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Implementation of Green Infrastructure in Sustainable Transportation in Supporting Urban Mobility: A Literature Review †

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Abstract: This research explores the implementation of green infrastructure in supporting sustainable transportation systems to improve urban mobility in big cities. The background of this research is based on the need to reduce the environmental impact of the transportation sector, which contributes significantly to carbon emissions and air pollution, especially in dense urban areas. Green infrastructure, such as bicycle lanes, pedestrian-friendly sidewalks, and green open spaces, has been proven to have a positive impact in reducing pollution and improving people's quality of life. This research aims to analyze how the implementation of green infrastructure can support sustainable transportation and improve the quality of mobility in urban areas, with a focus on case studies of cities such as Copenhagen, Amsterdam, and Singapore, and large cities in Indonesia, including Bandung. Using the literature review method, this research analyzes various reports, journal articles, and statistical data from previous studies regarding the impact of green infrastructure in reducing emissions and promoting environmentally friendly transportation. The results of the discussion show that the implementation of green infrastructure provides various benefits, such as reducing carbon emissions, improving public health, and creating a more comfortable urban environment. Large cities in Europe and Asia have been pioneers in implementing this system, while in Indonesia, cities such as Jakarta, Surabaya, and Bandung have begun to adopt similar concepts with some success, although they still face various challenges. In conclusion, green infrastructure is an important element in sustainable city development that not only improves mobility but also the overall quality of life of society.

Keywords: green infrastructure; sustainable transportation; urban mobility; environmental impact

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1. Introduction

The development of large cities in the world and Indonesia shows complex dynamics, including technological progress, economic growth, and urbanization challenges [1]. In the world, big cities such as New York, Tokyo, and London are growing rapidly along with their increasing population and role as global economic centers [2]. This development is supported by modern infrastructure, the application of advanced technology in transportation, energy, and public service systems, as well as urban planning aimed at improving the quality of life of citizens. These cities leverage innovations such as electric transportation, energy-efficient buildings, and green infrastructure to reduce environmental impact while supporting sustainable urban mobility [3].

In Europe, cities such as Copenhagen and Amsterdam are leading the way in implementing environmentally friendly transport, with a focus on cycling infrastructure, efficient public transport, and reduced carbon emissions [4]. Copenhagen, for example, has set an ambitious target to become a carbon-free city, placing cycling infrastructure as a priority. More than 60% of the population uses bicycles as the main mode of commuting every day. This city also integrates safe and comfortable bicycle lanes, complete with parking facilities and support services, so that cycling becomes the main choice compared to private vehicles. In Amsterdam, a similar approach is being implemented with a focus on cycling transport and the development of an integrated public transport network. Amsterdam is known as the "bike city" because the majority of its residents rely on bicycles for daily mobility. In addition, Amsterdam has also developed a public transportation system such as trams, trolleybuses, and trains, which are well connected to reduce dependence on private cars. The city is working to implement low-emission technologies, including electric vehicle charging stations spread throughout the city, to support the transition to cleaner energy.

Meanwhile, in Asia, large cities such as Singapore and Hong Kong face limited land but overcome this by developing vertical infrastructure, efficient management of green space, and sophisticated mass transportation systems [5]. This sustainable approach also involves implementing the smart city concept, where information and communication technology is utilized to optimize the management of public resources and services. Singapore, for example, has developed an integrated and highly efficient mass transportation system, including the MRT (Mass Rapid Transit), which covers almost the entire city area. In addition, the Singapore government implements a policy of limiting the number of private vehicles through a quota system and high taxes. This policy, combined with reliable public transportation facilities, makes Singapore one of the cities with the lowest levels of air pollution in Asia. Singapore is also promoting the use of electric vehicles and developing charging infrastructure in various locations to support the transition to cleaner energy. In Hong Kong, the public transportation system is also highly integrated, with the MTR (Mass Transit Railway) as the backbone of urban mobility. The MTR covers a wide area, from the city center to residential areas, thereby reducing dependence on private vehicles. Hong Kong also implements policies that encourage vertical development and optimize land use, which allows green space to be maintained even though the city has limited land. In addition, the Hong Kong government is actively encouraging the use of electric buses and environmentally friendly technologies in the public transportation system to reduce emissions and improve air quality.

In Indonesia, large cities such as Jakarta, Surabaya, and Bandung are also experiencing rapid growth, which is triggered by an increase in population and economic activity [6]. Jakarta, for example, has transformed into a business and government center, attracting migration from other regions. However, this development presents various challenges such as traffic jams, air pollution, and flooding. To overcome this problem, several cities in Indonesia are starting to focus on developing more environmentally friendly infrastructure, such as mass transportation systems (MRT, LRT, BRT), green spaces, and integrated drainage systems to reduce the risk of flooding. Bandung, for example, has initiated smart city initiatives and various green infrastructure programs to support a healthier and more sustainable environment.

Despite these ongoing efforts, many large cities in Indonesia still face major challenges in implementing sustainable urban planning and effective integration of technology [7]. Green infrastructure and environmentally friendly transportation still require policy support, funding, and wider community participation [8]. In the future, the development of large cities in the world and Indonesia will likely increasingly lead to development

that is in line with sustainability principles, with a focus on quality of life, environmental sustainability, and increasing the efficiency of urbanization [9].

Based on this background, it can be concluded that implementing green infrastructure in a sustainable transportation system is an urgent need for large cities throughout the world, including in Indonesia. The increasingly complex challenges of urbanization, such as increasing the number of vehicles, traffic congestion, air pollution, and climate change, demand innovative solutions that are able to integrate environmental sustainability with efficient mobility [10].

