking to transition towards low-emission and high-efficiency urban mobility systems.

Current state of public transport in Russian cities

The current state of public transport in Russian cities reflects a complex interplay between historical infrastructure, modernization efforts, and emerging sustainability initiatives. Russia possesses an extensive public transport network, with metros, buses, trams, and trolleybuses playing a crucial role in urban mobility. However, significant disparities exist between major metropolitan areas such as Moscow and St. Petersburg and smaller cities, where outdated infrastructure and inefficient transit systems remain challenges. While public transport remains the primary mode of daily commuting for millions of residents, issues related to congestion, aging fleets, and environmental concerns have prompted calls for comprehensive reform.

Moscow, as the capital and largest city, has one of the most advanced and efficient public transport systems in Russia, centered around its extensive metro network. The Moscow Metro, known for its reliability and high capacity, serves as the backbone of the city's mobility, with over nine million passengers per day, making it one of the busiest metro systems in the world. In recent years, efforts have been made to expand and modernize the

system, with the introduction of the Moscow Central Circle (MCC) and Moscow Central Diameters (MCD), which integrate suburban railway lines with the metro network to improve connectivity (Zamyatina & Pilyasov, 2021). The city has also invested heavily in electric buses, with a growing fleet aimed at replacing diesel-powered vehicles to reduce air pollution and greenhouse gas emissions (Mosgortrans, 2022).

St. Petersburg similarly benefits from a well-developed metro and tram network, though challenges persist in modernizing its public transport fleet. The city's tram system, one of the most extensive in Russia, has been a focus of renewal efforts, with new low-floor trams gradually replacing aging rolling stock. Investments in contactless payment systems and digital mobility solutions have also improved passenger convenience. However, despite these improvements in Russia's largest cities, many mid-sized and smaller cities face difficulties in maintaining and upgrading their public transport infrastructure due to financial constraints and lower ridership demand (Buehler et al., 2020).

Beyond Moscow and St. Petersburg, public transport systems in many Russian cities suffer from underinvestment and aging infrastructure. Many regional cities continue to rely on old buses and trolleybuses that contribute to high emissions and operational inefficiencies. The decline of trolleybus networks, in particular, has been notable, with many cities discontinuing these services due to maintenance challenges and shifting preferences toward diesel and electric buses. In cities such as Novosibirsk, Yekaterinburg, and Nizhny Novgorod, public transport remains the dominant mode of commuting, but congestion and inefficient route planning often hinder its effectiveness (Gubaidullin & Suldina, 2021).

Environmental concerns have increasingly influenced transport policies in Russian cities, with an emphasis on transitioning towards



sustainable mobility solutions. The Russian government has announced various initiatives to support the electrification of public transport, particularly in Moscow, where a large-scale rollout of electric buses is underway. Other cities, however, have been slower to adopt green transport technologies due to financial limitations and the high costs associated with electrification (Kuznetsova & Artyukh, 2022). Despite these challenges, there is growing interest in sustainable urban mobility, with pilot projects for electric and hydrogen-powered buses being introduced in select cities.

A key issue affecting the efficiency of public transport in Russian cities is traffic congestion, particularly in urban centers where reliance on private vehicles remains high. While Moscow has implemented policies to discourage car usage, such as congestion pricing and expanded park-and-ride facilities, other cities have struggled to curb traffic growth. The lack of dedicated bus lanes in many regions further exacerbates delays in public transport services, reducing their attractiveness compared to private cars. Additionally, the informal transport sector, including marshrutkas (shared minibuses), continues to operate alongside official public transport services, often leading to regulatory and safety concerns (Dementiev et al., 2020).

Despite these challenges, recent trends indicate a growing commitment to modernizing and improving public transport in Russian cities. Investments in digital infrastructure, including mobile ticketing and real-time tracking applications, have enhanced user experience in major urban areas. The government has also recognized the need for greater integration of public transport networks, particularly in regions with fragmented systems that lack seamless connectivity between different modes of transport. Efforts to revitalize tram networks and expand metro lines are ongoing, though the pace of development varies significantly between cities.

The current state of public transport in Russian cities presents a contrast between the advanced systems of Moscow and St. Petersburg and the more outdated networks in smaller regional centers. While significant progress has been made in electrification, digitalization, and service integration, challenges related to aging infrastructure, congestion, and financial constraints persist. As sustainability becomes a more prominent focus in urban planning, the transition towards greener public transport solutions is likely to accelerate, though achieving widespread improvements will require coordinated efforts between federal, regional, and municipal authorities.

