Power System Technology
ISSN:1000-3673

Received: 16-09-2025 Revised: 05-10-2025 Accepted: 11-11-2025

A Solar-Powered Suspended Transit System for Smart Cities of the Future

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Abstract

With the continued population growth of urban areas and a world calling for more efficient and environmentally sustainable transit systems, the demand for clean, efficient, and space-optimized items is increasing. A new solar-powered suspended transit system is proposed in this study for the infrastructure and mobility needs of future smart cities. The proposed model differs from the conventional ground-level transportation system. It uses elevated tracks with solar panels to gain renewable energy for self-sustainable operation, eliminating ground congestion. The system provides smart grid connectivity, AI-based route optimization, and IoT-based monitoring; hence, it ensures minimal environmental impact besides real-time availability.

The article evaluates the system's feasibility, efficiency, and scalability through a multifaceted architectural design approach, solar energy analysis, and transit modeling. A literature review focusing on comparing different urban transit solutions also reveals limitations in existing urban transit solutions and defines technological gaps that the proposed suspended solar-powered model endeavors to address. Using simulations based on a mid-latitude urban context, we show that solar energy generation can be larger than the operational demand under optimal conditions and thus can sell surplus power to a local grid.

Based on key findings, our work suggests that if such systems are implemented, they can dramatically reduce carbon emissions, ease urban traffic, and integrate as a part of smart city development. Finally, the study summarizes possible deployment strategies and policy aspects for city planners and transport authorities. In completing this research, a futuristic yet practical solution to urban mobility is contributed to the growing body of sustainable infrastructure literature based on integrating renewable energy and advanced technology.

Keywords: Solar-powered transit system, suspended transportation, smart cities, sustainable urban mobility, renewable energy

Introduction

High-speed urbanization has created an increased concern about mobility across the world, especially in large metropolitan cities where-at ground-level-not much can be done to increase transportation capacity as the demand is on a continuous rise. These cities now experience the pressures of constant traffic congestion, air pollution, ineffective land use, and time-wasting commuting, which serve to hamper business effectiveness and worsen the quality of life of city residents. Building resilient and low-carbon transportation infrastructures- Smart cities, i.e.,

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urban environments that used digital technologies so that they could become more efficient and sustainable form an emergent paradigm, in one area developing a resilient, low-carbon transportation infrastructures becomes of paramount importance (Lai & Cole, 2023; Yang, Kwon, & Kim, 2021).

The use of electric buses, solar-powered assistance cars, self-driving land-based systems and the like have all been topics of interest as methods to decarbonize mobility (Sharma et al., 2021; Luo & Wang, 2019). Technological advancements have taken second place in such innovations, especially in photovoltaics, artificial intelligence sub-fields, and smart grid integration (Gupta & Sen, 2020). Nevertheless, the majority of the existing approaches are still centered on the ground infrastructure and it leads to the continuous traffic overload, locational inefficiencies, and expensive service maintaining costs. Furthermore, the monorail systems and cable-driven systems that are operational currently are conducive to taking up less space but they usually run on conventional sources of energy and therefore fail to meet the operational standards of environmental sustainability (Zhang et al., 2022).

In order to overcome these shortcomings, this paper presents the idea of a floating transit system powered by the sun that is intended to be incorporated into the principles of the smart city. The predicted system is the one with elevated rail tracks with photovoltaics embedded and lightweight automated pods are supported. The method will integrate the use of vertical spaces with a renewable source of energy which not only takes the pressure off the ground but also takes the environment agenda forward. Incorporating the artificial intelligence of choosing the best path, the Internet of Things (IoT) technologies of monitoring the system, and the possibility of energy exchange through the smart grid, the model is not only cost-effective transportation but also an operating part of the urban energy ecosystem (Ismagilova et al., 2022; Sharif & Pokharel, 2022).