Green infrastructure has been proven to be effective in reducing negative environmental impacts caused by urbanization and urban transportation activities [11]. By providing green open space, vegetation, and environmentally friendly drainage systems, while supporting the transition to cleaner and healthier modes of transportation, it is able to reduce air pollution, reduce urban temperatures, and absorb carbon emissions [12]. The presence of vegetation helps improve air quality by absorbing pollutants and producing oxygen, thereby creating a healthier environment for city residents. In addition, green infrastructure plays a role in managing rainwater runoff through natural drainage systems such as bioswales, rain gardens, and permeable pavement [13]. This system helps prevent flooding by allowing rainwater to be absorbed into the ground more effectively, ultimately reducing the load on conventional drainage systems. This is very relevant for large cities that often face flooding problems due to drainage that is unable to accommodate high rainfall.

In the transportation sector, green infrastructure supports reduced emissions and improved quality of life through comfortable pedestrian and bicycle paths, as well as green spaces along transportation routes [14]. These routes encourage people to switch from motorized vehicles to more environmentally friendly modes of transportation, such as walking and cycling. The use of green spaces as buffers along roads can also reduce traffic noise and provide space for biodiversity, thereby increasing the attractiveness of cities as sustainable places to live [15].

In Indonesia, efforts to adopt green infrastructure in sustainable transportation are growing, although they still face various challenges in terms of policy, financing, and community participation [16]. Several large cities in Indonesia, such as Jakarta, Surabaya, and Bandung, have begun to integrate green infrastructure elements in transportation planning and urban spatial planning to create a healthier and more sustainable environment [17].

In Jakarta, for example, the implementation of green lanes along main roads, the construction of pedestrian-friendly sidewalks, and the development of bicycle lanes demonstrate a commitment to improving the environment and reducing dependence on motorized vehicles [18]. Pavement revitalization programs and tree planting in various areas also help create shadier and more attractive public spaces for the community. Apart from that, public transportation systems such as the MRT, LRT, and TransJakarta are now trying to be more integrated with green lanes so that people can access public transportation by walking or cycling through beautiful environments.

Surabaya is also an example of a city that is proactive in developing green infrastructure [19]. This city is known for its widespread city parks, green lanes, and comfortable pedestrian facilities. Surabaya continues to encourage increasing green open spaces and strengthening the role of local communities in protecting the environment through reforestation programs and sustainable waste management. This step not only improves the air quality and esthetics of the city but also has a positive impact on public health and tourist attraction.

In Bandung, initiatives to create an environmentally friendly environment include building bicycle lanes, reorganizing public open spaces, and adding sustainable public transportation facilities [20]. The Bandung city government is also focusing on the Bandung

Green and Clean program, which encourages the community to be actively involved in keeping the environment clean and reducing emissions. Initiatives such as thematic parks and green belts along public areas serve not only as greenery but also as places for social interaction and sports activities.

Sustainable transportation systems have a close relationship with green infrastructure because both support each other in creating a more environmentally friendly urban environment and improving people's quality of life [21]. Green infrastructure, such as bicycle paths, parks, and green open spaces, serves to strengthen transportation networks by providing safe and comfortable alternatives for pedestrians and cyclists. This encourages people to switch from motorized vehicles to more environmentally friendly modes of transportation, thereby reducing greenhouse gas emissions and air pollution. In addition, the presence of vegetation and green open spaces along transportation routes helps manage rainwater runoff, reduces the risk of flooding, and creates a cooler and more comfortable microclimate in urban areas. By integrating green infrastructure into transportation planning, cities can achieve sustainable mobility goals while maintaining ecosystem balance and improving people's quality of life [22]. This approach not only addresses the challenges of urbanization but also encourages sustainable economic growth and promotes social welfare [23].

The research gap between previous studies and this research lies in the differences in regional focus, infrastructure approach, and research methodology used. Previous research entitled "Sustainable Transportation in Southeast Asian Countries: Implementation of Green Transport" focused more on the implementation of environmentally friendly transportation in Southeast Asian countries, emphasizing specific efforts in each country to develop sustainable transportation modes, such as the use of vehicles, electricity, improving public transport, and developing bicycle lanes and pedestrian zones. This approach seeks to address regional challenges in Southeast Asia, including diverse socio-economic conditions, rapid levels of urbanization, and different policies in each country. On the other hand, this research, entitled "Implementation of Green Infrastructure in Sustainable Transportation in Supporting Urban Mobility: Literature Review," adopts a global perspective through a literature review that focuses on green infrastructure in supporting urban mobility. Rather than discussing transport modes, this research analyzes how green infrastructure, such as green lanes, green roofs, and permeable pavements, can support sustainable transport systems on a more fundamental basis in various urban contexts.

In addition, previous research tends to use case studies or direct analysis of policy implementation in the Southeast Asia region, while this research combines results from various studies to provide a comprehensive picture of green infrastructure in sustainable transportation. Thus, the gap in this research lies in the differences in approach; previous research provides direct insights that are highly relevant to the local context of Southeast Asia, while this research is more general and can be widely applied to a variety of urban situations. It is hoped that this research can fill this gap by providing a more comprehensive perspective on how green infrastructure can support sustainable transportation in big cities, as well as presenting concepts that can be adapted into transportation policies in Southeast Asia.

By reviewing related literature, this study aims to explore and analyze various aspects related to the implementation of green infrastructure in a sustainable transportation system, as well as its impact on urban mobility and the environment in Indonesia. This literature review will include a study of various models and best practices that have been implemented in other cities around the world, including experiences in Europe and Asia, which can be used as a reference for planning and developing green infrastructure in large Indonesian cities.

Through analysis of various previous studies, this study will identify key factors that influence the successful implementation of green infrastructure, such as government policy, community participation, and support from the private sector. Apart from that, this research will also discuss the challenges faced in implementing green infrastructure, including issues of funding, regulations, and space limitations, which often become obstacles in the development of sustainable transportation.

