Grassed Tramway Tracks and Sustainable Urban Mobility: Integrating Nature-based Solutions in City Transport Infrastructure

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Abstract: Urban mobility is crucial to sustainable city development, bridging environmental preservation, economic advancement, and social equity. This paper investigates the potential of grassed tramway tracks (or green tracks) in contributing to sustainable urban mobility and aligning with the United Nations Sustainable Development Goals (SDGs). The study highlights the transformative potential of green tracks by analyzing ecological impact, carbon sequestration, and a comparative evaluation of ecological footprints. The findings emphasize their role in mitigating climate change, enhancing urban biodiversity, and promoting resilient infrastructure, positioning them as a critical solution for achieving sustainable urban development.

Keywords: Sustainable urban mobility; Sustainable cities; Green tramway tracks

1 Introduction

Urban mobility is a cornerstone of sustainable city development, encompassing environmental preservation, economic progress, and social equity [1] [2] [3] [4]. Mobility by railway and tram has great impact [5]. With the increasing challenges of urbanization – such as congestion, air pollution, and climate change – there is a pressing need for innovative solutions to transition toward sustainable mobility [6]. The concept of sustainable urban mobility aligns with the United Nations' Sustainable Development Goals (SDGs), particularly SDG 11 ("Sustainable Cities and Communities"), emphasizing the importance of environmentally friendly, socially inclusive, and economically viable transportation systems. ") [7]. Grassed or "green" tramway tracks, incorporating vegetation such as Sedum species, offer multifaceted benefits, addressing ecological, aesthetic, and functional urban issues.

This paper explores the potential of grassed tramway tracks to solve urban sustainability challenges. By incorporating vegetation such as Sedum species into tramway infrastructure, these green tracks offer multifaceted benefits, including carbon sequestration, biodiversity enhancement, and improved urban microclimates. The study evaluates green tracks' ecological, aesthetic, and functional impact, situating them within the broader context of sustainable urban mobility.

2 Green Tracks and the SDGs

A detailed handbook on green tracks discusses their benefits [8]. Table 1 compares the benefits associated with Green Track in the handbook with the SDG indicators.

Table 1

Benefits of green tram tracks and their connection to relevant SDGs. (Source: [8] [9])

SDG Indicators [9]	Benefits and effects are associated with Green Tracks [8]
3.4.1 Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease	„Close link between provision of green space and levels of respiratory and heart problems indicate the significance of green areas."
6.4.1 Change in water-use efficiency over time	"Annual average: 50-70% of stormwater for each m² of Green Track; this corresponds to an average annual stormwater retention of 400-550 liters for each m² of vegetation area."
11.2.1 Proportion of the population that has convenient access to public transport by sex, age and persons with disabilities	„Better public acceptance of the tram schemes."
11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)	„Reduction in airborne particulate matter and other pollution through deposition on the vegetation surface and the vegetation base layer.

	Absorption of pollutants by plants and vegetation base layer. Reduction of continued dust dispersion within the track area.”
15.9.1 (a) Number of countries that have established national targets following or similar to Aichi Biodiversity Target 2 of the Strategic Plan for Biodiversity 2011–2020 in their national biodiversity strategy and action plans and the progress reported towards these targets; and (b) integration of biodiversity into national accounting and reporting systems, defined as implementation of the System of Environmental-Economic Accounting	“Green Tracks provide important habitats (biotopes) for biota.”

The list covers many areas but completely overlooks the positive impact of green tracks on climate change.

Similarly, the handbook notably fails to address their contribution to climate change mitigation, which is directly related to SDG13. Furthermore, certain benefits highlighted, such as noise reduction, have no direct correspondence with the current SDG framework. These gaps underscore the limitations of the SDG indicator system in recognizing local sustainability benefits, such as noise mitigation, despite their significant societal and environmental impact [10].

- Environmental Benefits: Green tracks mitigate the urban heat island effect, enhance air quality through CO_2 absorption, and support biodiversity by providing habitats for insects and small animals. These environmental contributions directly address the growing urban challenges of air pollution and loss of green spaces.
- Climate Action (SDG 13): Green tracks are pivotal in reducing greenhouse gas (GHG) emissions by sequestering carbon and promoting public transport. Their dual functionality as a transport solution and environmental intervention makes them a unique tool in the fight against climate change.
- Health and Well-being (SDG 3): Improved air quality and reduced noise pollution positively influence public health. Moreover, by creating a visually pleasing urban environment, green tracks encourage active modes of transport such as walking and cycling, further contributing to healthier lifestyles.
- Resilient Infrastructure (SDG 9): Green tracks integrate nature-based solutions into urban infrastructure, enhancing stormwater management and flood mitigation. This resilience-building aspect ensures that metropolitan areas are better prepared for extreme weather events brought about by climate change.

