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REVIEW

Coupling Transit, Land Use, and Ecology: A Critical Review of Urban Rail Transit's Environmental Co-Benefits and Trade-Offs

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ABSTRACT

Urban rail transit systems have now become a part of sustainable city development, bringing about environmental co-benefits such as lower greenhouse gas emissions, better air quality, and enhanced transit-oriented development. These advantages do not, however, come without trade-offs in the form of ecological costs associated with construction and habitat fragmentation, as well as the indirect effects of land-use changes. The article critically reviews the relationships among urban rail transit, land use, and ecology, with a focus on the intricate relationship between co-benefits and trade-offs. It provides a review of the main environmental impacts, including the decrease in car dependency and improvements in population health, as well as possible ecological impacts, including the carbon footprints of infrastructure and the disturbance of local ecosystems. The review highlights the significance of implementing an integrated planning approach with a focus on the ecological transit-oriented development (TOD) zoning concept, green rail design, and cross-sectoral policies that ensure the alignment of transportation, land-use, and ecological objectives. It also addresses spatial heterogeneity, determining how impacts can differ across urban densities, core-periphery processes, and regional contexts. The article ends by providing recommendations on how to advance social equity via inclusive governance and long-term environmental impact monitoring, thus indicating future research prospects in sustainable urban rail transport. Urban rails can help build stronger and more inclusive cities by balancing environmental sustainability and social inclusion.

Keywords: Urban Rail Transit; Environmental Co-Benefits; Transit-Oriented Development; Ecological Impacts; Sustainable Urban Planning

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1. Introduction

Urbanization has been one of the major causes of environmental degradation, and this has increased greenhouse effects, air pollution, habitat loss, and fragmentation of the ecosystem [1]. Nevertheless, urban sprawl has also triggered an international revolution in transportation systems, and among the advances that have been made is urban rail transit, which has become a pillar of sustainable urban transport. With the world's cities struggling with climate change and biodiversity loss issues, urban rail transit has become an important tool to decouple economic growth and the destruction of the environment. The possible environmental co-benefits of urban rail transit, including carbon emissions reduction, enhanced air quality, and urban biodiversity, are becoming well known. Nevertheless, these advantages come at the cost of various trade-offs such as ecological effects of construction, possible gentrification, and unintended effects that could threaten the sustainability of the long run [2–4].

Transit-oriented development (TOD) is one of the major ways in which urban rails impact urban environments. TOD seeks to encourage the development of mixed-use, high-density, transit hubs as a way of encouraging the transition to urban sprawl, which relies on cars. TOD can improve the quality of life in cities and reduce the environmental footprint by increasing urban density and decreasing automobile reliance. The ecological and social effects of TOD are, however, complex due to the spatial dynamics of the TOD. Although TOD may be effective in curbing urban sprawl and protecting open spaces, it may also cause the displacement of vulnerable populations, a decrease in green spaces, and strain the ecosystem around the development. These dynamics necessitate a keen consideration of both the good and the bad environmental impacts of the urban rail investments [5,6].

Although the research on the environmental co-benefits and trade-offs of urban rail is scattered, there is an increasing interest in rail transit and its role in supporting city sustainability. Most of the research focused on mitigating climate change and air pollution, but few studies have focused on the ecological and social implications of including transit systems in urban environments in the long run. In addition, the systems dynamics underlying the interrelationships among land use, transportation, and ecology have not been well understood. Avoiding a complete framework that links urban rail systems to ecological outcomes restricts policymakers in their ability to make informed decisions regarding the development of urban areas. Therefore, the environmental advantages and disadvantages of urban rail transit should be critically reviewed to inform future urban planning and policy [7].

This gap is filled through this review, which provides a critical analysis of the urban rail transit in the framework of its ecological co-benefits and trade-offs, especially at the intersection of transit, land use, and ecology [7]. It is the aim of the present paper to summarize the current information, define the most important processes by which urban rail transit can contribute to more ecological and sustainable cities, and emphasize what challenges and opportunities have to be addressed. This review will address the interaction between transit systems, land use modifications, and ecological effects, which will be covered as the positive aspects of the expansion of urban rail networks and potential risks [8].

Several themes are used to structure the review. First, we develop a conceptual framework, which brings out the relationship between transit, land use, and ecology [9]. This framework offers a prism in which the relationships between these systems may be viewed, mainly the feedback loops connecting the alterations in urban mobility to the ecological impacts. Then, we discuss the co-benefits of urban rail transit, where the environmental outcomes are in greenhouse gas emissions, air quality improvement, and ecosystem services conservation. This is followed by a critical evaluation of the trade-offs of the investment in urban rail, which takes into account the ecological cost of such construction, fragmentation of habitats, and the indirect cost of land-use shift increased by transit development. The spatial heterogeneity of these impacts is also discussed in the review, and this focuses on the effect of the fact that outcomes differ depending on geographical setting, urban density, and socio-economic circumstances. Moreover, we also discuss the approaches employed in the current research, which have a problem of measurement and interpretation of data. Lastly, we give policy recommendations on how to achieve maximum co-benefits of urban rail systems at minimum trade-offs, to present a roadmap for future research and urban planning [10–12].

The paper will add to the existing literature on sustainable urban development by providing a systems-based review of the environmental impact of urban rail transit. After all, we want to encourage more holistic, ecologically conscious city rail investments, so that the transit systems of tomorrow will not only address the mobility requirements in the rising cities, but also contribute to environmental sustainability and ecological resilience.

2. Conceptual Framework: Transit–Land Use–Ecology Coupling

City rail transit has also been strongly connected with the intricate land use, transportation, and environmental system[9]. It is also important to understand the interconnection between these systems and how they affect each other to assess the co-benefits and trade-offs of the expansion of urban rail. This section gives a conceptual framework on how to analyze the interaction between transit, land use, and ecology, emphasizing the feedback processes and spatial dynamics that induce positive as well as negative environmental effects[13].

The relationships between transit, land use, and ecological outcomes are illustrated in **Figure 1**, which highlights the feedback loops and spatial interactions that shape both the environmental co-benefits and trade-offs of rail transit systems.

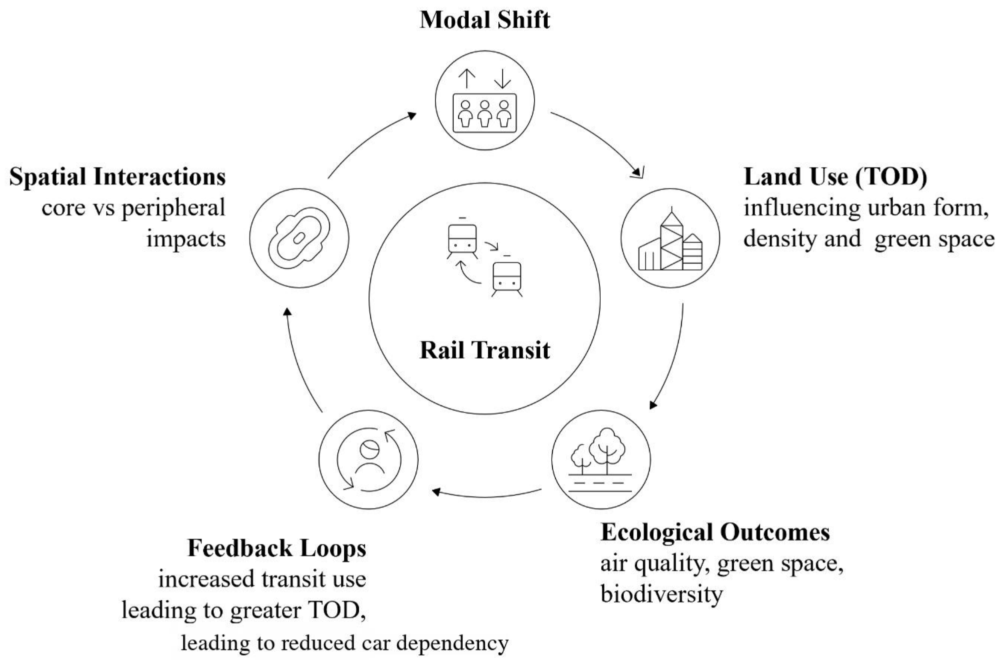


Figure 1. Conceptual framework of urban rail transit's environmental co-benefits and trade-offs.