This study is expected to provide relevant recommendations for policymakers, city planners, and other stakeholders in creating effective strategies for integrating green infrastructure into the transportation system. Thus, it is hoped that the implementation of green infrastructure can contribute to achieving sustainable development goals, improve people's quality of life, and create a cleaner and healthier urban environment in Indonesia.

2. Literature Review

2.1. Green Infrastructure Concept

The concept of green infrastructure can have different definitions, depending on the context in which it is used and by whom the idea is used. Green infrastructure originally came from conservation-related disciplines to describe multifunctional green spaces that support sustainable development [24]. In this definition, natural spaces are integrated with human-made systems to create synergy, such as floodplains, green roofs, and rainwater harvesting systems.

Green infrastructure is a concept, effort, or approach to maintaining a sustainable environment through arranging green open spaces and maintaining natural processes that occur in nature, such as the rainwater cycle, soil conditions, etc. [25]. However, in recent years, the term green infrastructure has evolved to mean man-made infrastructure that maintains or increases the productivity of natural resources, including reducing emissions intensity [26].

Although environmental function is often the main focus of the green infrastructure concept, social benefits are also a very important criterion [27]. Green infrastructure also contributes to community welfare by increasing connectivity between urban and rural areas, developing local distinctiveness, social inclusion, and a sense of togetherness [28].

The important point of implementing green infrastructure is maintaining the continuity of the natural water resource cycle, considering that using clean water, especially in urban environments, has increased along with population growth and city development. Reducing pollution is also part of efforts to achieve a healthy and clean environment for society. Community involvement is also vital in achieving this green infrastructure development [29].

Green infrastructure can be interpreted as a land planning and management concept that emphasizes using natural elements to improve environmental quality, support ecological sustainability, and improve human welfare. In an urban context, green infrastructure refers to a network of green spaces designed and managed to provide a community with ecological, social, and economic benefits.

2.2. Green Infrastructure in Sustainable Transportation

Green infrastructure in sustainable transportation is an approach that integrates natural elements and environmental engineering into the planning and management of transportation systems to increase efficiency, reduce negative impacts on the environment, and improve the quality of life in urban areas [30]. In the midst of modern challenges facing big cities, such as rapid population growth, air pollution, traffic jams, and climate change, green infrastructure is emerging as an innovative and holistic solution [31]. This concept

not only focuses on physical development but also on developing green spaces with dual functions for recreation, water absorption, heat reduction, and support for biodiversity [32].

Implementing green infrastructure in sustainable transportation includes various elements and strategies designed to promote environmentally friendly modes of transportation. One key element is the development of well-connected greenways and cycleways throughout the city [33]. These greenways provide safe and comfortable spaces for pedestrians and cyclists and are surrounded by vegetation that helps absorb air pollution, provide shade, and create ecological corridors that support biodiversity. By encouraging bicycle use and walking, these greenways help reduce dependence on motorized vehicles, greenhouse gas emissions, and air pollution levels in large cities.

Apart from that, green infrastructure also includes the development of vegetated sidewalks and green open spaces integrated with the urban transportation network [34]. Sidewalks planted with trees or other plants beautify the city landscape and reduce surface temperatures, manage rainwater runoff, and provide psychological benefits for city residents. These spaces play an essential role in reducing the urban heat island effect, where metropolitan areas tend to be hotter than their surroundings due to the concentration of buildings and hard surfaces that absorb and store heat. Increasing the amount of green open space allows cities to create more comfortable and attractive environments while supporting more sustainable transport patterns.

Implementing green infrastructure also involves innovation in rainwater and wastewater management [35]. Infrastructure such as permeable pavements and rain gardens around roads and parking areas helps reduce rainwater runoff, increase water absorption, and reduce the risk of flooding. This is especially important in dense urban areas, where space for conventional drainage infrastructure may be limited. By reducing the amount of rainwater that a city's drainage system must manage, this strategy not only helps reduce the risk of flooding but also reduces infrastructure maintenance costs [36].

In addition, green infrastructure can also support transit-oriented development (TOD), which integrates public transportation with green space and environmentally friendly pedestrian facilities [37]. TOD focuses on developing dense, mixed-use areas around public transport stations, emphasizing accessibility and connectivity for pedestrians and cyclists [38]. By creating an environment that supports non-motorized mobility and providing easy access to public transportation, TOD helps reduce the need for private vehicles, reduces emissions, and improves the quality of life in cities [39].

Besides that, green infrastructure also plays a role in supporting the use of environmentally friendly vehicles, such as electric ones. Providing charging stations integrated with renewable energy sources, such as solar panels or wind turbines, helps reduce dependence on fossil fuels and the greenhouse gas emissions produced by the transportation sector. Electric vehicles can also be encouraged by providing incentives for their use in urban areas, such as better parking access or special lanes for environmentally friendly cars.

Green infrastructure in sustainable transportation offers an integrated approach that combines ecological, economic, and social benefits [40]. By reducing the environmental impact of transportation systems, improving air and water quality, and creating better public spaces, green infrastructure helps build healthier, more resilient, and sustainable cities. Implementing these strategies requires significant initial investment and provides long-term returns in the form of reduced maintenance costs, improved public health, and increased city attractiveness for residents and visitors. Cities worldwide can move towards a greener, cleaner, and more sustainable future through green infrastructure.