Furthermore, as Ferto and Harangozo [11] argue, sustainability-focused urban development is a fundamental but often disregarded contributor to the overall achievements of the UN SDGs.

3 Noise Pollution and Urban Well-being

Urban transport noise pollution presents substantial environmental, health, and economic issues but remains overlooked within the SDGs [10]. Excessive noise exposure can lead to cardiovascular diseases, sleep disturbances, decreased productivity, and diminished property values. Green tramway tracks significantly mitigate noise pollution, reducing noise levels by approximately 2-4 dB(A) compared to traditional paved or gravel tracks [12]. The vegetation dampens vibrations and rolling noise, improving overall urban liveability. Green tracks offer more than noise reduction – they foster a multifunctional urban environment that enhances psychological well-being, boosts public acceptance of tramway systems, and encourages a shift toward sustainable transportation alternatives [13].

Additionally, the cooling effect of green tracks helps counteract the urban heat island phenomenon, reducing surface temperatures and contributing to climate adaptation efforts [14]. Integrating nature-based solutions into transportation infrastructure supports broader urban resilience strategies, simultaneously improving air quality, urban cooling, and ecological connectivity [15] while mitigating noise [16]. Although noise mitigation indirectly supports several SDGs (e.g., SDG3 and SDG11), explicit recognition in global sustainability frameworks remains inadequate, highlighting a critical area for policy development.

4 Nature-based Solutions

Cities represent opportunities for forwarding biodiversity and sustainability goals. The environmental problems caused by carbon dioxide and other greenhouse gases are increasingly attracting the attention of people living in urban areas: for example, the formation of urban heat islands, unhealthy air quality, changes in human thermal comfort and drastic reductions in biodiversity [17]. Although nature and biodiversity protection frameworks and policies (such as the Natura 2000 network in the EU) focus on enhancing ecosystem services [18], the impacts are limited in urban areas. Urban green provides different ecosystem services, such as carbon sequestration and storage (CSS) [19] and climate change adaptation [20]. The EU has adopted a priority strategy on green infrastructure to preserve biodiversity and ecosystem services in urban environments [21] and supports sustainable nature-based solutions (NBSs) and urban regeneration [22]

[23]. NBSs are eco-solutions to societal challenges, inspired and supported by nature, simultaneously delivering harmonious environmental, social and economic benefits [22] [24]. In the urban context, NBSs are green solutions that bring nature into cities. The Commission defines nature-based solutions as cost-effective solutions inspired and supported by nature that deliver quantifiable environmental, social and economic benefits and help build resilience. Such solutions bring diverse nature into cities through locally adapted, resource-efficient solutions [25]. Nature-based solutions are relevant to the Kunming-Montreal Global Biodiversity Framework. Target 11: Restoring, maintaining and enhancing the contribution of nature to people, including ecosystem functions and services such as regulation of air, water and climate, soil health, and pollination, through nature-based solutions and ecosystem-based approaches for the benefit of all people and nature. Target 12: Enhance Green Spaces and Urban Planning for Human Well-Being and Biodiversity. In the context of the above objectives, the carbon sequestration potential of greenways will play an important role in future urban planning practice. Green tracks could provide a modern, highly efficient solution to several urban environmental problems. The grass tramway is predominantly made up of grasses and partly succulent plants, typically having a substrate depth of more than 15 cm and high water and maintenance requirements. The type of vegetation planted on the surface of a green track is one of the most important determinants of its performance. Sunlight requirements, water requirements, drought tolerance, cold tolerance, and disturbance tolerance are some factors influencing plant selection. Literature data confirms that *Sedum acre*, *Frankenia thymifolia* and *Vinca major*, which have good tolerance and performance characteristics and the best energy requirements and carbon dioxide emissions, are the best plants for the climate experienced in the field trial. Sedum acre is a good choice for a green track because of the plant's characteristics. It is a succulent plant that lives on the surface of the planting medium, does not grow tall, and does not interfere with passing vehicles (Figure 1).

Figure 1
Sedum species

In our study, we examined the species Sedum acre, assessing its effectiveness and environmental benefits. Green roof experiments show that if the dry mass of the plants is measured monthly for one year, the annual CO_2 uptake by photosynthesis of a Sedum acre green roof can be estimated at 0.14 kg/m^2 [26]. If a newly installed green track on an urban green roof can experimentally absorb approximately 150,000,000 to 180,000,000 ppm of carbon dioxide annually over a 100 square meter surface area for one year – depending on the photosynthetic activity and physiological characteristics of the plant species used – then the potential CO_2 absorption can be quantified based on the specific design parameters of the track.

