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The Role of Public Transportation Systems in Promoting Sustainable Mobility in Green Cities

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abstract

Public transportation systems are pivotal in fostering sustainable mobility within green cities by addressing key environmental and societal challenges. This study highlights the significance of public transportation in promoting sustainability in green cities. It explores various factors including modal shift, mass transportation, integrated networks, transit-oriented development, emission reduction, active transportation infrastructure, and technological advancements. Public transportation plays a crucial role in encouraging people to switch from private vehicles to sustainable modes of transport, resulting in reduced carbon emissions and less traffic congestion. Mass transportation efficiently moves a large number of individuals in a single vehicle, leading to lower energy consumption and a smaller carbon footprint compared to individual cars. Integrated transportation networks offer seamless travel experiences and decrease reliance on private vehicles by incorporating buses, trains, ferries, and cycling infrastructure. Transit-oriented development reduces long commutes, lessens car dependency, and improves accessibility to public transportation and active transport. Public transportation systems, especially electric or hybrid buses and trains, contribute to the reduction of greenhouse gas emissions and the enhancement of air quality. Active transportation infrastructure, such as pedestrian pathways and bike lanes, encourages walking and cycling for short trips, resulting in reduced emissions and the promotion of healthier lifestyles. Technological advancements in public transportation, such as smart ticketing, real-time information, optimized routes, and electric vehicle charging, enhance user experiences, operational efficiency, and environmental impact reduction.

Keywords: Public transportation systems, Sustainable mobility, Modal shift, Transit-oriented development (TOD), Emission reduction

introduction

Sustainable mobility refers to the concept of providing efficient and convenient transportation options while minimizing negative environmental, social, and economic impacts. It aims to meet the mobility needs of individuals and communities in a way that reduces greenhouse gas

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emissions, air pollution, traffic congestion, and reliance on non-renewable energy sources. Sustainable mobility encompasses various modes of transportation, including public transit, walking, cycling, carpooling, and electric vehicles, as well as supporting infrastructure and policies[1].

One of the key components of sustainable mobility is the promotion of public transit systems. Efficient and accessible public transportation plays a vital role in reducing individual car usage and congestion on roads. Well-connected and reliable bus, train, and subway networks provide an affordable and eco-friendly alternative to private vehicles. Additionally, investing in the expansion and improvement of public transit infrastructure encourages more people to choose public transportation, leading to fewer cars on the road and a decrease in greenhouse gas emissions [2].

Another essential component of sustainable mobility is active transportation, which includes walking and cycling. Encouraging and facilitating these modes of transport helps reduce traffic congestion, improve air quality, and promote healthier lifestyles. Designing cities and communities with pedestrian-friendly infrastructure, such as sidewalks, bike lanes, and safe crossings, supports active transportation [3]. It also involves creating bike-sharing programs, promoting bike-friendly policies, and raising awareness about the benefits of walking and cycling for both individuals and the environment.

Furthermore, the adoption of electric vehicles (EVs) is a crucial component of sustainable mobility . EVs have the potential to significantly reduce greenhouse gas emissions and air pollution compared to traditional internal combustion engine vehicles. Transitioning to electric transportation requires the development of a robust charging infrastructure, incentives for EV adoption, and the integration of renewable energy sources into the power grid. By promoting the use of electric vehicles, sustainable mobility aims to mitigate the negative impacts of transportation on climate change and improve air quality in urban areas.

Traditional transportation systems, heavily reliant on fossil fuel-powered vehicles, pose several challenges that necessitate the adoption of sustainable mobility solutions. One significant challenge is the ever-increasing traffic congestion in urban areas. The rise in private car ownership has led to overcrowded roads, longer commuting times, and reduced overall efficiency of transportation networks. This congestion not only hampers productivity and economic growth but also contributes to increased carbon emissions and air pollution [4].

Another challenge is the dependence on non-renewable energy sources. Conventional vehicles rely on fossil fuels, such as gasoline and diesel, which are finite resources and contribute to greenhouse gas emissions when burned. This reliance on non-renewable energy exacerbates the issue of climate change and

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compromises long-term energy security. As the global demand for transportation continues to rise, finding sustainable alternatives becomes imperative [5].

Fossil fuel-powered vehicles have significant environmental impacts, primarily in terms of greenhouse gas emissions and air pollution. Carbon dioxide (CO2) emissions from the combustion of fossil fuels in vehicles contribute to global warming and climate change. These emissions are a major driver of the escalating environmental crisis and require urgent attention to mitigate their effects.