2.3. Benefits of Green Infrastructure in Urban Mobility

Green infrastructure provides various significant benefits for urban mobility by integrating natural elements and green infrastructure into the transportation system, creating a more environmentally friendly, efficient, and comfortable city for its residents [41]. One of the main benefits of green infrastructure in urban mobility is improving air quality and reducing pollution [42]. By reducing dependence on motorized vehicles and increasing accessibility for pedestrians and cyclists through green lanes and vegetated sidewalks, green infrastructure directly reduces greenhouse gas emissions and other air pollutants [43]. This is especially important in large cities, where air pollution is often a significant health problem affecting residents' quality of life. Green spaces such as urban parks, rain gardens, and green roofs also help filter pollutants from the air, reduce surface temperatures, and combat the urban heat island effect, all of which contribute to a healthier and more comfortable urban environment [44].

In addition, green infrastructure is important in improving transportation connectivity and accessibility in cities [45]. Green infrastructure facilitates smoother and more sustainable mobility by creating a network of green lanes that connect various parts of the city, including residential, commercial, and recreational areas [46]. These greenways provide safe and enjoyable routes for pedestrians and cyclists and improve connectivity with public transport networks, such as buses and trains. This encourages more people to switch from private vehicles to more sustainable modes of transport, reducing traffic congestion and increasing the efficiency of the transport system as a whole [47]. In addition, green spaces integrated with transportation facilities can also function as rest areas and meeting points, which support social activities and strengthen community ties [48].

Another benefit of green infrastructure in urban mobility is its ability to reduce the risk of flooding and improve stormwater management [49]. By incorporating elements such as porous pavement, rain gardens, and bioswales into street and sidewalk designs, green infrastructure helps increase rainwater absorption, reduce surface runoff, and prevent water from pooling on streets [50]. This is especially important in urban areas that frequently experience flooding due to poor drainage or prolonged heavy rain [43]. By managing stormwater effectively, green infrastructure protects transportation infrastructure from damage, reduces maintenance costs, and extends the life of roads and sidewalks [51]. In addition, this strategy also helps maintain groundwater quality and supports a healthy urban ecosystem.

Green infrastructure also brings significant economic benefits by increasing property values and city attractiveness. The presence of green spaces and environmentally friendly transportation facilities can improve an area's visual appeal and environmental quality, which in turn can increase property values and attract investment [52]. In addition, by reducing dependence on private vehicles and encouraging public and non-motorized transportation, green infrastructure also helps reduce fuel and vehicle maintenance expenditure, providing direct economic benefits for residents [44]. At the city level, investment in green infrastructure is often more cost-effective in the long term than conventional infrastructure development, as it can reduce road maintenance costs, reduce the need for expensive drainage systems, and improve community welfare [53].

Overall, green infrastructure provides various interrelated benefits for urban mobility, such as improving air quality and reducing pollution, increasing connectivity and accessibility, and better rainwater management to significant economic benefits. By integrating natural elements into transportation planning and management, green infrastructure helps create more environmentally friendly, efficient, and sustainable cities, which meet their citizens' mobility needs and improve their quality of life and overall well-being. Thus,

implementing green infrastructure in urban mobility is an essential step towards building greener and more resilient cities in the future.

2.4. Challenges in Implementing Green Infrastructure

Implementing green infrastructure in urban mobility faces various challenges and requires a holistic and collaborative approach to overcome them. One of the biggest challenges is the lack of understanding and awareness of the long-term benefits of green infrastructure among decision-makers and the general public [54]. Many parties still see investment in green infrastructure as an additional cost compared to conventional infrastructure [55]. Additionally, technical challenges and space limitations are significant obstacles, especially in large cities that are already congested and have limited space to develop new green infrastructure. Implementing elements such as greenways, vegetated sidewalks, and stormwater management systems often requires space not always available in dense urban environments.

In addition, coordination between the various parties involved, including local governments, landowners, developers, and communities, is often challenging. Each party has different interests and priorities, so achieving agreement and effective collaboration often requires significant time and effort. Regulatory aspects can also be a barrier, especially if no policies support the implementation of green infrastructure or if existing regulations do not accommodate the integration of green infrastructure in city planning. Lastly, limited funds and resources are a challenge that is no less important.

Although green infrastructure offers many long-term benefits, the initial costs of building and developing green infrastructure are often considered high, especially in the context of limited government budgets [56]. This is exacerbated by the lack of access to adequate funding or financial incentives to encourage the adoption of green infrastructure by the private sector and local communities. All of these challenges demand innovative approaches, comprehensive education, and strong partnerships to ensure that the benefits of green infrastructure can be optimized for future cities' sustainability.

3. Materials and Method

This study employs a literature review methodology to investigate the application of green infrastructure in supporting sustainable urban mobility. The materials used for this research include various secondary sources such as scholarly articles, government reports, statistical data, and case studies from cities with successful green infrastructure implementation, including Copenhagen, Amsterdam, Singapore, Jakarta, Surabaya, and Bandung. These sources provide a comprehensive overview of the environmental impact, benefits, and challenges of green infrastructure in the context of urban transportation.

The research method begins with collecting relevant secondary data from reputable sources, focusing on publications that discuss green infrastructure and sustainable transportation policies. The collected data are then analyzed to identify key trends, impacts, and barriers in the implementation of green infrastructure that supports urban mobility. Additionally, the research compares data across cities to understand the factors contributing to the success or challenges faced by different locations.

The analysis aims to draw insights into the key factors of green infrastructure implementation in reducing emissions, improving air quality, and fostering eco-friendly mobility. This method provides a broad perspective on the role of green infrastructure in sustainable urban development, offering valuable insights that can guide other cities, particularly in Indonesia, in developing sustainable transportation systems.

4. Discussion

The results of research and discussions regarding the application of green infrastructure in urban transportation often show significant positive impacts on various aspects of mobility and the environment, and essential novelties in this field are identified [57]. Findings from research generally reveal that green infrastructure, including green lanes, vegetated sidewalks, stormwater management systems, and other green elements, provides broad benefits in urban transportation [58]. One of the main results is reduced pollution and improved air quality [59].