2.1. Rail Transit as a Coupled Human–Natural System

Urban rail is not an independent technological solution, but a part of a great socio-ecological system. Rail transportation exists within the boundaries of the human-nature relations, which impact both the social organization and the ecological actions. Transit, land use, and ecology are coupled by the actions of the urban planners, policy makers, and citizens, as well as the physical features of the natural environment[14]. According to this system, rail transit is a cause of land-use change, which changes local ecosystems and their services. Indicatively, the economic density of transit centers can be increased due to a rail line, thereby decreasing the land area required to develop an urban area. Nevertheless, the environmental impact of such changes is complex and affects such aspects as air quality and biodiversity[15].

Moreover, even rail transit systems are also prone to environmental limitations and effects. Though they have a facilitating effect on more sustainable mobility patterns, the building and running of rail systems may cause ecological perturbation, including habitat fragmentation or the installation of impervious surfaces. The combination of human activity (using transit systems) and the natural environment helps to emphasize the need to pay attention to the idea that urban rail is a component of an integrated system, but not a separate solution [16].

2.2. Pathways Linking Transit to Land-Use Change

Among the core processes through which the rail transit itself impacts the environment is its effect on the land-use patterns. Transit-oriented development is a common phenomenon as a result of the introduction of rail transit into a city, which results in land use changes. TOD focuses on mixed-use, high-density development of transit areas, which will minimize the use of personal vehicles and promote walking, cycling, and the use of public transportation. TOD can go a long way in mitigating sprawl through the development of locations that are well-served by mass transit and encourage more sustainable land use patterns [17].

The transit and land use relationship is complicated, though. The availability of rail transit can have a direct impact on the location, density, and kind of development that will happen in a particular area. Greater availability of transit stations has the potential to raise land values, which may further draw in increased-density development. Simultaneously, the development can send away lower-income groups or decrease the open space, resulting in social and ecological trade-offs. The environmental benefits are also applied in this space dynamic, which is the creation of green areas and maintenance of ecosystems, usually a by-product of increased urban development, as urban sprawl is diminished [18].

2.3. Land-Use Change as an Ecological Mediator

The urban rail transit provides direct and indirect impacts on the local ecology due to land-use changes [19]. These effects depend on the character of the land-use shifts, which may include the transformation of the natural habitats to the urban areas, the establishment of new green areas, and ecological corridors. An example is transit-oriented development, which could result in the conservation of open spaces because the growth of urban sprawl is inhibited, thereby conserving important ecological processes like carbon sequestration, water purification, and protection of biodiversity. On the other hand, the presence of rail corridors built in ecologically sensitive locations may lead to the fragmentation of the habitat, which changes the local ecosystem and makes it more vulnerable to environmental changes [20].

Spatial structure of land-use dynamics is an important parameter that defines their ecological impacts. Regions that are densified in areas near transit hubs can offer prospects of reclaiming the degraded landscapes or incorporating green infrastructure into urban environments. Nonetheless, such advantages should be measured against the possible appearance of the more impermeable surfaces and the weakening connections among the ecosystems. The ecological effects of land-use change, in turn, cannot be adequately interpreted out of the context of the larger space of the urban setting, not to mention the time and magnitude of development around the rail activity [21].

2.4. Feedback Loops and Non-Linear Effects

The connection between transit, land use, and ecology is a one-directional relationship, but it consists of various feedback loops that either enhance or diminish the original impacts of the urban rail transit. As an example, the establishment of the rail transit can cause, at the very beginning, the development of the areas around transit stations, which translates to a rise in population density and mobility demands. This, in turn, may also trigger further transit usage, leading to a positive feedback loop that will reinforce the positive effect of rail transit usage on the reduction of personal car usage and emissions [22]. Reinforcing loops, such as increased ridership leading to further transit investment and densification, can amplify environmental benefits, while balancing loops, such as rising land values displacing residents to car-dependent peripheries, may counteract intended sustainability gains. Identifying these loop structures is essential for predicting net environmental outcomes. Nevertheless, there are also unintended consequences of such feedback.

The non-linear effects further complicate the connection between these systems. The introduction of a new rail station is a minor alteration in land use, which can influence ecological processes, making its impact substantial depending on the setting. As an example, one railway line can trigger global transformations of urban structure, and the impact on the local air quality, noise reduction, and the quality of habitat. Such non-linear impacts underscore the necessity of having full-fledged modeling and planning that considers the far-reaching effects of transit development, which, as it were, has long-term and cumulative effects that could be generated by merely minor changes within the urban environment [23].

2.5. Analytical Framework for Assessing Coupling Dynamics

The analysis of the relationship between transit, land use, and ecology requires a sound analytical framework. Such a framework should be based on qualitative and quantitative approaches in order to be able to capture the intricacy of involved systems. The major tools to determine the effects of rail transit on the environment are spatial econometrics, lifecycle analysis, and remote sensing. These methods enable the parameters of indirect and direct effects, in addition to the determination of space patterns and trends that result from transit investments. Also, the multi-agent modeling and system dynamics techniques would help to explain the feedback and non-linear interactions that define the coupling of such systems.

This framework can also be used to understand the interaction of urban rail transit systems with land use and ecology in a more comprehensive way by combining different analytical techniques. This is necessary in order to come up with strategies that will optimize the co-benefits of urban rail and reduce the trade-offs that may arise. These relationships will be discussed more thoroughly in the subsequent sections, where we will review the current studies regarding the benefits and trade-offs of urban rail transit to the environment and how these impacts have been measured and assessed [5].

3. Environmental Co-Benefits of Urban Rail Transit

The potential of the urban rail transit systems to make cities develop in a more sustainable and resilient way has long been acknowledged. Environmental co-benefits of rail transit are due to the capacity of rail transit to diminish car dependency, high density of development, and more sustainable urban forms [24]. The benefits are multi-environmental, including climate reduction, air quality, and ecosystem services, and these are important to the growing environmental crisis experienced by urban areas across the world. Nevertheless, these co-benefits are not guaranteed, but rather they depend on how the transit rail networks are incorporated into the urban environment, or the overall land-use policy and planning models informing development around transit stations. The magnitude of environmental co-benefits, such as reductions in CO_2 emissions and improvements in air quality. As shown in **Figure 2**, urban rail transit exhibits a substitution effect on road-based public transportation, evidenced by the decline in bus ridership per capita, and is also associated with a reduction in carbon dioxide emissions per capita in cities with urban rail transit (URT) [25,26].