The table below presents the ground cover plants we compared for use in green tracks (Table 2).

Table 2

Compared ground cover plants (Source: [27])

Plant	Sunlight requirement	Temperature tolerance	Water requirement	Plant height (m)	Leaf area index (m^2/m^2)	Soil thickness (m)	Humidity (%)	Toxicity
Sedum acre L.	Full sunlight	Cold tolerant	Drought tolerant	0.1	3.5	0.2	40	+
Sedum album L.	Full sunlight	Cold tolerant	Drought tolerant	0.05-0.1	3.5	0.2	40	-
Sedum floriferum	Full sunlight	Cold tolerant	Drought tolerant	0.05-0.2	2.74	0.2	40	+

Since children and animals may come into contact with plants in an urban environment, it is also necessary to test the toxicity of the chosen plants. Sedum acre and Sedum floriferum are toxic to pets and humans if ingested. Sedum album is non-toxic to pets and humans. It is safe to grow in households with animals and children. Our analyses of Sedum acre show that Sedum acre vegetation has a significant carbon sequestration capacity, sequestering approximately 0.143 kg of carbon per square metre per year. A 10 km greenway planted at a standard density (25 seedlings/m^2) sequesters approximately 734.4 kg of carbon per year. Increasing plant density significantly improves carbon sequestration, reaching up to 1836 kg per year for a 25 km stretch. This change represents a significant ecological advantage over unvegetated sections in an urban environment. The carbon sequestration capacity of greenways is almost identical to green walls. Hence, our research confirms our hypothesis that using greenways in urban environments has ecological benefits, even in urban areas that are highly degraded, overused and have low biodiversity indicators due to climate change. Using several sedum species mixed in a random pattern is recommended when creating green corridors. In addition to the increase in carbon sequestration potential, an increase in biodiversity can also be seen, as the diversity of the habitat to be created results in the appearance of animal species that prove the importance of the natural environment and the rightness of the human-nature relationship system in the highly degraded built urban environment. The main urban ecological and environmental benefits are reducing run-off, controlling evaporation, aesthetic value, noise/acoustic buffer, reducing temperature, reducing the urban heat island effect, water buffer, providing food for birds and insects, increasing green space, and increasing the wellbeing of the urban population. This research confirms our hypothesis that even in urban areas severely affected by climate change, built up, overdeveloped and with low biodiversity indicators, green tracks and their application in planning practice have significant quantifiable ecological benefits.

5 Quantifying Carbon Sequestration of Green Tracks

To fully appreciate the advantages of green tracks, a comparative analysis of traditionally designed paved tramway tracks and grassed versions was conducted. This evaluation, supported by Figures 2 and 3, highlights their environmental superiority.