To reduce pollution levels and improve air quality, a number of strategic steps need to be taken. First, reducing emissions from motorized vehicles by adopting clean transportation technologies such as electric and hybrid vehicles is an important step. In addition, developing and improving efficient and environmentally friendly public transportation can reduce dependence on private cars, thereby reducing exhaust emissions. Policies such as limiting motorized vehicles in city centers, imposing emissions taxes, and providing incentives for environmentally friendly cars can also help in this effort. Second, promoting non-motorized mobility, such as cycling and walking, must be encouraged by developing supporting infrastructure, such as safe bicycle paths and decent sidewalks. This reduces emissions from transportation and improves people's health by encouraging a more active lifestyle. Third, controlling pollution from the industrial sector is also very important. This can be achieved through the imposition of stricter emissions standards, the adoption of cleaner technologies, and tighter monitoring of industry compliance with environmental regulations. Industries that use fossil fuels as the primary energy source must be encouraged to switch to cleaner and more sustainable renewable energy. Research shows that green spaces integrated with transportation systems reduce motor vehicle emissions and filter atmospheric pollutants, thereby improving public health and reducing pollution-related respiratory illnesses.

Furthermore, research often identifies that implementing green infrastructure contributes to improving the accessibility and efficiency of transportation systems [60]. Well-designed bicycle lanes and greenways enable safer and more comfortable non-motorized mobility and reduce dependence on private vehicles [61]. This reduces traffic congestion and improves journey times for all road users. Research also shows that green infrastructure can improve connectivity between various modes of transportation, such as integrating bicycle lanes with public transportation stations, which supports wider use of public transportation and reduces the need for private vehicles.

The results of discussions and discussions regarding the application of green infrastructure in urban transportation become stronger when supported by statistical data that shows its positive impact [62]. For example, in Copenhagen, around 62% of daily trips are made by bicycle, thanks to more than 400 km of safe and comfortable cycle paths [63]. These data reflect the real impact of green infrastructure in encouraging a shift in transportation modes, so that the city has succeeded in reducing CO_2 emissions by up to 40,000 tons every year. This makes a major contribution to the C40 Cities targets, a global initiative aimed at reducing carbon emissions in cities, of which Copenhagen is one of the pioneers.

In Amsterdam, the number of bicycles is recorded to exceed the population, with more than 800,000 bicycles used every day [64]. This is supported by more than 500 km of bicycle paths and integrated parking facilities, enabling 50% of all trips within the city to be made by bicycle. The positive impact can be seen from reducing greenhouse gas emissions and improving air quality, where air pollution levels in Amsterdam are much lower than in other European cities that depend on motorized vehicles.

In Singapore, the government has succeeded in increasing green space from only around 36% in 1986 to almost 47% of the city area in 2021 [65]. This city is implementing

the Park Connector Network (PCN) concept, which connects city parks with greenways along more than 300 km, making it easier for people to walk or cycle. As a result, more than 10% of Singapore's population now regularly uses non-motorized modes of transportation, and PM2.5 air pollution levels in the city remain low, namely below 20 $\mu g/m^3$, in line with standards recommended by WHO.

In Indonesia, big cities are starting to show commitment to green infrastructure even though the scale is still limited. Jakarta, for example, in 2022 will record a 7% decrease in the number of private vehicles in the city center area after adding bicycle lanes and improving sidewalks along main roads [66]. In Surabaya, the addition of 15 new city parks and 20 km of pedestrian paths in the city center has significantly improved the air quality index, making Surabaya the best air quality in Indonesia for the large city category [67]. Meanwhile, Bandung also recorded an increase in the number of bicycle lane users of up to 30% after revitalizing and adding bicycle facilities in public areas.

These statistics show that green infrastructure has a real impact in supporting sustainable transportation and improving people's quality of life [68]. Apart from reducing emissions and air pollution, green infrastructure also encourages community participation in using more environmentally friendly modes of transportation, improves health, and adds to the esthetics of the city. The implementation of green infrastructure in large cities, if equipped with continuous monitoring and evaluation data, can become a pilot model for further expansion in various other regions.

Overall, the research results and discussions show that green infrastructure has great potential to improve environmental quality and mobility in urban areas. The novelties discovered through this research provide new insights into innovative ways to integrate green elements into transport systems and show how a more holistic and participatory approach can address urban challenges more effectively.

5. Conclusions

This study explores the essential aspects of green infrastructure implementation within urban transportation, highlighting its impact on sustainable mobility, emission reductions, air quality improvement, and public health. Through case studies from cities like Copenhagen, Amsterdam, Singapore, Jakarta, Surabaya, and Bandung, this research illustrates how green infrastructure elements, such as bicycle lanes, pedestrian-friendly walkways, and green public spaces, contribute to a more eco-friendly urban environment. These aspects underscore the potential of green infrastructure in transforming urban transportation systems to be more sustainable and resilient.

The analysis identifies critical factors influencing the successful implementation of green infrastructure in urban settings. These include robust government commitment, adequate funding, comprehensive urban planning, and community involvement. Cities with effective green infrastructure typically have supportive policies, cross-sector collaboration, and strong public engagement, which drive the adoption and utilization of sustainable transportation options. In cities facing challenges, factors such as limited land availability, high dependency on private vehicles, and financial constraints often hinder progress.

Based on the findings, this study provides several recommendations for policymakers aiming to promote sustainable urban transportation through green infrastructure. These include developing integrated green infrastructure plans within urban areas, securing dedicated funding for sustainable transport initiatives, enhancing community outreach to increase public awareness and participation, and setting clear regulatory frameworks to support the shift towards green mobility. By addressing these factors, policymakers can foster a more sustainable, accessible, and environmentally friendly urban transportation network, benefiting both the environment and public health in the long term.