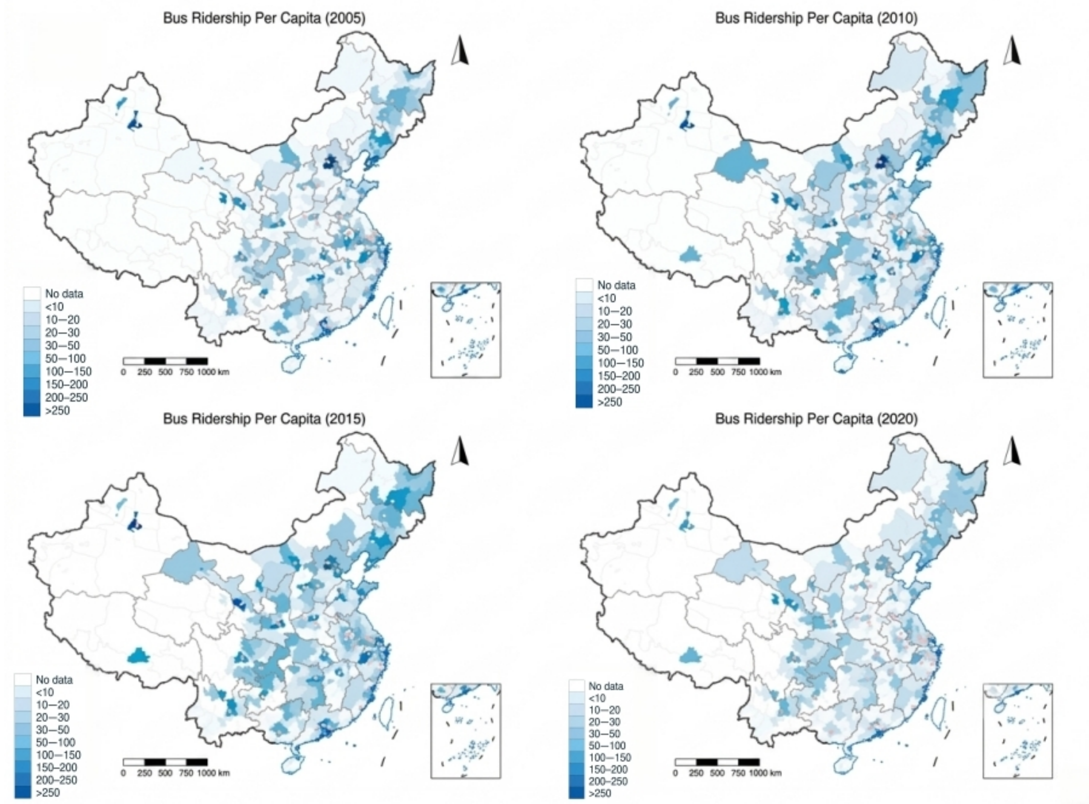
As shown in **Table 1**, urban rail transit systems can provide a variety of environmental co-benefits, including reductions in carbon emissions, improved air quality, and enhanced land-use efficiency, each contributing to overall urban sustainability.

This section explores the key environmental co-benefits of urban rail transit, focusing on three primary areas: climate and air quality, land use and ecosystem services, and public health. Each of these areas presents distinct opportunities for cities to leverage urban rail systems as tools for promoting sustainability while mitigating the adverse environmental impacts typically associated with urbanization [27].

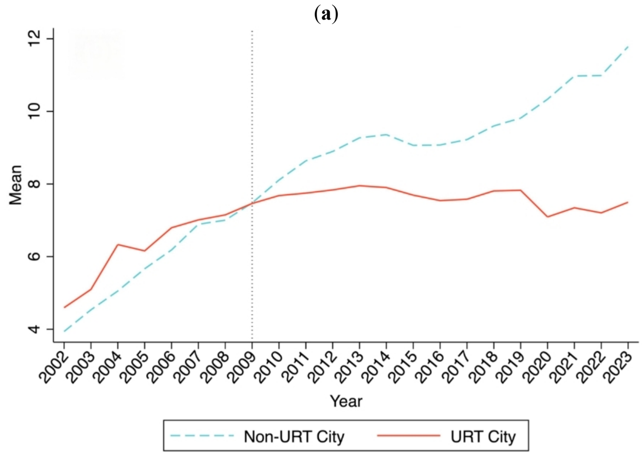
3.1. Climate and Air Quality

Urban rail transit has one of the greatest co-benefits by potentially reducing greenhouse gas (GHG) emissions, especially through its ability to replace car travel and promote the adoption of more efficient transportation modes. Rail networks in cities, particularly those that are run on renewable energy sources, have a significant cut in CO_2 pollution as compared to personal cars. The promise of mitigation of climate change by rail transit can be noted especially in cities that have a high degree of congestion and pollution by road transport, where a viable substitute can be fulfilled by rail transport that will limit the use of vehicles that are powered by fossil fuels [28,29].

Besides reducing climate change, urban rail transit can also be of importance in promoting air quality in the vicinity. The burning of fossil fuels in cars leads to a variety of air contaminants, such as nitrogen oxides (NO_x), particulate matter ($PM_{2.5}$), and volatile organic compounds (VOCs), that cause the creation of urban smog and have severe health consequences. Cities can get significant reductions in these pollutants by transferring commuters to rail systems and substituting the use of their own vehicles, thereby enhancing the quality of the air and the overall health of the population. When rail systems are incorporated with policies to reduce car use in the city, the overall effect on the air quality may be groundbreaking, especially in places where automobile emissions are a significant source of local pollution[30].



(**a**)



(**b**)

Figure 2. Environmental co-benefits of urban rail transit. Impacts of urban rail transit on public transport use and carbon emissions in Chinese cities: (**a**) Changes in bus ridership per capita, reflecting substitution effects of URT on road-based public transportation; (**b**) Trends in carbon dioxide emissions per capita in cities with and without URT. The pink dots indicate that the city opened urban rail transit[25].

Table 1. Summary of the Environmental Co-Benefits of Urban Rail Transit.

Co-Benefit	Environmental Impact	Outcome
Climate Mitigation	Reduced CO_2 emissions from vehicle travel	Lower greenhouse gas emissions from modal shift
Air Quality Improvement	Reduction in NO_x, $PM_{2.5}$, and other pollutants	Enhanced air quality, improved public health
Land Use Efficiency	Reduced sprawl, compact development around stations	Preservation of green spaces, increased density

Table 1. *Cont.*

Co-Benefit	Environmental Impact	Outcome
Ecosystem Services Enhancement	Integration of green infrastructure, stormwater management	Improved urban heat resilience, flood mitigation
Public Health	Increased walking and cycling, reduced exposure to pollution	Reduced rates of respiratory and cardiovascular diseases

Moreover, these benefits may be increased with the assistance of urban rail, combined with active transportation systems (cycling and walking). The overall impact of mobility on the environment can be minimized by increasing the first- and last-mile distance between rail stations and residential or commercial districts, in addition to making moves to promote more sustainable and healthier modes of transport.

3.2. Land-Use and Ecosystem Services

The environmental co-benefits of urban rail transit are not limited to its direct impacts on air quality and climate mitigation, but it also has an effect on land-use patterns and ecosystem services. The capability of the rail system to support transit-oriented development is one of the most important advantages of this transportation mode because it facilitates the creation of increased-density and mixed-use development around the transit stations. TOD helps to curb urban sprawl by centering development along transit corridors, and thus residential zones, commercial zones, and recreation space can be concentrated in places well served by the transit systems [31].

By enabling smarter urbanism, the rail systems can be used to conserve some of the natural environments and green areas that would have been lost to low-density sprawl that relies on cars. Additionally, TOD has the potential to improve the incorporation of green infrastructure in the cityscape. The design of the rail corridors, stations, and the surroundings can be done in a manner that includes green spaces, rain gardens, permeable surfaces, and other natural systems that offer ecosystem services, including stormwater management, temperature regulation, and habitat connectivity. These environmental gains can improve urban habitation, sustain biodiversity, and alleviate the effects of urban heat islands.

The reuse of degraded or unproductive land, especially brownfields or former industrial sites, is especially important in cities where there already exists a rail network. The spaces that are usually situated close to transit lines can be regenerated to form green city areas that will help not only the environment but also the people. Such a process helps in the sustainability of urban development as well as the replenishment of key ecosystem functions that can otherwise have disappeared due to past industrial processes [32].