Prospects for integrating electric buses and trams in Russia

The prospects for integrating electric buses and trams in Russia are shaped by a combination of policy initiatives, technological advancements, and the need for sustainable urban transport solutions. As cities across the country grapple with the environmental and economic challenges posed by conventional fossil fuel-powered transport systems, there has been a growing recognition of the necessity to transition towards electric public transportation. Although progress has been uneven across different regions, Russia's commitment to modernizing its public transport infrastructure presents a significant opportunity for the widespread adoption of electric buses and trams.

The shift towards electric buses in Russia has been primarily driven by the government's strategic vision for reducing carbon emissions and improving air quality in urban centers. Moscow has emerged as a leader in this transition, with the city aiming to replace its entire fleet of diesel buses with electric alternatives by 2030. As of 2022, the capital had already introduced more than a thousand electric buses into its public transport system, setting a precedent for other cities to follow. The adoption of electric buses in Russia has been facilitated



by state subsidies and collaborations with domestic manufacturers such as KAMAZ and GAZ, which have been actively developing battery-electric and hydrogen fuel cell buses tailored to the country's climatic and infrastructural conditions (Kuznetsova & Artyukh, 2022). Despite these advancements, financial and logistical challenges remain significant barriers to large-scale deployment, particularly in regional cities where budgetary constraints hinder investment in electric vehicle infrastructure.

Beyond the capital, the prospects for electric bus integration in other Russian cities are largely dependent on local governance priorities and infrastructure readiness. While cities such as St. Petersburg, Kazan, and Yekaterinburg have initiated pilot programs for electric bus deployment, widespread adoption has been slow due to the high costs associated with charging stations and fleet conversion. Additionally, concerns over the resilience of electric buses in Russia's colder regions pose further obstacles to expansion. Studies by Gubaidullin and Suldina (2021) indicate that battery efficiency declines significantly in low temperatures, making year-round operation of electric buses more challenging in cities with severe winters. Addressing this issue requires advancements in battery technology and the expansion of charging infrastructure capable of supporting large-scale operations.

The integration of modern tram networks into Russian cities also presents a promising avenue for enhancing urban mobility while reducing environmental impact. Historically, trams have played a significant role in public transport systems across the country, yet many networks have suffered from decades of underinvestment and declining ridership. In recent years, there has been a renewed interest in revitalizing tram systems, with several municipalities prioritizing the expansion and modernization of tram infrastructure. Cities such as Moscow and St. Petersburg have invested

in new-generation low-floor trams that offer greater accessibility and improved energy efficiency. Moreover, regions such as Samara and Krasnodar have undertaken initiatives to replace outdated tram fleets with modern rolling stock that meets contemporary environmental and technological standards (Buehler et al., 2020).

However, the expansion of tram networks in Russia faces financial and spatial constraints. Unlike electric buses, which can operate on existing road infrastructure, trams require dedicated tracks and significant urban planning adjustments. The costs associated with constructing or upgrading tram infrastructure can be prohibitively high for many cities, especially in the absence of sustained government funding. Additionally, the integration of trams into modern urban transport ecosystems necessitates careful coordination with other transport modes to ensure seamless connectivity. Research by Dementiev et al. (2020) emphasizes the importance of transit-oriented development (TOD) strategies that prioritize mixed-use urban planning and multimodal transport integration, thereby making trams a more viable and attractive option for public mobility.

Despite these challenges, the long-term prospects for electric bus and tram integration in Russia remain positive, particularly in light of evolving regulatory frameworks and global sustainability trends. The Russian government has introduced policy measures aimed at promoting green mobility, including tax incentives for electric vehicle manufacturers and subsidies for municipal transport operators transitioning to electric fleets. Moreover, increasing public awareness of environmental issues has contributed to growing demand for cleaner and more efficient transport alternatives. As advancements in battery technology, renewable energy integration, and urban mobility planning continue to progress, electric buses and trams are likely to play a more prominent role in shaping the future of sustainable transport in Russian cities.