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References

1. Taghvaee, V.M.; Nodehi, M.; Saber, R.M.; Mohebi, M. Sustainable development goals and transportation modes: Analyzing sustainability pillars of environment, health, and economy. *World Dev. Sustain.* **2022**, *1*, 100018. [CrossRef]
2. Monteiro, R.; Ferreira, J.C.; Antunes, P. Green infrastructure planning principles: An integrated literature review. *Land* **2020**, *9*, 525. [CrossRef]
3. Badiu, D.L.; Nita, A.; Iojă, C.I.; Niţă, M.R. Disentangling the Connections: A Network Analysis of Approaches to Urban Green Infrastructure. *Urban For. Urban Green.* **2019**, *41*, 211–220. [CrossRef]
4. Hussein, J.; Kumble, P.; Hanson, H.W.A., IV. A Study of Green Infrastructure in European Cities: Opportunities and possibilities. *J. Reg. City Plan.* **2023**, *34*, 270–285. [CrossRef]
5. Li, S.; Lang, M.; Yu, X.; Zhang, M.; Jiang, M.; Tsai, S.; Wang, C.K.; Bian, F. A Sustainable transport competitiveness analysis of the China railway express in the context of the belt and road initiative. *Sustainability* **2019**, *11*, 2896. [CrossRef]
6. Agni, S.N.; Djomiy, M.I.; Fernando, R.; Apriono, C. Evaluasi penerapan smart mobility di Jakarta (evaluation of smart mobility implementation in Jakarta). *J. Nas. Tek. Elektro Dan Teknol. Inf.* **2021**, *10*, 214–220. [CrossRef]
7. Primastuti, N.A.; Puspitasari, A.Y. Studi literatur: Penerapan green transportation untuk mewujudkan kota hijau dan berkelanjutan. *J. Kaji. Ruang* **2022**, *1*, 62. [CrossRef]
8. Apriliana, R. Dampak pembangunan jalan merr terhadap pertumbuhan ekonomi dalam konsep pembangunan berkelanjutan di wilayah Gunung Anyar, Surabaya. *J. Ekon. Bisnis Dan Akunt.* **2021**, *1*, 86–96. [CrossRef]
9. Erwinsyah, E. Peluang ekonomi hijau dan ketrampilan hijau menuju netral karbon indonesia tahun 2060. *JABE (J. Appl. Bus. Econ.)* **2021**, *8*, 159–181. [CrossRef]
10. Fitri, A.; Invanni, I.; Arfan, A. Tingkat kebutuhan ruang terbuka hijau. *LaGeografia* **2020**, *18*, 90–98. [CrossRef]
11. Rustiadi, E.; Pravitasari, A.E.; Setiawan, Y.; Mulya, S.P.; Pribadi, D.O.; Tsutsumida, N. Impact of continuous Jakarta megacity urban expansion on the formation of the Jakarta-Bandung conurbation over the rice farm regions. *Cities* **2021**, *111*, 103000. [CrossRef]
12. Shahin, M.; Ghasri, M.; Abbasi, A. Exploring the psychological drivers of sustainable transport consumption: The role of Big-Two personality traits. *Int. J. Sustain. Transp.* **2024**, *18*, 547–561. [CrossRef]
13. Putri, A.B.; Farda, M.; Santosa, S.P.; Dirgahayani, P.; Suthanaya, P.A.; Andani, I.G.A.; Sutanto, H.; Charky, L.R.; Nurjanah, N. Study of Public Transport Development in South Bali Districts: Potential Public Transport Mode. *Int. J. Sustain. Transp. Technol.* **2021**, *4*, 9–21. [CrossRef]
14. Magauda, S.; D'Ascanio, R.; Muccitelli, S.; Palazzo, A.L. "Greening" Green Infrastructure. Good italian practice for enhancing green infrastructure through the common agricultural policy. *Sustainability* **2020**, *12*, 2301. [CrossRef]
15. Vinichenko, V. Green transportation: Myth vs. reality. *E3S Web Conf.* **2023**, *371*, 04050. [CrossRef]
16. Eckersten, S.; Gunnarsson-Östling, U.; Balfors, B. Inclusion and exclusion of environmental aspects in early-stage planning of transport infrastructure projects: A Swedish case study. *Int. J. Sustain. Transp.* **2023**, *17*, 369–381. [CrossRef]
17. Hamurcu, M.; Eren, T. Electric bus selection with multicriteria decision analysis for green transportation. *Sustainability* **2020**, *12*, 2777. [CrossRef]
18. Hasselwander, M.; Bigotte, J.F.; Antunes, A.P.; Sigua, R.G. Towards sustainable transport in developing countries: Preliminary findings on the demand for mobility-as-a-service (maas) in Metro Manila. *Transp. Res. Part A Policy Pract.* **2022**, *155*, 501–518. [CrossRef]
19. Holden, E.; Gilpin, G.; Banister, D. Sustainable mobility at thirty. *Sustainability* **2019**, *11*, 1965. [CrossRef]
20. Juyal, S.; Yedla, S. Sustainability of transport system: Case study of Greater Mumbai. *J. Sustain. Dev. Transp. Logist.* **2020**, *5*, 153–167. [CrossRef]