In addition to CO2 emissions, vehicles also release other harmful pollutants into the atmosphere. Nitrogen oxides (NOx), volatile organic compounds (VOCs), and particulate matter (PM) contribute to poor air quality and have adverse effects on human health [6]. These pollutants can lead to respiratory diseases, cardiovascular problems, and even premature deaths. The detrimental impact of vehicle emissions on air quality underscores the need for sustainable mobility solutions that reduce or eliminate these harmful emissions.

The rapid pace of urbanization has had profound effects on mobility patterns and poses challenges for sustainable transportation. As more people flock to cities in search of economic opportunities, urban areas face increased pressure on transportation infrastructure and services. The traditional car-centric model of mobility becomes unsustainable in densely populated cities, leading to congestion, reduced accessibility, and a decline in the quality of life for residents.

Moreover, urbanization often results in sprawling urban landscapes, characterized by long commuting distances and urban sprawl. This pattern of development increases the reliance on private vehicles, leading to higher energy consumption, greater emissions, and reduced mobility options for those without access to private cars [7]. It further exacerbates social inequities by limiting opportunities for disadvantaged populations who may face barriers to car ownership. To address the challenges posed by growing urbanization, sustainable mobility solutions are essential. These solutions prioritize efficient public transit systems, promote active transportation modes like walking and cycling, and facilitate the transition to electric vehicles [8].

discussion

Modal Shift

Public transportation plays a crucial role in promoting a modal shift from private vehicles to more sustainable modes of transport, including buses, trams, light rail, and subways. By providing convenient and accessible alternatives to driving, public transportation encourages individuals to opt for these greener options, thereby reducing the number of cars on the road. This shift towards sustainable modes of transport has numerous environmental benefits, most notably in the reduction of carbon emissions [9].

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Private vehicles are a significant contributor to greenhouse gas emissions, which are a major driver of climate change [10]. By choosing public transportation, individuals contribute to the mitigation of carbon emissions and help combat climate change. Buses, trams, and trains are capable of carrying a large number of passengers at once, thereby maximizing the use of fuel and reducing per capita emissions. Moreover, many public transportation systems are increasingly adopting electric or hybrid technologies, further reducing their environmental impact by minimizing reliance on fossil fuels [11].

Another advantage of public transportation is its ability to alleviate traffic congestion. With fewer cars on the road, the overall traffic flow improves, leading to shorter travel times and reduced delays. Congestion reduction benefits not only public transportation users but also private vehicle drivers, as they experience less gridlock and smoother traffic conditions. By providing efficient and reliable alternatives, public transportation helps optimize the use of existing road infrastructure and supports the overall mobility of a city or region [12].

Public transportation also promotes more sustainable urban development patterns. By prioritizing the development of transit-oriented communities, where residential and commercial areas are conveniently connected to public transportation hubs, cities can reduce the need for excessive car usage [13].

This approach fosters compact, walkable neighborhoods that are less reliant on private vehicles and encourage active transportation methods such as walking and cycling. In turn, this leads to improved air quality, healthier lifestyles, and reduced dependence on fossil fuels.

Furthermore, public transportation can enhance social equity and accessibility. By offering affordable and reliable transportation options, public transit ensures that individuals from all socio-economic backgrounds have access to essential services, education, employment opportunities, and recreational activities. It helps bridge the gap between urban centers and suburban or marginalized communities, providing equal access to vital resources and reducing transportation-related inequalities. Public transportation plays a vital role in encouraging a modal shift from private vehicles to sustainable modes of transport. By reducing the number of cars on the road, public transportation helps combat climate change by decreasing carbon emissions. It also alleviates traffic congestion, supports more sustainable urban development patterns, and enhances social equity and accessibility. Investing in robust public transportation systems is crucial for creating greener, more livable cities and fostering a sustainable future [14].

Mass Transportation

Public transportation plays a crucial role in facilitating mass transportation by efficiently moving a large number of people in a single vehicle. This

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mode of transport utilizes available infrastructure more effectively compared to individual cars, leading to significant reductions in energy consumption and carbon footprint. By consolidating passengers into buses, trams, trains, or other modes of public transit, emissions per passenger kilometer are significantly decreased [15].

When multiple individuals choose to travel together in a single public transportation vehicle, the energy required to transport each passenger is shared among them. This efficient use of energy results in a lower overall energy consumption compared to the same number of individuals traveling in separate cars [16]. Furthermore, public transportation systems are often designed to optimize routes and schedules, reducing unnecessary detours and ensuring a more streamlined flow of passengers, further improving energy efficiency [17].