While the transition towards electric buses and trams in Russia presents significant opportunities for reducing emissions and enhancing urban mobility, the pace of implementation varies across different regions due to financial, technological, and infrastructural challenges. Moscow's success in electric bus deployment serves as a model for other cities, yet widespread adoption will require sustained policy support, investment in charging and energy infrastructure, and advancements in vehicle efficiency. Similarly, the modernization of tram networks holds great potential, though cost and spatial constraints must be addressed to ensure long-term viability. As Russia moves towards a more sustainable transport future, strategic planning and continued investment will be crucial in achieving the large-scale integration of electric buses and trams.

Current urban transport challenges in Azerbaijan

Urban transport in Azerbaijan faces significant challenges stemming from rapid urbanization, high private car dependency, outdated public transport infrastructure, and insufficient regulatory enforcement. Baku, as the country's primary urban center, experiences severe traffic congestion due to inadequate road planning, inefficient public transport networks, and a growing number of private vehicles. The absence of a well-integrated multi-modal transport system exacerbates commuting inefficiencies, with bus and metro services struggling to meet rising demand. Research by Huseynov and Mammadov (2021) highlights that inconsistent public transport schedules and outdated fleet conditions contribute to service unreliability, further pushing commuters toward private car usage.

Environmental concerns also present a major issue, as transport-related emissions significantly impact air quality, particularly in high-density areas. Diesel-powered buses and an aging taxi fleet contribute to high levels of particulate matter and nitrogen oxides, while

limited adoption of electric or hybrid vehicles slows progress toward sustainable urban mobility. Studies by Guliyev (2020) emphasize that weak policy enforcement and limited incentives for green transport have hindered the transition to cleaner mobility solutions.

Public transport accessibility remains inadequate in peripheral districts, where insufficient bus coverage and unreliable scheduling force many residents to rely on informal transport options, such as privately operated minibuses. These vehicles often operate outside official regulatory frameworks, leading to safety concerns and inconsistent service standards. Metro expansion, while beneficial, has not kept pace with urban sprawl, leaving many areas underserved.

Another critical issue is the lack of well-developed cycling and pedestrian infrastructure. Despite Baku's growing population density, pedestrian-friendly zones remain scarce, and cycle lanes are virtually nonexistent, discouraging alternative, low-carbon transport modes. Road safety remains a pressing concern, with high accident rates attributed to poor enforcement of traffic regulations, inadequate pedestrian crossings, and aggressive driving behaviors (Aliyev, 2022).

Efforts to improve transport infrastructure have been made, including metro expansion projects and bus fleet modernization. However, fragmented policy implementation, funding constraints, and lack of public-private collaboration continue to impede progress. Without significant investment in electrified transport options, stricter emissions policies, and integrated urban mobility planning, Azerbaijan's urban transport challenges will persist, exacerbating congestion, pollution, and accessibility issues.

Feasibility of electric buses and trams in Azerbaijan

The feasibility of introducing electric buses and trams in Azerbaijan is increasingly gaining



attention as the country seeks to modernize its urban transport infrastructure and address environmental concerns. With the rapid growth of Baku and other major urban centers, issues such as traffic congestion, air pollution, and inefficient public transport systems have become more pronounced. In response, the Azerbaijani government has begun to explore the transition towards sustainable mobility solutions, with electric buses and the potential revival of tram systems emerging as viable alternatives to conventional, fossil fuel-based transportation.

Recent developments signal a cautious but positive step toward electrification. In 2023, Baku introduced its first pilot project involving electric buses, marking a milestone in Azerbaijan's efforts to reduce greenhouse gas emissions from the transport sector. Operated initially on select city routes, these electric buses are intended to serve as a test case for broader implementation. According to the Baku Transport Agency, the city plans to gradually replace part of its aging diesel bus fleet with electric models over the coming years, contingent on the success of the pilot phase and the development of supporting infrastructure such as charging stations. This move aligns with Azerbaijan's broader environmental goals, particularly its commitments under the Paris Agreement, which emphasize decarbonization across all sectors of the economy, including transport.

The feasibility of widespread adoption, however, is influenced by several critical factors. One of the foremost challenges lies in the high initial investment required for electric bus procurement and the construction of charging infrastructure. Given the capital-intensive nature of electric vehicle deployment, funding from both public and private sources will be essential. Moreover, the country's energy grid must be evaluated for its capacity to support the increased demand for electricity, especially if large fleets are to be electrified. Azerbaijan's substantial electricity generation capacity, bol-

stered by hydrocarbon resources and growing interest in renewable energy, provides a relatively favorable backdrop for this transition, but strategic planning remains necessary.