21. Kraus, L.; Proff, H. Sustainable urban transportation criteria and measurement a systematic literature review. *Sustainability* **2021**, *13*, 7113. [CrossRef]
22. Reimer, M.; Rusche, K. Green Infrastructure under pressure. A global narrative between regional vision and local implementation. *Eur. Plan. Stud.* **2019**, *27*, 1542–1563. [CrossRef]
23. Lowe, M.; Adlakha, D.; Sallis, J.F.; Salvo, D.; Cerin, E.; Moudon, A.V.; Giles-Corti, B. City planning policies to support health and sustainability: An international comparison of policy indicators for 25 cities. *Lancet Glob. Health* **2022**, *10*, e882–e894. [CrossRef] [PubMed]
24. Ahmed, M.M.A.W.; El Monem, N.A. Sustainable and green transportation for betterquality of life case study greater Cairo—Egypt. *HBRC J.* **2020**, *16*, 17–37. [CrossRef]
25. Bamwesigye, D.; Hlavackova, P. Analysis of sustainable transport for smart cities. *Sustainability* **2019**, *11*, 2140. [CrossRef]
26. Sultana, S.; Salon, D.; Kuby, M. Transportation sustainability in the urban context: A comprehensive review. *Urban Geogr.* **2019**, *40*, 279–308. [CrossRef]
27. Thaller, A.; Posch, A.; Dugan, A.; Steininger, K. How to design policy packages for sustainable transport: Balancing disruptiveness and implementability. *Transp. Res. Part D Transp. Environ.* **2021**, *91*, 102714. [CrossRef]
28. Shifflett, S.D.; Newcomer-Johnson, T.; Yess, T.; Jacobs, S. Interdisciplinary collaboration on green Infrastructure for urban watershed management: An Ohio Case Study. *Water* **2019**, *11*, 738. [CrossRef]
29. Alanbari, D.H.A.; Alkindi, S.K.; Al_Ahbabi, S.H. Green infrastructure to enhance urban sustainability. *Int. J. Health Sci.* **2022**, *6*, 9256–9269. [CrossRef]
30. Gebru, G.H. Creating Interconnected Outdoor Green Infrastructure in The Case of Aksum Historical Sites, Ethiopia. *CSID J. Infrastruct. Dev.* **2023**, *6*, 2. [CrossRef]
31. Sarjana, S. Green transportation: Development opportunities in support of sustainable transportation. *E3S Web Conf.* **2023**, *429*, 03003. [CrossRef]
32. Berghöfer, A.; Zyl, H.V.; Förster, J.; Rode, J.; Mitlacher, G.; Schröter-Schlaack, C. *Natural Capital in International Environmental Cooperation: Concepts and Application*; Helmholtz Centre for Environmental Research—UFZ, Leipzig; WWF: Berlin, Germany, 2020; 22p. [CrossRef]
33. Coombes, M.; Viles, H. Challenges, opportunities, and prospects for linking green infrastructure and the conservation of urban built heritage. In Proceedings of the EGU General Assembly 2021, online, 19–30 April 2021.
34. Di Turo, F.; Medeghini, L. How Green Possibilities Can Help in a Future Sustainable Conservation of Cultural Heritage in Europe. *Sustainability* **2021**, *13*, 3609. [CrossRef]
35. Gelan, E.; Girma, Y. Sustainable Urban Green Infrastructure Development and Management System in Rapidly Urbanized Cities of Ethiopia. *Technologies* **2021**, *9*, 66. [CrossRef]
36. Kuc, G.; Chormański, J. SENTINEL-2 IMAGERY FOR MAPPING AND MONITORING IMPERVIOUSNESS IN URBAN AREAS. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2019**, *XLII-1-W2*, 43–47. [CrossRef]
37. Monteiro, R.; Ferreira, J.C.; Antunes, P. Green Infrastructure Planning Principles: Identification of Priorities Using Analytic Hierarchy Process. *Sustainability* **2022**, *14*, 5170. [CrossRef]
38. Ogryzek, M.; Adamska-Kmieć, D.; Klimach, A. Sustainable Transport: An Efficient Transportation Network—Case Study. *Sustainability* **2020**, *12*, 8274. [CrossRef]
39. Yirga Ayele, B.; Megento, T.L.; Habetemariam, K.Y. The governance and management of green spaces in Addis Ababa, Ethiopia. *Heliyon* **2022**, *8*, e09413. [CrossRef]
40. Grabowski, Z.J.; McPhearson, T.; Matsler, A.M.; Groffman, P.; Pickett, S.T.A. What is green infrastructure? A study ofdefinitions in US city planning. *Front. Ecol. Environ.* **2022**, *20*, 152–160. [CrossRef]
41. Wild, T.C.; Dempsey, N.; Broadhead, A.T. Volunteered information on nature-based solution-Dredging for data on deculverting. *Urban For. Urban Green.* **2019**, *40*, 254–263. [CrossRef]
42. Artmann, M.; Mueller, C.; Goetzlich, L.; Hof, A. Supply and Demand Concerning Urban Green Spaces for Recreation by Elderlies Living in Care Facilities: The Role of Accessibility in an Explorative Case Study in Austria. *Front. Environ. Sci.* **2019**, *7*, 136. [CrossRef]
43. Brzoska, P.; Spāģe, A. From City- to Site-Dimension: Assessing the Urban Ecosystem Services of Different Types of Green Infrastructure. *Land* **2020**, *9*, 150. [CrossRef]
44. McFarland, A.R.; Larsen, L.; Yeshitela, K.; Engida, A.N.; Love, N.G. Guide for using green infrastructure in urban environments for stormwater management. *Environ. Sci. Water Res. Technol.* **2019**, *5*, 643–659. [CrossRef]
45. Mell, I. The impact of austerity on funding green infrastructure: A DPSIR evaluation of the Liverpool Green & Open Space Review (LG & OSR), UK. *Land Use Policy* **2020**, *91*, 104284. [CrossRef]
46. Pauleit, S.; Ambrose-Oji, B.; Andersson, E.; Anton, B.; Buijs, A.; Haase, D.; Elands, B.; Hansen, R.; Kowarik, I.; Kronenberg, J.; et al. Advancing urban green infrastructure in Europe: Outcomes and reflections from the GREEN SURGE project. *Urban For. Urban Green.* **2019**, *40*, 4–16. [CrossRef]