In terms of carbon emissions, public transportation offers a more sustainable alternative to private vehicles. As the number of cars on the road decreases through the adoption of public transit, the overall carbon footprint is significantly reduced. Public transportation vehicles, such as buses and trains, have higher passenger capacities and are designed to maximize fuel efficiency. Additionally, advancements in technology have led to the introduction of cleaner and greener public transportation options, such as electric buses or trains powered by renewable energy sources, further decreasing the carbon emissions associated with mass transportation.

Public transportation also contributes to the reduction of traffic congestion, which in turn helps minimize energy consumption and carbon emissions. As more individuals choose to utilize public transit, the number of cars on the road decreases, resulting in improved traffic flow and reduced idling time. This not only leads to shorter travel times but also lowers the energy wasted in stop-and-go traffic situations. By efficiently managing the movement of large numbers of people, public transportation systems contribute to a more sustainable and environmentally friendly transportation network [18].

Moreover, the availability of reliable and accessible public transportation options encourages individuals to rely less on private vehicles, leading to a shift in travel behavior and a decrease in overall transportation-related energy consumption. Public transportation networks that cover a wide geographic area and provide convenient access to key destinations, such as residential areas, employment centers, and educational institutions, make it easier for individuals to choose public transit over individual car usage. This modal shift towards public transportation not only reduces energy consumption but also promotes a more sustainable and environmentally conscious lifestyle [19].

Public transportation facilitates mass transportation by efficiently moving a large number of people in a single vehicle. By maximizing the use of available infrastructure, public transit

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significantly reduces energy consumption and carbon emissions compared to individual cars. Through the consolidation of passengers, optimized routes, and advancements in technology, public transportation systems contribute to a more sustainable and environmentally friendly transportation network, helping to create greener cities and mitigate the impact of transportation on the environment [20].

Integrated Transportation Networks

Public transportation systems are designed to integrate multiple modes of transport, creating a comprehensive network that offers seamless travel options for commuters. By combining various modes such as buses, trains, ferries, and cycling infrastructure, these systems encourage individuals to utilize a mix of transportation options for their daily commutes. This integration plays a key role in reducing reliance on private cars and promoting the use of sustainable modes of transport [21].

The integration of different modes of public transportation allows individuals to plan their journeys more efficiently. Commuters can utilize buses or trains for longer distances, while switching to cycling or walking for shorter distances within their destination area. This multimodal approach offers flexibility and convenience, as people can choose the most suitable modes of transport based on factors such as distance, time constraints, and personal preferences. By providing interconnected options, public transportation systems facilitate a smoother and more efficient travel experience.

Furthermore, integrating various modes of transport enhances the overall accessibility of public transportation networks. By including cycling infrastructure, such as bike lanes or bike-sharing programs, in conjunction with buses or trains, individuals can easily combine cycling with other modes of transport. This promotes active transportation, reduces carbon emissions, and improves personal health and well-being [22]. The availability of ferries as a mode of transport in coastal areas or cities with rivers can also provide an alternative and scenic way to travel, further diversifying the transportation options available to commuters [23].

Integrated public transportation systems also contribute to reducing congestion and optimizing the use of existing infrastructure. By offering a range of interconnected options, individuals are encouraged to leave their cars at home and utilize sustainable modes of transport. This helps alleviate traffic congestion, particularly during peak hours, and reduces the need for extensive road expansions. By maximizing the capacity of existing infrastructure through multimodal integration, public transportation systems can effectively accommodate a larger number of passengers while minimizing the environmental impact associated with additional road construction [24].

In addition to reducing congestion and promoting sustainability, the integration of multiple modes of transport in public transportation

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systems improves overall transportation equity. By providing various options that cater to different needs and preferences, such as accommodating individuals with disabilities or those who prefer cycling or walking, these systems ensure that transportation services are accessible to a diverse range of people. This promotes social inclusion and ensures that everyone has equal opportunities to access education, employment, healthcare, and other essential services [25]. The integration of multiple modes of transport within public transportation systems encourages individuals to adopt a multimodal approach to their daily commutes. By offering seamless travel options and promoting the use of sustainable modes of transport, such as buses, trains, ferries, and cycling infrastructure, public transportation systems reduce reliance on private cars and contribute to a more sustainable and efficient transportation network [26]. This integration enhances accessibility, reduces congestion, optimizes existing infrastructure, and promotes transportation equity, making public transportation a viable and attractive choice for commuters [27].