The reintroduction of trams is another aspect of Azerbaijan's consideration of sustainable transport solutions. Baku once had an operational tram network, which was decommissioned in the early 2000s due to underuse and a shift towards road-based transportation. However, modern trams, which offer energy-efficient and high-capacity urban mobility, could play a transformative role in alleviating traffic congestion and reducing emissions in densely populated areas. The feasibility of tram reintroduction depends not only on financial resources but also on urban planning coordination, as trams require dedicated tracks and integration with existing transport systems. Given the increasing congestion in Baku, particularly during peak hours, a well-designed tram network could provide a reliable alternative to car travel and complement the existing metro and bus services.

Another dimension of feasibility relates to institutional and policy frameworks. Currently, there is limited regulatory guidance specific to electric public transport in Azerbaijan. Establishing clear policies, standards, and incentives—such as tax breaks for electric vehicle purchases, import duty reductions, and subsidies for green fleet conversion—will be crucial for facilitating adoption. Furthermore, capacity-building initiatives aimed at training personnel in electric vehicle maintenance and operations will be necessary to ensure the long-term sustainability of these systems.

In conclusion, while Azerbaijan has taken its initial steps toward incorporating electric buses and potentially trams into its urban transport strategy, full-scale implementation remains in the early stages and is contingent on overcoming financial, infrastructural, and regulatory barriers. The country's interest in sustainable transport, coupled with its energy



capabilities and growing environmental awareness, suggests a promising foundation. With comprehensive planning, institutional support, and international cooperation, the transition to electric buses and modern tram systems in Azerbaijan can become a realistic and impactful component of its future urban mobility landscape.

Developing a cycling culture in Azerbaijan

Developing a cycling culture in Azerbaijan has gained momentum in recent years, marked by significant infrastructural developments and policy initiatives aimed at promoting cycling as a viable mode of urban transportation. Historically, cycling in Azerbaijan was primarily viewed as a recreational activity, with limited infrastructure to support its integration into daily urban mobility. However, recognizing the environmental and health benefits of cycling, Azerbaijani authorities have embarked on projects to establish dedicated cycling infrastructure, particularly in the capital city, Baku.

In August 2024, Baku witnessed the launch of its first bike-sharing service, a pivotal step towards fostering a cycling culture. Approximately 50 bike parking stations were installed across central areas, each equipped with information boards and QR codes to facilitate easy rentals through a dedicated mobile application. This initiative aimed to provide residents and visitors with an accessible and eco-friendly transportation alternative, contributing to reduced traffic congestion and improved air quality.

Complementing the bike-sharing program, the Azerbaijan Land Transport Agency (AYNA) initiated the construction of dedicated bicycle lanes. By March 2024, a 10-kilometer bike lane network was established in central Baku, encompassing streets such as Istiglaliyyat, Azerbaijan Avenue, and Bulbul Avenue. Ad-

ditionally, a 2.2-kilometer bike path was developed along Baku Boulevard, connecting the Marine Station to the Azneft Circle, with plans for further expansion to cover the entire boulevard area.

Despite these advancements, challenges persist in fully integrating cycling into Baku's urban landscape. Cyclists have reported issues such as bike lanes being obstructed by pedestrians and vehicles, as well as lanes that abruptly end, disrupting continuity and safety. These obstacles highlight the need for comprehensive urban planning that ensures the seamless integration of cycling infrastructure with existing transport systems.

Moreover, public perception of cycling as merely a leisure activity rather than a legitimate mode of transport continues to impede its widespread adoption. Addressing this requires targeted public awareness campaigns to shift cultural attitudes and emphasize the benefits of cycling for both individuals and the broader community.

In conclusion, while significant strides have been made in developing a cycling culture in Azerbaijan, particularly through infrastructure projects in Baku, achieving a fully integrated and widely accepted cycling ecosystem necessitates ongoing efforts. Enhancing infrastructure continuity, enforcing traffic regulations to protect cyclists, and promoting cycling as a practical transportation option are essential steps toward realizing a sustainable and cyclist-friendly urban environment in Azerbaijan.