47. Faisal, B.; Dahlan, M.Z.; Chaeriyah, S.; Hutriani, I.W.; Amelia, M. Analysis of Green Infrastructure Development Policy in Indonesia: An Adaptive Strategy for Sustainable Landscape Development. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *1092*, 012013. [CrossRef]
48. Janiszek, M.; Krzysztofik, R. Green Infrastructure as an Effective Tool for Urban Adaptation—Solutions from a Big City in a Postindustrial Region. *Sustainability* **2023**, *15*, 8928. [CrossRef]
49. Navarrete-Hernandez, P.; Laffan, K. The impact of small-scale green infrastructure on the affective wellbeing associated with urban sites. *Sci. Rep.* **2023**, *13*, 9687. [CrossRef]
50. Ying, J.; Zhang, X.; Zhang, Y.; Bilan, S. Green infrastructure: Systematic literature review. *Econ. Res.-Ekon. Istraživanja.* **2022**, *35*, 343–366. [CrossRef]
51. Chatzimentor, A.; Apostolopoulou, E.; Mazaris, A.D. A review of green infrastructure research in Europe: Challenges and opportunities. *Landsc. Urban Plan.* **2020**, *198*, 103775. [CrossRef]
52. Kim, D.; Song, S.-K. The multifunctional benefits of green infrastructure in community development: An analytical review based on 447 cases. *Sustainability* **2019**, *11*, 3917. [CrossRef]
53. Raei, E.; Reza Alizadeh, M.; Reza Nikoo, M.; Adamowski, J. Multi-objective decision-making for green infrastructure planning (LID-BMPs) in urban storm water management under uncertainty. *J. Hydrol.* **2019**, *579*, 124091. [CrossRef]
54. Rodrıguez Andara, A.; Rio Belver, R.M.; Garcia Marina, V. Sustainable university institutions: Determination of gases greenhouse effect in a university center and strategies to decrease them. *DYNA* **2020**, *95*, 47–53. [CrossRef] [PubMed]
55. Sun, F.; Xiang, J.; Tao, Y.; Tong, C.; Che, Y. Mapping the social values for ecosystem services in urban green spaces: Integrating a visitor-employed photography method into SolVES. *Urban For. Urban Green.* **2019**, *38*, 105–113. [CrossRef]
56. Van Oijstaeijen, W.; Van Passel, S.; Cools, J. Urban green infrastructure: A review on valuation toolkits from an urban planning perspective. *J. Environ. Manag.* **2020**, *267*, 110603. [CrossRef]
57. Venkataramanan, V.; Lopez, D.; McCuskey, D.J.; Kiefus, D.; McDonald, R.I.; Miller, W.M.; Packman, A.I.; Young, S.L. Knowledge, attitudes, intentions, and behavior related to green infrastructure for flood management: A systematic literature review. *Sci. Total Environ.* **2020**, *720*, 137606. [CrossRef]
58. Zhang, K.; Chui, T.F.M. Linking hydrological and bioecological benefits of green infrastructures across spatial scales—A literature review. *Sci. Total Environ.* **2019**, *646*, 1219–1231. [CrossRef]
59. Al Faraby, J.; Trisedya, R.A.A.; Priambudi, B.R.J.N.; Pramesti, A.Z. Tipologi Aplikasi Infrastruktur Hijau Skala Komunitas pada Kampung Kota di Indonesia. *Jurnal Lanskap Indonesia* **2024**, *16*, 38–47. [CrossRef]
60. Wilker, J.; Rusche, K.; Rymsa- Fitschen, C. Improving Participation in Green Infrastructure Planning. *Plan. Res.* **2016**, *31*, 229–249.
61. Taguchi V., J.; Weiss, P.T.; Gulliver, J.S.; Klein, M.R.; Hozalski, R.M.; Baker, L.A.; Finlay, J.C.; Keeler, B.L.; Nieber, J.L. Its Not Easy being green: Recognizing unintended consequences of green storm water Infrastructure. *Water* **2020**, *12*, 522.
62. C40 Cities. Climate Action in Megacities: C40 Cities Baseline Emissions Report. 2022. Available online: https://www.c40.org (accessed on 16 October 2024).
63. City of Copenhagen. Bicycle Account: Cycling Statistics for Copenhagen. 2021. Available online: https://international.kk.dk/ (accessed on 7 October 2024).
64. Municipality of Amsterdam. Amsterdam Cycling Statistics: Biking Trends and Environmental Impact. 2020. Available online: https://www.amsterdam.nl/ (accessed on 1 November 2024).
65. Government of Singapore. *Green Infrastructure and Urban Transport: Park Connector Network (PCN) Development Report*; Urban Redevelopment Authority: Singapore, 2021. Available online: https://www.ura.gov.sg (accessed on 20 October 2024).
66. Jakarta Government. *Data Penurunan Jumlah Kendaraan Pribadi di Area Pusat Kota dan Pengembangan Jalur Sepeda*; Dinas Perhubungan Provinsi DKI Jakarta: Jakarta, Indonesia, 2022. Available online: https://jakarta.bps.go.id/id/statistics-table/2/Nzg2IzI=/jumlah-kendaraan-bermotor-menurut-jenis-kendaraan-unit-di-provinsi-dki-jakarta.html (accessed on 15 October 2024).
67. Pemerintah Kota Surabaya. *Laporan Kualitas Udara dan Pengembangan Infrastruktur Hijau Kota Surabaya*; Dinas Lingkungan Hidup Kota Surabaya: Surabaya, Indonesia, 2023.
68. Sutandi, A.C.; Rahman, D. Evaluasi Implementasi Jalur Sepeda di Kota Bandung: Tantangan dan Potensi. *J. Transp. Infrastruktur Perkota.* **2020**, *18*, 45–56.