Transit-Oriented Development (TOD)

Public transportation systems have the potential to shape urban development patterns through the implementation of transit-oriented development (TOD). TOD is a planning strategy that emphasizes the creation of dense, mixed-use developments centered around transit hubs. By designing communities that prioritize easy access to public transportation, TOD promotes walking, cycling, and reduced car dependency, leading to more sustainable urban lifestyles.

Transit-oriented development aims to create vibrant, livable neighborhoods where residents have convenient access to a variety of services, amenities, and transportation options. By locating residential, commercial, and recreational facilities in close proximity to transit stations, TOD encourages people to walk or cycle for their daily needs, reducing the reliance on private vehicles [28]. This compact and connected approach minimizes the need for long commutes and fosters a sense of community, as residents can easily access essential resources without traveling long distances [29].

One of the key benefits of transit-oriented development is its potential to reduce traffic congestion and associated environmental impacts. By providing residents with convenient access to public transportation, TOD discourages excessive car usage, especially for commuting purposes [30]. This helps to alleviate congestion on road networks, reducing the number of vehicles on the streets and mitigating traffic-related emissions [31]. The emphasis on sustainable transportation modes in TOD areas promotes a shift towards greener alternatives, resulting in improved air quality and reduced carbon footprint [32].

Moreover, transit-oriented development contributes to the efficient use of land and infrastructure. By concentrating development around transit hubs, TOD maximizes the utilization of existing public

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transportation infrastructure and encourages its expansion where necessary. This approach reduces the need for sprawling, car-dependent developments that require extensive road networks and increases the efficiency of public transportation systems. It also helps optimize the use of land by creating compact, mixed-use neighborhoods that minimize urban sprawl and preserve open spaces [33].

Transit-oriented development also supports economic growth and enhances the overall quality of life in urban areas. By promoting dense, mixed-use developments, TOD attracts businesses, stimulates local economies, and creates employment opportunities within walking distance of residential areas. This not only reduces commuting times and expenses for individuals but also enhances community connectivity and social interactions. Access to a variety of amenities, such as shops, restaurants, parks, and cultural facilities, within close proximity further enriches the urban experience and promotes a vibrant and sustainable urban lifestyle. Public transportation systems can shape urban development patterns through the implementation of transit-oriented development. By building dense, mixed-use communities around transit hubs, TOD encourages walking, cycling, and easy access to public transportation. This approach reduces the need for long commutes, minimizes car dependency, and supports a more sustainable urban lifestyle. Transit-oriented development contributes to the reduction of traffic congestion, optimizes land and infrastructure use, stimulates economic growth, and enhances the overall livability of cities [34]. By prioritizing sustainable transportation options and community connectivity, TOD creates more vibrant, accessible, and environmentally friendly urban environments [35].

Emission Reduction

Public transportation systems, especially those utilizing electric or hybrid buses and trains, play a critical role in reducing greenhouse gas emissions. These vehicles are designed to produce lower or zero tailpipe emissions, resulting in improved air quality and a smaller environmental footprint when compared to conventional internal combustion engine vehicles [36].

Electric buses and trains have gained prominence as sustainable alternatives to traditional fossil fuel-powered vehicles. By relying on electricity as their primary source of energy, these vehicles eliminate direct tailpipe emissions of greenhouse gases such as carbon dioxide (CO2), nitrogen oxides (NOx), and particulate matter. This reduction in emissions significantly contributes to improving air quality and mitigating the negative impacts of transportation on public health and the environment [37].

The adoption of electric or hybrid buses in public transportation systems offers numerous benefits. Electric buses produce zero tailpipe emissions and have a much smaller carbon footprint compared to diesel or gasoline-powered buses. Their use helps to reduce local air pollution,

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especially in densely populated urban areas where air quality is a major concern. Moreover, electric buses are often quieter and provide a smoother ride, enhancing the overall passenger experience and comfort [38].

Similarly, electric or hybrid trains are instrumental in reducing greenhouse gas emissions in the transportation sector. Trains powered by electricity produce zero direct emissions during operation, resulting in improved air quality along rail corridors and in surrounding communities [39]. By transitioning from diesel-powered trains to electric or hybrid alternatives, public transportation systems can significantly reduce their carbon footprint and contribute to a more sustainable and environmentally friendly mode of transport [40].