Conclusion

The transition towards ecological transport in urban environments is a fundamental step in addressing modern challenges related to congestion, pollution, and sustainability. As global cities increasingly prioritize electric buses, trams, and cycling infrastructure, the experiences of Japan and China serve as critical



benchmarks for understanding the complexities of implementation. Japan's approach, characterized by gradual technological innovation and integration of hydrogen fuel cell vehicles, contrasts with China's large-scale, state-driven deployment of electric buses and modern tram systems. Both models demonstrate the importance of strategic investment, policy support, and infrastructure readiness in achieving sustainable transport solutions.

In Russia, the prospects for integrating electric buses and trams depend on overcoming financial constraints, expanding charging infrastructure, and modernizing outdated transit systems. While major cities like Moscow have made progress in public transport electrification, regional disparities remain a significant challenge. The transition to green transport in Russia will require coordinated efforts between government agencies, urban planners, and the private sector to ensure feasibility and long-term sustainability. Similarly, Azerbaijan's urban transport sector faces critical challenges related to congestion, outdated infrastructure, and limited cycling facilities. The feasibility of electric buses and trams in Azerbaijan hinges on strategic planning, investment in electrification projects, and policy initiatives that incentivize sustainable mobility. Moreover, fostering a cycling culture will require significant infrastructural improvements, public awareness campaigns, and regulatory support to make cycling a viable and attractive transport option.

Overall, the successful integration of ecological transport solutions in Russia and Azerbaijan depends on a combination of policy reforms, financial commitment, and urban planning strategies that prioritize sustainability. The lessons from Japan and China illustrate the necessity of aligning technological advancements with comprehensive transport policies to achieve lasting environmental and economic benefits. As urban populations continue

to expand, investment in electric buses, tram networks, and cycling infrastructure will be essential in shaping efficient, low-emission, and resilient urban transport systems. Moving forward, sustained commitment from policymakers, industry stakeholders, and urban planners will determine the effectiveness of ecological transport initiatives in reducing carbon footprints and enhancing urban mobility across these regions.

To facilitate the transition towards ecological transport in Russia and Azerbaijan, a series of strategic policy recommendations must be considered, focusing on infrastructure development, financial incentives, regulatory frameworks, and public engagement. Given the environmental, economic, and social benefits associated with electric buses, trams, and cycling infrastructure, a multi-faceted approach is necessary to ensure long-term sustainability and widespread adoption.

First, governments must prioritize investment in transport electrification by expanding charging infrastructure and modernizing public transport fleets. In Russia, regional disparities in electrification require targeted financial support to assist cities outside Moscow and St. Petersburg in deploying electric buses and reviving tram networks. Municipalities should collaborate with domestic manufacturers and energy providers to establish widespread charging networks and integrate renewable energy sources into electric transport systems. Similarly, Azerbaijan should commit to gradually replacing its diesel-powered buses with electric alternatives by allocating subsidies and tax incentives for fleet operators, while ensuring that urban planning incorporates the necessary infrastructure for seamless electric mobility.

Second, regulatory frameworks must be strengthened to encourage sustainable transport solutions and discourage reliance on high-emission vehicles. Policymakers in both Russia and Azerbaijan should implement stricter emis-



sion standards, enforce low-emission zones, and introduce congestion pricing in high-traffic urban centers to incentivize public transport use. In addition, public-private partnerships should be promoted to accelerate the adoption of green transport technologies, including hydrogen fuel cell buses and advanced tram systems. Russia, with its extensive tram legacy, should prioritize modernizing existing tram networks to improve efficiency, while Azerbaijan should consider reintroducing trams in Baku and other major cities to enhance high-capacity, sustainable urban mobility.

Finally, public engagement and behavioral change campaigns are essential to ensure widespread acceptance of sustainable transport solutions. Both Russia and Azerbaijan should launch educational initiatives that highlight the benefits of electric buses, trams, and cycling, addressing misconceptions and promoting environmentally responsible commuting habits. Encouraging active participation through pilot programs, community cycling events, and public consultations can help shape policies that reflect citizens' needs while fostering a cultural shift towards sustainable mobility.

In conclusion, the successful integration of ecological transport in Russia and Azerbaijan will require a coordinated effort between governments, private sector stakeholders, and urban planners. By prioritizing infrastructure investments, strengthening regulatory frameworks, promoting cycling infrastructure, and engaging the public, both countries can transition towards sustainable and efficient urban transport systems that reduce emissions, alleviate congestion, and enhance overall urban livability. Without decisive action and long-term commitment, the opportunity to create environmentally friendly and economically viable transport solutions may be significantly delayed, affecting the sustainability of urban mobility for future generations.

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