3.3. Public Health and Social-Ecological Benefits

In addition to climate and ecological effects, urban transit has significant co-benefits for public health. Expressive transportation, such as walking and cycling, is promoted by the availability of effective and convenient rail systems, which offer people the opportunity to use the transit stations safely and conveniently. A lot of physical exercise, such as walking and cycling, can cause drastic changes in physical well-being, such as a decrease in obesity and cardiovascular diseases, among other illnesses related to sedentary living. By so doing, rail systems will indirectly be able to encourage healthier populations in cities due to increased active transport [33].

The rail transit systems also help to reduce noise pollution, which is a major stressor in the environment in most urban centers. The noise caused by the traffic of personal vehicles has been associated with various negative health consequences, such as elevated stress, sleeping problems, and heart disease. These noise levels can be tremendously diminished through the use of rail systems, especially those constructed with technologies that help to control noise, and/or through the use of routes that avoid going through residential areas, thus the quality of life of the residents living close to these rail systems will be enhanced.

Also, urban rail networks can improve social equity because they are affordable and efficient means of transportation that can offer low-income groups, who are the most vulnerable groups when it comes to the adverse health impacts of urban pollution and climate change, access to transportation. With increased access to employment, education, health services, and other critical services, rail systems will increase the levels of social inclusion and benefit the overall welfare of disadvantaged groups [34].

Lastly, environmental co-benefits of rail transit tend to be confused with social-ecological benefits. As one case in point, the development of green corridors along the rail lines can offer important community amenities for recreational and social activities, as well as provide ecological benefits like habitat protection and climatic stability. All these interrelated advantages underscore the need to consider the social and ecological aspects of urban rail systems planning.

4. Environmental Trade-Offs and Hidden Costs

As much as urban rail transit systems have considerable environmental co-benefits, they also have considerable trade-offs and hidden costs that should be properly considered when undertaking a holistic analysis. The mentioned trade-offs can be especially observed in the context of studying the lifecycle effects of rail system construction and operation, or the indirect effects of land-use changes that present themselves as a result of transit-oriented development. Knowledge of these trade-offs is crucial to developing policies and strategies that will allow the urban rail systems to achieve the highest sustainability potential and reduce the negative ecological effects. While urban rail systems offer substantial environmental benefits, they are also associated with various trade-offs, as summarized in **Table 2**. These include carbon emissions during construction, habitat fragmentation, and potential gentrification effects [35,36].

This part examines the major environmental trade-offs of urban rail transit, which include the construction stage effects, the lifecycle emissions, the ecological fragmentation effects, and the rebound effects. All these regions pose different challenges to the urban planners and policymakers, thus making it necessary to plan and develop a unified model for the development of transit. As depicted in **Figure 3**, the introduction of rail transit significantly reduces travel times, as shown in **Figure 3a,b**, improving accessibility in the city center while enhancing connectivity in fringe areas. This improvement promotes the communication of social, economic, and cultural activities across the city. **Figure 3c** highlights accessibility changes, with the largest gains in Conghua District and the smallest in northern Zengcheng, where the rail transit impact is limited [37–39].

Table 2. Environmental Trade-Offs Associated with Rail Transit Development.

Trade-Off	Impact Type	Description	Mitigation Strategy
Construction Carbon Footprint	Carbon Emissions	High emissions during construction, use of carbon-intensive materials	Use of low-carbon materials, energy-efficient construction methods
Ecological Fragmentation	Habitat Disruption	Disruption of wildlife corridors and local ecosystems	Design of wildlife crossings, habitat restoration efforts
Gentrification & Displacement	Social Displacement	Rising property values leading to displacement of low-income residents	Affordable housing policies, rent control measures
Water Quality Degradation	Stormwater Runoff, Sedimentation	Increased runoff during construction, soil erosion	Implementation of permeable pavements and green infrastructure

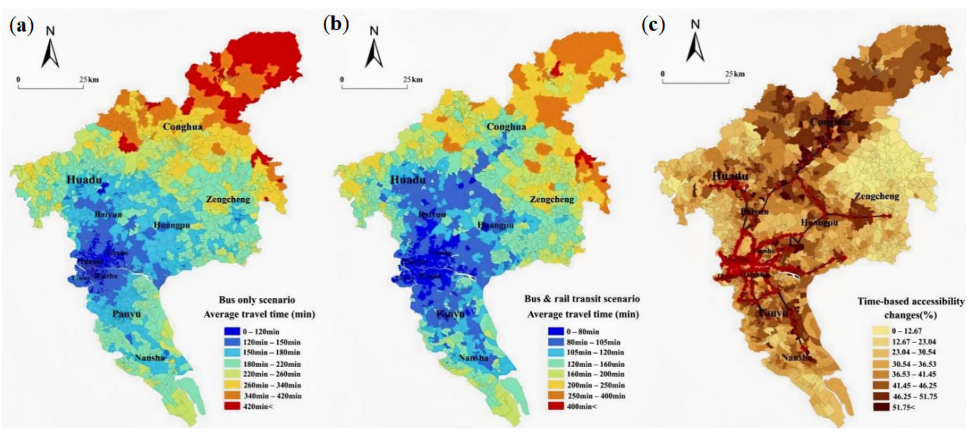


Figure 3. Changes in time-based accessibility with the introduction of rail transit and its impact on socio-economic and cultural communication: (**a**) Spatial distribution of accessibility in the bus-only scenario; (**b**) Spatial pattern after rail transit implementation; (**c**) Percentage change in accessibility between the two scenarios, demonstrating varying improvements across districts [37].

4.1. Lifecycle Carbon and Material Footprints

The design and performance of urban rails are linked to the high carbon emissions of the life cycle and material consumption. The carbon captured in the infrastructure of rail systems, including stations, tracks, tunnels, and bridges, can be significant, and this is especially true of systems that involve wide-scale excavation, tunnelling, or the use of materials that demand a lot of energy, such as steel and concrete. The disadvantages of these materials on the environment need to be balanced with the future advantages of rail transit in the form of vehicle emissions. The carbon footprint linked to the construction phase of rail systems, in most instances, may exceed the emissions reduction that is realized during the operation phase, and especially during the first years of operation.

Moreover, energy consumed to build and operate rail systems (which is usually non-renewable) might also contribute to the carbon intensity of rail systems. Although rail transport might have fewer emissions per kilometer of passenger transportation than automobile transport, the energy mix employed to operate the trains affects the overall environmental impact. The emissions benefits of the rail networks in cities where the rail systems use fossil-based electricity could be less compared to the cities operating their rail networks on renewable energy.

Due to the increasingly ambitious climate targets of cities, it is essential to look at the net environmental benefit of rail transit throughout its lifecycle. Initial expenses incurred in the environment in the construction process must be balanced by the long-term savings in the emissions produced by the modal change out of cars. Lifecycle assessments (LCAs) are the vital instruments for determining such trade-offs, and they offer an overall perspective on the environmental footprint of rail systems throughout their lifespan [40,41].

4.2. Ecological Fragmentation and Habitat Loss

Among the most troubling trade-offs in urban rail transit, there can also be the risk of ecological fragmentation. Natural habitats may be destroyed or disturbed with the construction of rail lines and rail stations that may be in wetlands, forests, or grasslands. Rail lines, especially those that pass through ecologically sensitive regions, may divide up habitats, sever wildlife corridors, and cause biodiversity loss. The effect of this fragmentation can cascade to the local ecosystems, exposing them to external stressors like climate change, invasive species, and pollution [10].

Besides the degradation of habitat, rail systems may also cause obstacles to the movement of animals. Although the purpose of urban rail transit is to facilitate human movement, the physical infrastructure can also block animal migration, and the species will not be able to access important resources, including food, water, and breeding areas. The ecological impact of the development of the rail systems may be disastrous in cities that have a rich biodiversity (i.e., in the regions close to wetlands, forests, or coastal areas). The control measures, including wildlife crossings and green corridors, can also be integrated along the rail corridor to reduce these impacts [42].