In addition to their direct environmental benefits, electric and hybrid buses and trains also help to drive the transition toward renewable energy sources. By integrating these vehicles into public transportation systems, there is an increased demand for clean energy to power them [41]. This, in turn, promotes the development and expansion of renewable energy infrastructure, such as wind and solar farms, to meet the growing electricity needs of the transportation sector. The integration of electric vehicles in public transportation thus creates a positive feedback loop, encouraging the generation and utilization of cleaner energy sources.

Furthermore, the deployment of electric or hybrid buses and trains sends a powerful message regarding the commitment to sustainability and the reduction of greenhouse gas emissions. It serves as a demonstration of the potential for electrification in the transportation sector and inspires further advancements in clean technology. By leading the way in adopting low or zero-emission vehicles, public transportation systems set an example for other industries and individuals to follow, promoting broader sustainable practices and fostering a greener future. Public transportation systems that utilize electric or hybrid buses and trains significantly contribute to the reduction of greenhouse gas emissions [42]. These vehicles produce lower or zero tailpipe emissions, leading to improved air quality and a smaller environmental footprint compared to conventional internal combustion engine vehicles. By adopting electric or hybrid alternatives, public transportation systems play a crucial role in mitigating climate change, improving local air quality, driving the transition to renewable energy sources, and inspiring sustainable practices in the transportation sector and beyond [43]

Infrastructure for Active Transportation

Public transportation systems go beyond offering traditional modes of transport by providing infrastructure and facilities that promote active transportation, such as pedestrian pathways, bike lanes, and bike-sharing programs. This integration of active modes of transportation encourages individuals to consider walking and cycling as viable alternatives for short-distance trips, resulting in reduced

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emissions and the promotion of healthier lifestyles.

By incorporating pedestrian pathways into public transportation networks, cities and communities create safe and convenient walking routes for pedestrians. These pathways are designed to connect transit stations, residential areas, and key destinations, encouraging individuals to choose walking as a sustainable mode of transportation. Promoting walking not only reduces greenhouse gas emissions but also improves public health by providing opportunities for physical activity and reducing sedentary behaviors [44].

Public transportation systems also incorporate dedicated bike lanes and infrastructure, recognizing cycling as an important component of sustainable transportation [45]. Bike lanes provide cyclists with a designated space to ride safely, separate from vehicle traffic. This infrastructure encourages individuals to choose cycling for short-distance trips, such as commuting to work or running errands, reducing the reliance on private cars and decreasing emissions associated with motorized transport [46].

Furthermore, public transportation systems often implement bike-sharing programs, making bicycles easily accessible to commuters. Bike-sharing initiatives allow individuals to rent bicycles from designated stations, providing a flexible and convenient option for short-distance travel [47]. By integrating bike-sharing programs with public transportation, individuals can combine cycling with bus or train journeys, promoting a multimodal approach that further reduces emissions and increases transportation options.

The integration of infrastructure and facilities for active modes of transportation not only reduces emissions but also has a positive impact on the overall livability and sustainability of urban areas. By promoting walking and cycling, public transportation systems contribute to the development of more walkable and bike-friendly communities. This, in turn, leads to a range of benefits, including reduced traffic congestion, improved air quality, enhanced public health, and increased social interaction among community members [48].

Moreover, the provision of infrastructure for active transportation supports the concept of complete streets, where roadways are designed to accommodate all users, including pedestrians, cyclists, and public transportation users. Complete streets prioritize safety and accessibility, creating a more inclusive transportation system that caters to the diverse needs of individuals. By considering the needs of pedestrians and cyclists alongside public transportation, cities and communities can create well-integrated and sustainable transportation networks [49].

Public transportation systems play a crucial role in promoting active transportation by integrating infrastructure and facilities for walking, cycling, and bike-sharing. By encouraging individuals to choose walking and cycling for short-distance trips, public transportation systems

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contribute to the reduction of emissions and promote healthier and more sustainable lifestyles. The integration of active modes of transportation enhances the overall livability of urban areas, improves air quality, and supports the development of inclusive and well-connected transportation networks [50].

Technological Advancements

Modern public transportation systems are embracing technological advancements to enhance efficiency and sustainability. These innovations encompass a range of features, including smart ticketing systems, real-time passenger information, optimized route planning, and electric vehicle charging infrastructure [51]. By incorporating these technologies, public transportation systems aim to improve the overall user experience, increase operational efficiency, and reduce environmental impacts [52].