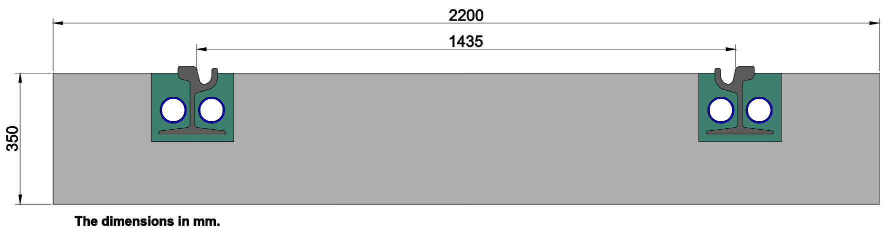

Figure 2a
General design and dimensions of paved tramway track

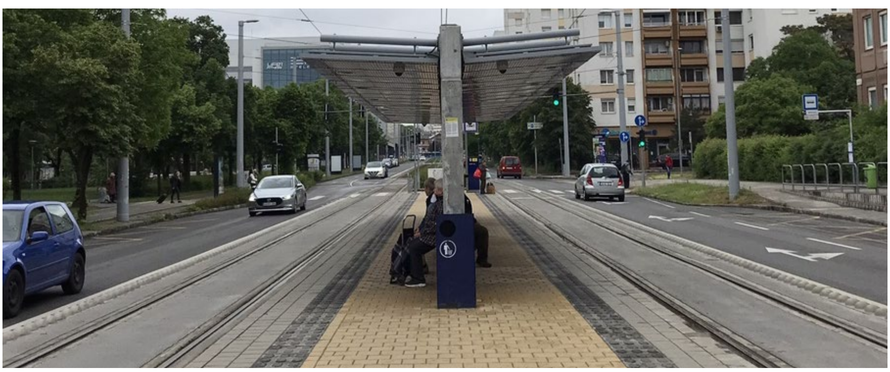

Figure 2b
Paved tramway track in Budapest

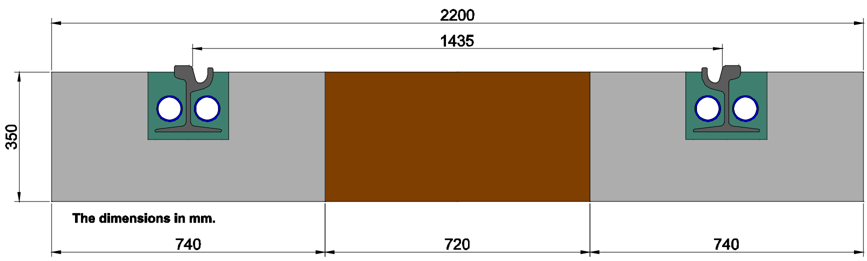

Figure 3a
General design and dimensions of grassed tramway track

Figure 3b
Grassed tramway track in Budapest

The four components below were examined in detail to perform the comparative analysis. The specific CO_2 emissions for each material were all considered according to the Inventory of Carbon and Energy Database (ICE) for 1 track meter [28]. To determine the CO_2 value from the transport of each component, the authors calculated the specific masses per 1 track meter. The initial data source is from "Treibhausgasemissionen durch die Schieninfrastruktur und Schienenfahrzeuge in Deutschland" [29].

Rails:

- 116.28 kg/track meter (59Ri2 rails),
- specific value of CO_2 emissions:1.27 kgCO_2/kg (structural steel),
- useful life: 15 years,
- transport distance: 500 km on railway. The specific emission is 26.7 g/tkm.

Embedding material:

- specific volume: 52.61 l/track meter (59Ri2),
- density of the embedding material: 0.9 kg/l,
- specific value of CO_2 emissions based: 4.84 kgCO_2/kg (flexible polyurethane foam),
- useful life: 15 years,
- transport distance: 500 km on road. The specific emission is 199.3 g/tkm for solo trucks (>26 t).

Track slab / beams:

- specific volume of the beams: 0.518 m3/track meter for two beams (740 x 350 mm),
- specific volume of the slab: 0.770 m3/track meter (2,200 x 350 mm),
- density of the concrete: 2,500 kg/m m^3,
- specific mass of the concrete: 1.295 t/ track meter,
- specific value of CO_2 emissions is 0.132 kgCO_2/kg (precast concrete pavement),
- useful life: 60 years,
- transport distance: 250 km on road. The specific emission is 199.3 g/tkm for solo trucks (>26 t).

Soil:

- thickness of the soil layer: 350 mm,
- width of the soil layer: 720 mm,
- specific volume of the soil: 0.252 m3/track meter,
- density of 2,000 kg/m3 was assumed,
- specific mass of the soil: 0.504 t/ track meter,
- specific value of CO_2 emissions: 0.024 kgCO_2/kg (compacted soil),
- useful life: 60 years,
- transport distance: 50 km on road. The specific emission is 199.3 g/tkm for solo trucks (>26 t).

Tables 3 and 4 provide a summary of the analysis results.

Table 3
Analysis from an Ecological Perspective Paved Design

Component	Material $kgCO_2$/track m	Transport $kgCO_2$/track m	Specific value $kgCO_2$/track m/y
Rails	147.7	1.552	9.950
Embedding m.	229.2	4.718	15.594
Track slab	254.1	95.913	5.833
Soil	0.0	0.0	0.0
		Σ	**31.377**

Table 4
Analysis from an Ecological Perspective Grassed Design

Component	Material $kgCO_2$/track m	Transport $kgCO_2$/track m	Specific value $kgCO_2$/track m/y
Rails	147.7	1.552	9.950
Embedding m.	229.2	4.718	15.594
Track beams	170.9	64.523	3.923
Soil	12.1	5.022	0.285
		Σ	**29.752**

These findings illustrate that grassed tramway tracks have a lower environmental footprint than their paved counterparts, particularly concerning CO_2 emissions. Furthermore, beyond lowering the resource use on the demand site in urban areas, green tracks also improve the quality of biocapacity available on the supply side [30]. Substituting concrete with soil and vegetation significantly contributes to this reduction. A further reduction in CO_2 emissions can be achieved by choosing the right rail steel material [31] [32] [33] and with the proper rail management [34]. It is also possible to reduce the environmental load caused by electric propulsion from the vehicle side, and we can typically see an effort to do so in traditional rail transport nowadays [35]. This question requires further research in an urban environment. Further research is also required on how the CO_2 emissions can be compared to the traditional crushed stone track [36] [37], especially if special elements [38] [39] have been placed in order to improve noise and acoustic properties. In this case, the authors naturally envisage a comparison with a different green track design than the one presented here.