Moreover, the rail systems can interfere with the natural behavior of wildlife because of light and noise pollution. The artificial light around the rail stations and along the railways can disrupt the feeding, mating, and migration behaviors of nocturnal species. By the same token, sounds produced by trains may interfere with sensitive species, particularly species that use sound as a mode of communication or orientation. These environmental effects should be well controlled by designing and planning.

4.3. Indirect Rebound and Displacement Effects

Besides the direct environmental effects that are caused by the construction of rail transit and their operation, there are indirect rebound effects as well as displacement effects, which can be enhanced by the total environmental footprint of the rail systems. Rebound effects are the changes in behavior or unintended effects that reverse the environmental benefit of rail transit, expected to be achieved as a decrease in car usage and a reduction in emissions. An example is when new rail lines are introduced, which can be followed by development along the rail lines, which will attract more people to relocate to areas that were not easily accessible. Although this can minimize urban sprawl, it can also cause a general increase in travel demand and increase the amount of urban density, which might, in turn, lead to an increase in the amount of overall emissions caused by the increased activity [22,43,44].

Moreover, the phenomenon of displacement is also a problem in the regions where rail systems cause swift gentrification or rise in property prices. With the introduction of rail lines into the low-income neighborhoods, property values are likely to increase and displace the vulnerable populations, usually priced out by the more affluent residents. It may also increase the level of social inequalities and environmental degradation, as the displaced people may turn to more ecologically sensitive places at the periphery of the city, thus putting a strain on them.

The ecological impacts of the relocation of the current land uses are indirect as well. As an illustration, green spaces, community gardens, and other natural resources managed locally might be lost when affordable housing or community spaces are converted into high-end residential or commercial development. Such modifications have the potential to diminish urban resilience, especially in localities that use such spaces to manage stormwater, control temperature, or provide communal welfare [45].

4.4. Impacts of Challenges: Disturbance

Lastly, one should be able to take into account the construction stage effects of urban rail systems that may encompass soil erosion, water pollution, habitat loss, and higher levels of emissions during construction [22,46]. Rail systems tend to destroy a lot of land, involve the use of heavy machinery and excavations, all of which cause environmental degradation in the short term. Such activities may interfere with the local ecology, reduce the water quality as sediments run off, and augment air pollution caused by construction, automobiles, and hardware.

Most of these construction impacts during the construction phase are temporary and can be eliminated using best management practices, including erosion prevention methods and sustainable construction methods. These effects, however, vary in severity depending on the area of rail construction and the sensitivity of the environment around it. The effects of the construction of the rail system can be long-term in urban areas where the infrastructure is dense, and in areas that are more rural or are ecologically sensitive [47].

5. Spatial Heterogeneity and Scale Effects

When discussing the effects of urban rail transit on the environment, these effects are not equally experienced across cities or even areas. Instead, they are influenced by different spatial factors, which include geographical setting, intensity of development, the point of rail lines, and the general shape of the city. **Figure 4** illustrates the spatial pattern and dynamics of urban population change from 2011–2021 and shows that high-speed rail new towns significantly enhance urban economy, resources, and environmental system development, particularly in cities experiencing net population inflow, with central-type new towns having stronger coordination effects [48]. The spatial heterogeneity of the effects of these impacts is essential in assessing the possible benefits and trade-offs of rail systems. In this section, the author examines the impacts of urban rail transit at different spatial levels and contexts, particularly how the central and peripheral locations, and cities in the Global North and South differ [49,50]. The environmental impacts and challenges of urban rail transit in cities from the Global North versus the Global South are compared in **Table 3**.

5.1. Core versus Periphery: Urban Rail in Different Contexts

The spatial layout of rail transit lines in an urban area is an important factor in the environmental effects of rail lines. The core areas, which were usually densely populated and urban, were more likely to enjoy a closer and concentrated range of advantages of rail transit, including air pollution improvement, more access to transportation services, and better health-related outcomes for citizens. Here, it is possible to incorporate the concept of rail transit into the infrastructure to facilitate the elimination of traffic jams, decrease automobile usage, and encourage more environmentally friendly means of movement.

The peripheral areas, however, which tend to be more suburban or exurban areas, can encounter yet another set of concerns and opportunities. Although rail transit could lead to less reliance on cars and encourage the development of a higher population in these regions, the effects may be less pronounced or take time to be evident. Along the periphery, the population density may be less to begin with, and more automobile-dependent, and thus the environmental benefits of rail systems may take longer or be more mitigated. Also, the growth of rail services in suburbs has the potential to cause urban sprawl if it is not well-regulated, which would further contribute to environmental pollution through the promotion of low-density development in the regions surrounding transit stations [51].

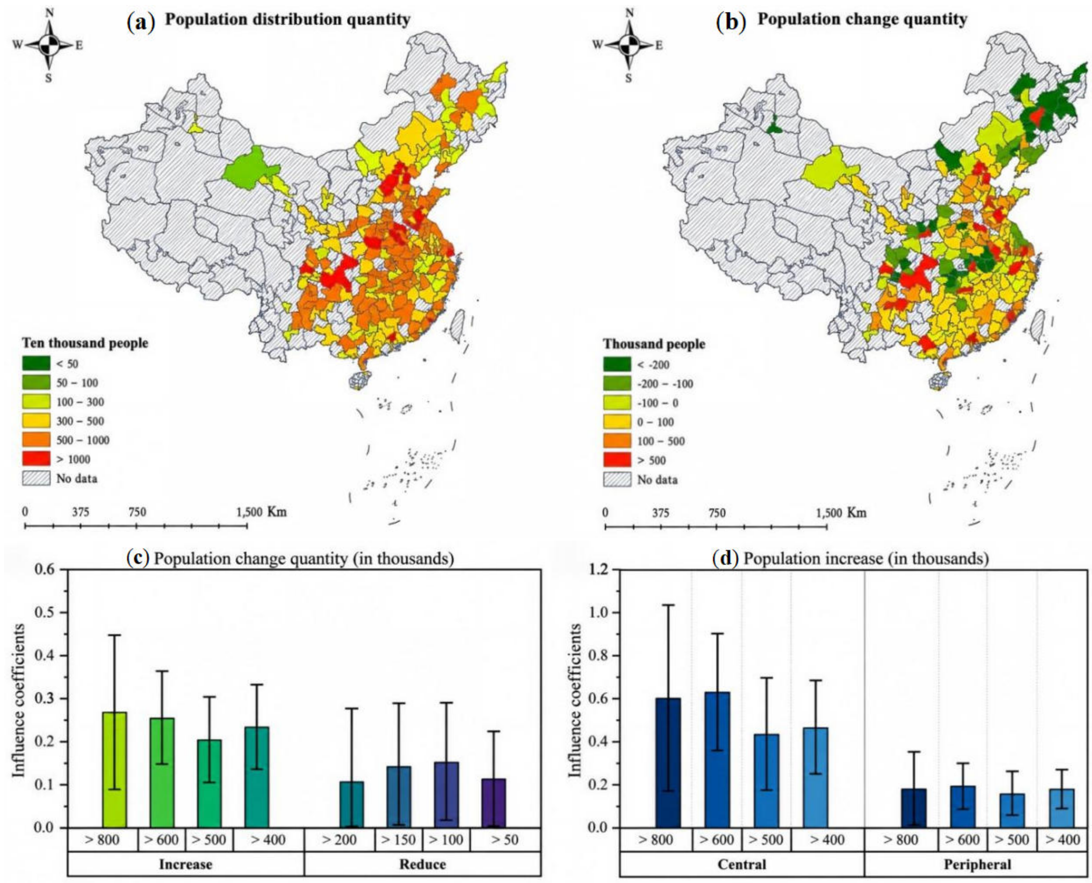


Figure 4. Urban population dynamics and the effects of high-speed rail new towns on urban economy, resources, and environmental systems: (**a**) Average annual permanent population distribution (2011–2021); (**b**) Net population change; (**c**) Effects under different population flow scales; (**d**) Central vs. peripheral high-speed rail new towns under large-scale population inflow [48].