Smart ticketing systems have revolutionized the way passengers access and pay for public transportation services. Instead of traditional paper tickets, passengers can use smart cards, mobile apps, or contactless payment methods to easily and conveniently purchase and validate their fares. These systems streamline the ticketing process, reducing boarding times and minimizing the need for physical infrastructure such as ticket booths or turnstiles. By simplifying fare payment and reducing friction, smart ticketing systems improve the overall user experience and encourage the use of public transportation.

Real-time passenger information systems provide commuters with up-to-date information about routes, schedules, and service disruptions. This information is accessible through digital displays at transit stops, mobile apps, or online platforms. By keeping passengers informed about estimated arrival times, delays, and alternative routes, real-time passenger information systems enhance convenience and enable better trip planning. This leads to reduced waiting times, improved reliability, and a more seamless travel experience for passengers [53].

Optimized route planning utilizes data analytics and algorithms to determine the most efficient routes and schedules for public transportation vehicles. By analyzing factors such as passenger demand, traffic patterns, and travel times, transportation authorities can optimize the deployment of buses, trains, or trams. This helps reduce empty or underutilized trips, improves service frequency, and minimizes operational costs [54]. Optimized route planning also contributes to reduced congestion and emissions by ensuring that public transportation services are strategically aligned with passenger needs [55].

The integration of electric vehicle charging infrastructure is another key innovation in modern public transportation systems [56]. Electric buses and trains are becoming increasingly common, as they offer lower emissions and reduced noise pollution compared to their fossil fuel counterparts. Public transportation systems are incorporating charging

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stations and depots to support the electrification of their fleets [57]. This infrastructure enables the efficient charging and maintenance of electric vehicles, encouraging the adoption of cleaner transportation options and reducing the environmental impact of public transportation [58].

In addition to enhancing the user experience and operational efficiency, these technological advancements in public transportation systems yield environmental benefits. By incorporating real-time passenger information and optimized route planning, public transportation services become more reliable and efficient, leading to reduced congestion and lower emissions. The adoption of electric vehicle charging infrastructure supports the transition to greener transportation options, contributing to improved air quality and reduced carbon footprint [59].

Modern public transportation systems are embracing technological advancements to enhance efficiency and sustainability. Smart ticketing systems, real-time passenger information, optimized route planning, and electric vehicle charging infrastructure are revolutionizing the way people access and utilize public transportation services. These innovations improve the overall user experience, increase operational efficiency, and reduce environmental impacts by streamlining ticketing processes, providing timely information to passengers, optimizing service routes, and supporting the adoption of electric vehicles. By integrating these technologies, public transportation systems are poised to offer greener, more convenient, and more sustainable mobility options for communities.

conclusion

Public transportation systems have a significant impact on promoting sustainable and efficient modes of transport. By encouraging a shift from private vehicles to buses, trams, light rail, and subways, public transportation reduces the number of cars on the road, leading to lower carbon emissions and decreased traffic congestion. These systems facilitate mass transportation by efficiently utilizing infrastructure, resulting in reduced energy consumption and a smaller carbon footprint compared to individual cars [60]. The integration of multiple modes of transport, such as buses, trains, ferries, and cycling infrastructure, promotes seamless travel and encourages people to adopt a combination of modes for their daily commutes, further reducing car dependency and promoting sustainable options [61].

Public transportation systems can also shape urban development patterns through transit-oriented development (TOD). TOD focuses on building dense, mixed-use developments around transit hubs, minimizing the need for long commutes, reducing car dependency, and supporting a more sustainable urban lifestyle. Furthermore, public transportation systems contribute to significant reductions in greenhouse gas emissions through the adoption of electric or hybrid buses and trains. These vehicles produce lower or zero

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tailpipe emissions, improving air quality and reducing the environmental footprint compared to conventional internal combustion engine vehicles [62], [63].

Public transportation systems are incorporating technological advancements to enhance efficiency and sustainability. Smart ticketing systems, real-time passenger information, optimized route planning, and electric vehicle charging infrastructure improve the overall user experience, increase operational efficiency, and reduce environmental impacts. These innovations streamline fare payment, provide timely information to passengers, optimize service routes, and support the transition to cleaner transportation options.

Public transportation systems play a vital role in promoting sustainable and efficient transportation. They encourage a modal shift from private vehicles, integrate multiple modes of transport, shape urban development patterns through TOD, and reduce greenhouse gas emissions through the adoption of electric and hybrid vehicles. Additionally, these systems embrace technological advancements to enhance efficiency and sustainability, ultimately improving the overall user experience while reducing environmental impacts.

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