6 Implementation Challenges and Policy Implications

Grassed tramway tracks are a practical application of sustainable urban planning. They enhance the aesthetic appeal and user experience of public transport systems, contributing to modal shift objectives. By improving the attractiveness and comfort of public transit, green tramway tracks encourage greater public transport use, reduce dependence on private vehicles, and support the EU's emission reduction goals. Furthermore, their integration into Sustainable Urban Mobility Plans (SUMPs) underscores their strategic importance in creating cohesive and environmentally sustainable urban networks.

However, successful implementation requires careful consideration of several factors. First, the selection of appropriate plant species is crucial: plants must tolerate the local climate, withstand urban stressors such as pollution and drought, and be safe for both humans and animals. While Sedum acre performed well in our study, further research is needed to test other species and planting combinations that could enhance biodiversity and carbon sequestration without compromising maintenance requirements.

Second, maintenance strategies must balance ecological benefits with operational feasibility and cost-effectiveness. Regular monitoring, targeted watering, and periodic trimming are essential to maintain both the functional and aesthetic qualities of green tracks. Policymakers and urban planners must also consider how to integrate these maintenance practices into existing transport infrastructure management.

Third, regulatory frameworks and funding mechanisms need to support the widespread adoption of green tracks. This includes incorporating green infrastructure into urban planning guidelines, providing incentives for sustainable construction, and aligning green tracks with broader sustainability goals, such as the European Green Deal and national climate action plans.

Finally, the long-term success of green tracks depends on public acceptance and stakeholder engagement. Transparent communication of their environmental, social, and economic benefits is key to building trust and support among residents, transport operators, and decision-makers.

Overall, while grassed tramway tracks offer a promising path toward sustainable urban mobility, their implementation requires coordinated efforts across multiple disciplines. Integrating technical, ecological, and social dimensions will ensure that green tracks not only enhance the urban landscape but also deliver tangible contributions to climate action, biodiversity protection, and improved quality of life.

Conclusions

Grassed tramway tracks exemplify the integration of ecological innovation into urban transport systems. Beyond their environmental benefits, they enhance urban aesthetics, improve microclimates, and promote biodiversity, contributing to several SDGs. As cities worldwide strive for sustainable development, green tracks offer a scalable solution to achieving efficient, resilient, and inclusive urban mobility.

Our findings confirm that green tracks have a lower environmental footprint compared to traditional paved tracks, particularly in terms of carbon dioxide emissions and embodied energy. The Sedum acre vegetation investigated in our study demonstrated a noteworthy carbon sequestration capacity of approximately 0.143 kg of carbon per square metre per year, adding to the overall carbon balance of urban areas. A 10 km greenway planted at standard density can sequester approximately 734.4 kg of carbon per year, while the comparative analysis of construction materials shows that green tracks save about 16,250 kg of carbon dioxide emissions annually compared to paved alternatives. This dual benefit – capturing carbon and reducing emissions from construction – highlights the significant role green tracks can play in climate change mitigation.

Moreover, green tracks are more than just a transport solution. They provide added value by trapping air pollutants, improving air quality, and reducing noise pollution. They also contribute to more attractive urban spaces, encouraging walking and cycling, which can further promote healthier lifestyles.

However, several challenges remain that need to be addressed to fully harness the potential of green tramway tracks. These include optimizing vegetation selection to balance drought tolerance and biodiversity, developing effective maintenance strategies that reduce costs without compromising ecological performance, and evaluating the long-term resilience of green tracks under varying urban conditions. While Sedum acre proved effective in our study, exploring other species or mixed planting schemes might further enhance ecosystem services and biodiversity.

Overall, grassed tramway tracks represent a forward-thinking, people-centered approach to sustainable urban development. By bridging the gap between transport and ecology, they symbolize how cities can become not just less harmful but actively restorative to the environment. Integrating green tracks into urban mobility plans is, therefore, not merely an aesthetic upgrade but a strategic investment in healthier, more sustainable, and more liveable cities.

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