Table 3. Comparative Analysis of Rail Transit Impacts in the Global North vs. Global South.

Region	Key Challenges	Environmental Co-Benefits	Trade-Offs
Global North	Aging infrastructure, higher capital costs	Significant reduction in car emissions, enhanced air quality	Gentrification, construction carbon footprint
Global South	Rapid urbanization, limited financial resources	Major improvements in mobility access, reductions in traffic congestion	Lack of green infrastructure, displacement of informal settlements
Both Regions	Increased demand for urban mobility	Sustainable growth through TOD, reduced urban sprawl	Habitat disruption due to rail line construction

Social and ecological trade-offs can also be brought about by rail transit introduction in the peripheral areas, especially in places with prized natural resources or delicate ecosystems. Rail lines into suburban or rural locations will disturb local habitats or cause habitat fragmentation, even as they introduce other benefits such as a decrease in car use. This is to demonstrate the relevance of considering regional planning in the development of rail transit so that the ecological and social implications of transit investment are harmonized and induced in various spatial contexts [52].

5.2. The Role of Urban Density in Shaping Impacts

One of the most influential factors of the environmental consequences of urban rail systems is the urban density. Rail transport has the potential to become one of the most effective instruments for decreasing car driving, restricting the amount of emitted gases, and stimulating sustainable development in megacities. Dense areas are generally well served by rail infrastructure, which provides fast service with high frequency to a high concentration of people, resulting in major decreases in per capita energy consumption and greenhouse gas emissions of transportation. In these regions, rail corridors are more apt to utilize transit-oriented development, in which the density of the development around transit stations decreases the demand for cars and promotes walking and cycling [22].

The advantages of rail transit are, however, less in low-density or sprawling cities. Low-density development is associated with higher commutes, a decrease in ridership, and higher infrastructure expenses. Under these circumstances, the rail systems might not be able to follow the same environmental benefits as in the case of dense urban centers because they cannot compensate for the nature of the surrounding areas that are car-dependent. Rail transit can also cause unintended adverse effects on the environment in these areas, including high energy use, because the transit stations are many miles apart, or the development of new suburban sprawl to serve the transit stations, which are also a source of ecological degradation [53,54].

City density also determines the socioeconomic aspects of rail commuters and the degree of environmental co-benefit achievement. Rail systems in large cities can have a wide scope of socioeconomic communities, offering them the use of popular services and eliminating pollution. By comparison, rail systems in lower-density locations can only primarily work with people who are more affluent and less dependent on cars, thus constraining the wider social and environmental advantages that could be met [55].

5.3. Global North versus Global South: Diverging Impacts and Opportunities

Urban rail transit also has important differences in its environmental impacts on urban areas in the Global North and Global South, which are highly affected by the patterns of urbanization, the development of infrastructure, and access to resources. The Global North cities tend to have more advanced infrastructure and are generally more dependent on cars, so the system of rail is often introduced in the wider context of decarbonization of transportation systems, congestion, and air pollution. Urban rail in these cities can produce large-scale effects in terms of car usage reduction, improving the population, and reducing climate change. Also, environmental co-benefits of rail systems can be enhanced by combining rail transit with other sustainability projects, like the encouragement of green building standards and the establishment of pedestrian-friendly areas [56].

Yet, even Global Northern rail systems can be subjected to immense ecological trade-offs, especially in the case of older cities, where the construction of the rail infrastructure can cause disruption of the urban fabric or ecologically sensitive regions. In such situations, transit systems in the city can lead to gentrification or displacement of low-income neighborhoods, which casts doubt on the social fairness of transit investments. Further, it is also true that cities of the Global North have a higher chance of facing a high construction-phase carbon footprint because, many times, the creation of the rail system includes massive investments in infrastructure and materials.

Contrastingly, other cities of the Global South may have dissimilar challenges and opportunities to develop the urban rail systems. Rapid urbanization and population growth have been witnessed in many cities in the Global South, resulting in extreme congestion, pollution, and the inability to use public transportation. Urban rail systems in these cities present an essential possibility of minimizing the emissions of vehicles and enhancing the accessibility of mobility for poorly served population groups. These cities, however, are often struggling to fund rail systems, and the benefits of rail systems to the environment may be undermined by ineffective infrastructure building, lack of connectivity, and lack of holistic urban planning.

Ecological trade-offs of the Global South do not necessarily share the same level as those of the Global North. Rail systems in most cities might be forced to deal with informal settlements, or naturally sensitive sites that could be displaced or eroded by the rail construction. Also, it is important to note that because of the absence of green infrastructure in most cities in the Global South, the environmental benefits of TOD might not be as significant. Nevertheless, the rail infrastructure in the areas does have a chance of providing the sustainable urban development of the areas that would focus on both human mobility and ecological power [57,58].

5.4. Non-Linear Effects and Thresholds of Impact

It is also worth noting that the environmental effects of the urban rail transit are usually non-linear and prone to threshold effects. The same small alterations in the development of transit systems (introducing a new rail line, extending an existing system, etc.) may give disproportionately large effects on the land use, air quality, and ecosystem services, depending on the surrounding situation. The effects are greatest in cities that are actively changing their structure, where the inclusion of rail transit into the urban environment can stimulate dramatic shifts in the developmental trends, the movement patterns, and the environmental situation.

In others, the combined impacts of several rail projects could extend beyond some spatial limits, resulting in massive changes in the form of the city, people, and environmental resilience. To illustrate this, a set of transit lines, TOD policies, and investments in green infrastructure can overall change whole neighborhoods for the better, enhancing the quality of life and decreasing the environmental burden. Nevertheless, these systems need to be planned; otherwise, the city can go beyond some ecological or social limits, which cause negative externalities to the system, including gentrification, biodiversity loss, or more emissions [59].

6. Methods and Evidence Synthesis

To evaluate the environmental co-benefits and tradeoffs of urban rail transit systems, numerous methods of analysis as well as data sources have been utilized. These approaches give the researchers the ability to measure and model the multidimensional interactions between the transit systems, land-use changes, and ecological consequences. Knowledge of the strengths and weaknesses of these approaches can be essential in interpreting available research as well as informing future research in this area. The section of the literature review summarizes the most significant approaches to assessing environmental impacts of urban rail transit, the most prevalent challenges faced in measuring these impacts, and summarizes the available evidence on the effectiveness of rail systems to produce the desired environmental benefits [60]. **Table 4** outlines the main methodologies employed in the literature to assess the environmental impacts of urban rail transit.

Table 4. Methodologies Used in Evaluating the Environmental Impacts of Urban Rail Transit.

Methodology	Description	Strengths	Limitations
Difference-in-Differences (DID)	Compares pre- and post-transit environmental data in cities with and without rail transit	Controls for confounding factors, identifies causal impacts	Requires robust comparative data across similar cities
Regression Discontinuity Design (RDD)	Compares areas just inside and outside rail service zones	Allows for localized impact analysis	Requires clear cut-off points for service areas
Spatial Econometrics	Examines the spatial distribution of rail impacts using econometric models	Captures spillover effects and geographic variation	Requires high-quality spatial data
Remote Sensing	Uses satellite imagery and aerial photography to monitor land-use and ecosystem changes	Provides large-scale, continuous data across regions	Limited by resolution, accuracy of remote sensing data
Life Cycle Assessment	Evaluates environmental impacts across the entire lifecycle of rail systems	Comprehensive assessment of all phases (construction, operation)	High data and modeling requirements

6.1. Causal Inference Approaches: Difference-in-Differences and Regression Discontinuity Designs

Causal inference methods used to determine the environmental impacts of urban rail transit are some of the most widespread methods, which seek to establish a direct cause-and-effect correlation between the implementation of rail transit and the observed changes in the environment. Some of the most common methods include difference-in-differences (DID) and regression discontinuity designs (RDD) that are meant to address the effect of confounding variables and isolate the effects of rail transit on important outcomes, including emissions, air quality, and land use [22,61].

The difference-in-differences approach comes in especially handy when the researcher can contrast differences made to the environmental variables at the beginning and the end of the introduction of a rail system, not only in the cities that have rail transit, but also in similar cities that do not. The DID approach can explain time-varying factors potentially contributing to environmental outcomes using these differences between the outcomes of these two groups, e.g., economic growth, policy changes, or other urban development efforts.

Another useful tool is the regression discontinuity design, particularly where a clear threshold or cut-off point is used to locate rail systems. To illustrate, when a rail line is proposed to service a particular District or neighborhood, RDD can be applied to compare regions directly within and outside the service area to provide information about the local impact of rail transit on the quality of the air, land values, and other environmental indicators. Both DID and RDD techniques are useful, especially in the assessment of the causal relationships, although they must be done with high-quality and granular data to attain accurate results [61].

6.2. Spatial Econometrics and Geographic Information Systems

Due to the nature of urban rail systems (spatial) and the environmental effects on the environment, spatial econometrics and Geographic Information Systems (GIS) have become critical in understanding such relationships. Spatial econometric methods, which include spatial lag models and spatial error models, enable researchers to investigate the extent to which the environmental effects of rail transit are not confined only to immediate neighborhoods but also spill to the immediate environment. Such approaches will be useful to measure the impact of rail systems on the quality of air in the region, emissions savings, and land-use patterns by integrating spatial autocorrelation and considering the geographic distribution of the impacts.

GIS, in turn, is important in the visualization and mapping of the spatial distribution of environmental outcomes associated with rails. GIS tools facilitate a combination of disparate data, including land-use maps, air quality, and demographic information, to determine the spatial implications of rail transit. Such tools particularly come in handy to simulate the effects of transit-oriented development since they can be used to identify where TOD is most likely to happen and predict the magnitude of the environmental gains or trade-offs of greater density and land-use change around transit stations [18,51,62,63].

Integrating spatial econometrics and GIS allows the researcher to learn more about the geographical extent and scale of the environmental impact of rail transit and, therefore, determine those locations that might have to be modified through special mitigation measures or through adaptive management opportunities.

6.3. Remote Sensing and Environmental Indicators

Remote sensing devices such as satellite imagery and aerial photography have gained more significance in the evaluation of the environmental implications of urban rail transit, especially with regard to the change of land use and the dynamics of ecosystems. Remote sensing enables the researcher to monitor how the land cover changes, including changing agricultural or natural land into urban development, over a time period. This comes in handy, particularly in areas where ground data of high quality might be sparse or hard to acquire [64,65].

As an example, researchers can monitor urban heat islands or vegetation cover alterations in the neighborhoods affected by rail transit development using remote sensing. The comparison of pre- and post-construction satellite images also allows detection of a shift in temperature, the number of green spaces, and impervious surfaces, which are key ecological health indicators. Moreover, remote sensing can be used to determine the fragmentation of habitats and how much new rail lines can interfere with available wildlife corridors.

In the same way, additional data on the environmental indicators, including air quality levels, noise, and carbon emissions, can be incorporated with the remote sensing data in order to provide a more holistic picture of the ecological impacts of rail transit. Remote sensing is a priceless resource that offers an assessment method of the environmental effects of urban rail systems over the long term using a combination of both terrestrial and satellite-based measurements [66].

6.4. Life Cycle Assessment and Hybrid Models

The Life Cycle Assessment is a long-standing process of assessing the entire environmental effects of rail systems throughout the entire life cycle, including the building and operation/decommissioning of systems. The LCA enables the researcher to estimate the total energy utilization, resource use, and emissions of each stage of the rail system development, and this gives a complete picture of the environmental impact of the rail system. It is especially applicable when comparing the environmental effects of various modes of transportation since it takes into consideration the direct effects of rail operation, and the indirect effects of the materials and infrastructure that are to be built during construction.

Along with LCA, hybrid models, i.e., models that integrate LCA with other environmental modeling tools (energy modeling, air quality modeling, and transportation demand forecasting), have also been utilized in an ever-increasing manner to determine the overall environmental effects of urban rail transit. Through these models, indirect environmental impacts of rail investments can be predicted (e.g., how energy consumption will change with the shift in travel behavior or how land use will be displaced to other areas not necessarily served by rail).

Although the LCA and hybrid models offer an in-depth evaluation of the environmental performance of rail systems, the models are also associated with difficulties in the context of data accessibility and complexity. It may need high-quality data on material flows, factors of emission, and use of energy, and results of models may be sensitive to assumptions made regarding the future mixes of energy or technological progress in rail infrastructure [67].

6.5. Assessment of Existing Evidence: Findings and Limitations

The available literature on the environmental effects of urban rail transit indicates that there are several key findings. First, rail systems have high potential with regard to emitting fewer greenhouse gases and enhancing the quality of air by displacing the use of personal vehicles by commuters. Yet, the size of such advantages greatly depends on factors like the types of sources of energy applied to power the rail system, the density of developments around transit stations, and the level of integration of the rail systems with other forms of sustainable transport [5].

Second, even though the urban rail systems are typically linked with the diminishing urban sprawl and conservation of green space, they do not necessarily come true. Rail development has caused land prices and gentrification in some instances, displacing low-income people, which amplifies social inequality. It is a significant topic of concern that the effects of rail transit on social and ecological equity will be noticed, especially in cities where the affordability of housing and green spaces is already constrained [22].

Lastly, more longitudinal research studies are required that will monitor the long-term environmental impact of rail transit as time goes by. A lot of the available literature concentrates on the short-term effects or case studies of a particular city, so we still know little about the long-term ecological effects of the development of the rail system.

7. Planning and Policy Implications

The growth and evolution of the urban rail transit systems have enormous possibilities to design the future of the cities, as they will affect the land use, transportation behavior, and environmental performance. Nevertheless, in order to maximize environmental co-benefits of rail systems and minimize trade-offs, planners and policymakers of urban areas have to follow integrated and strategic approaches to the design, implementation, and operation of rail transit. This section delves into the main planning and policy implications that arise out of the above discussions, which provide an idea of how cities can maximize the environmental performance of their rail systems, in addition to developing sustainable and resilient cities [68].

7.1. Ecological Transit-Oriented Development Zoning

Transit-oriented development is one of the most effective ways to increase the environmental co-benefits of urban rail systems. TOD is concerned with supporting increased transit-based development density around transit stations and minimizing reliance on automobiles, in favor of walking and cycling, and limiting urban sprawl. Development that focuses on rail lines can help cities develop more efficient urban structures to maximize the utility of commuter transit, minimize car travel, and limit low-density suburban sprawl that wastes precious natural resources.

To achieve the full realization of the ecological potential of TOD, cities are to implement ecological TOD zoning policies, which would entail integrating environmental concerns in the process of planning. This may involve policies to conserve green lands, increase the biodiversity of cities and towns, and allow the incorporation of green infrastructure (permeable pavements, urban trees, and green roofs) to TOD areas. In urban centers where natural habitats and ecosystems are endangered by urbanization, TOD must focus on the restoration of the environment and the establishment of ecological corridors linking the urban areas with the natural landscape around them. Avoiding land use around rail stations will enable the cities to enhance the efficiency of rail systems, conserve ecosystems, and enhance climate change resilience at the same time [69].

7.2. Green Rail Design and Infrastructure

Green rail design is needed to make sure that the rail systems themselves are a positive contribution to environmental sustainability. Green rail design is the concept of sustainable construction and operation practices embedded into the creation and use of the rail systems. This involves low-carbon materials that will be used to build stations, tracks, and other infrastructure, and the setting up of rail systems that will consume less energy and generate less carbon. Rail system technologies can significantly minimize the carbon footprint of transit systems through energy-efficient rail operations (e.g., electric rail systems powered using renewable energy sources (solar, wind, etc.). Also, the regenerative braking technologies, where the energy may be captured and reused during the braking process, will also contribute to decreasing energy consumption and improving railway systems' efficiency. Replacement of sustainable rail vehicles, including hydrogen-powered trains or battery-electric trains, can also go a long way in mitigating the environmental impact of the rail system, especially in regions where the grid continues to rely on fossil fuels [22,70].

Outside of the trains, there are rail stations and terminals, which are subject to green implementation. Rail stations can act as green spaces with rain gardens, bioswales, and canopy-like trees being some of the elements used to treat stormwater, minimize the urban heat island effect, and improve the overall environmental quality of the surrounding environment. These green facilities could offer a useful source of public good in cities with low green cover, which enhances the quality of life of urban dwellers and leads to urban biodiversity.

7.3. Integrated Land-Use, Transportation, and Ecology Planning

Land-use, transportation, and ecology planning should be considered at the very beginning, in order to maximize the environmental advantages of rail systems. The isolated nature approach to urban planning, in which transportation, housing, and environmental policies are worked out in isolation, usually results in suboptimal results for both environmental sustainability and social equity. Cities can make sure that the development of urban rail transit can be used as the driver of sustainable development in all spheres by applying a holistic approach formed by systems-based planning.

This should be done through integration of transportation policies with land-use policies to facilitate smart growth and curb urban sprawl. To illustrate, cities can establish policies that focus high-density development around transit stations and, at the same time, limit low-density development that is based on automobiles to the locations that are further away from the rail lines, too. These policies must include ecological planning in which new developments will not affect the critical habitats or natural ecosystems. The integrated approach to planning also needs a collaborative way of governance and the contributions from the urban planners, transportation professionals, environmentalists, community bodies, and the local inhabitants. Participation of stakeholders in planning may assist in making sure that the environmental and social advantages of rail transit are well-spread over the city and that disadvantaged groups are not impacted by gentrification and displacement [71].

7.4. Mitigation Strategies for Environmental Trade-Offs

Even though urban rail transit systems demonstrate considerable environmental co-benefits, they have certain trade-offs that need to be reduced with the help of careful planning and policy interventions. Environmental mitigation measures must be utilized to cope with the environmental costs of rail construction, including habitat destruction, degradation of water quality, and soil erosion. An example is the construction of rail corridors in ecologically sensitive regions, where the city should embrace the environmental impact assessments (EIAs) to determine the risks involved and come up with measures that will lead to minimal damage. This could include the diversion of rail lines or rail lines around important wildlife habitats or the inclusion of wildlife crossings and green bridges that would enable animals to move safely through fragmented landscapes. Flight noise and light pollution by rail systems, especially along railways, can be alleviated through train design (creating quieter trains), the use of sound barriers, and employing strategies of minimizing the spillage of light, especially at night, in places with nocturnal animals [14,15].

Also, green infrastructure interventions, including planting trees along railways and near stations, can be used to mitigate the environmental effects of construction and operation. Plants and trees are used to absorb the stormwater, reduce air pollution, and provide a home to animals. In the right places, biodiversity conservation can be incorporated into rail development so that the urban rail transit systems reinforce and do not do so to the detriment of ecological health.

7.5. Policy Tools for Enhancing Social Equity and Sustainability

Although the environmental co-benefits of rail transit in urban areas cannot be undervalued, it is also vital to note that rail systems also lead to social equity. The development of railways can contribute to the increase of social inequality unintentionally, due to the processes of gentrification and the removal of low-income groups of the population. The policymakers have to embrace tools and strategies that would make the advantages of the rail systems available to everyone, including the marginalized population [72].

Planning of TODs must consider affordable housing policies to make sure that the increase in land prices in areas surrounding rail stations does not dislocate people with low-income levels. Cities may implement inclusionary zoning regulations that stipulate a percentage of new residential housing construction close to transit stations to be affordable to low-income households. Also, the community land trusts and the anti-displacement measures can be used to ensure that vulnerable residents are not negatively impacted by the high prices of properties.

Besides, bus networks must be structured to ensure they address the demands of the entire population, including those in underserved or discriminated communities. This can be achieved through making transit stations accessible, a fare structure of fares, and proper coverage of lower-income neighborhoods. Rail systems are also supposed to encourage active mobility by encouraging people to walk and to bike, particularly in places where individuals have the highest chances of using better transportation [73].

7.6. Governance and Implementation Challenges

To effectively apply the planning and policy recommendations that have been discussed in this section, there has to be an effective government structure and a concerted effort by the various levels of government. Many city rail transit systems are surrounded by complicated decision-making processes that might need cooperation among the national, regional, and local administrations, and the representatives of the business world.

The other dimension of effective governance is dealing with the financial and political issues associated with large-scale rail investments. The innovation needed in funding rail systems with minimal budgets is to utilize alternative financing schemes, including public-private partnerships (PPPs), infrastructure bonds, and international funding solutions. Secondly, there must be a long-term political commitment to sustainable transit so that the rail systems can be well incorporated into the other longer urban development strategies and remain strong despite any change in political or economic circumstances [68,74].

8. Conclusion

The urban rail transit has become a major urban approach to urban mobility and the sustainability of the environment. With effective transport, which is less carbon-intensive, the rail system has a high level of co-benefits, such as the generation of greenhouse gases, better air quality, and the development of more sustainable urban models through transit-oriented development. Nevertheless, such advantages are also linked to trade-offs, such as the ecological costs of construction, possible fragmentation of habitats, and the indirect impacts of the land-use changes, which may result in social inequality and environmental degradation in some situations.

This review has revealed that transit, land use, and ecology have a complicated relationship and a need to combine urban planning in a manner that emphasizes both the ecological and social aspects of rail transit. The co-benefits of urban rail are most significant in cities that focus on ecological TOD zoning, invest in green rail design as well, and implement integrated land-use, transportation, and ecological planning strategies. All of this effort can be used to make sure that rail systems not only serve to provide more efficient transportation, but they also aid in the establishment of more resilient and sustainable urban environments.

Although there is a definite possibility of the development of urban rail transit to accommodate sustainability objectives, there are major challenges. The environmental trade-offs and lifecycle carbon emissions of construction, in particular, the fragmentation of ecosystems, and the possibility of rebound and displacement effects, drive the importance of careful planning, mitigation, and continuous monitoring of rail system effects. Combining spatial econometrics and GIS tools, remote sensing, and life cycle assessments may offer useful insights into these complicated dynamics and assist in determining where the rail systems can have the most positive impact on the environment and social well-being. In the future, the cities must implement policies that will promote environmental sustainability and social equality. This involves making sure that the development of rail transit does not cause gentrification or the relocation of vulnerable groups and that the positive effects of rail systems are fairly shared. These goals will be realized through inclusive governance, whereby the voices of the local communities, environmental experts, and policymakers are included.

To sum up, the concept of urban rail transit has a significant potential for developing more sustainable, livable cities, yet its implementation relies on the careful planning of the systems that would consider both environmental and societal aspects of urbanization. Research in the future must address the knowledge gaps in the existing literature, especially when it comes to the long-term environmental effects of rail systems and how they contribute to creating urban resilience, as well as the overall consequences of transit-oriented development. Since cities in the global society are still busy with the development of rail infrastructure, a safe balance should be struck between the short-term environmental gains and the long-term effects of urbanization in such a way that urban transformation through rail development is relevant towards a really sustainable urban future.

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The author declares no conflict of interest.

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