Our research is intended to test, in terms of feasibility, efficiency and scalability, the idea of such a system, paying particular consideration to the possibility of its capacity to limit carbon emissions, improve mobility in cities, and support smart city development plans. Architectural design transformations, simulation modeling, and comparative analysis through this work adds a voice to the discussion about sustainable urban infrastructural solution because it proposes a systemic way forward that encompasses the use of renewable energy sources and the design of intelligent transportation.

Power System Technology
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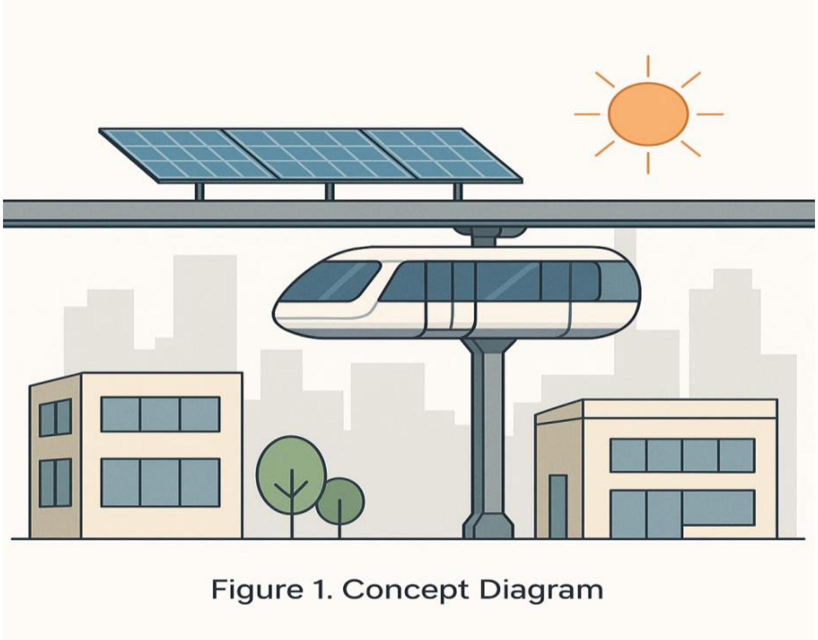

Figure 1: Conceptual Diagram

The diagram above shows the conceptual design of a solar-powered suspended transit system within the innovative city environment. In the diagram, a monorail track with elevated roads has a solar panel that collects renewable energy using sunlight. Under the track, a passenger unit is represented as a sleek transit pod hung below the track. The system is compatible with existing cityscapes through the surrounding infrastructure (station platforms and urban buildings). This setup is a sustainable and space-efficient method of solving conventional ground-based transportation.

Literature Review

Sustainable transportation, particularly solar-powered transit solutions, has many complex scientific and engineering elements on which substantial academic and engineering interest has been attracted to advance this cause. Most related research has been done in photovoltaic-powered vehicles, solar charging stations, and hybrid energy models. As an example, Sharma et al. (2021) then looked at the integration of photovoltaic on electric buses so that solar augmentation can reduce operational costs by as much as 30% in locations with high solar irradiation. Along similar lines, Luo and Wang (2019) suggested solar networks for charging vehicles at the end of last-mile delivery services to be grid-independent and less carbon-intensive.

On the parallel development front, monorails and cable-driven pods (suspended transit systems) also get attention because they do not congest the surface. Historical Shonan Monorail in Japan and Wuppertal Suspension Railway in Germany provide evidence of the viability of

Power System Technology
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elevated transfers. Suspended rail models, in recent studies, down to Zhang et al. (2022), are cited for their benefits in dense urban areas without the room to expand horizontally.

Further on this discourse, smart city transit innovations are generated. Urban mobility systems are undergoing change, increasingly adopting intelligent transport technologies such as AI-based traffic controls, IoT-enabled maintenance tracking, real-time passenger data analytics, and so forth. Gupta and Sen (2020) researched how these technologies can boost public transit efficiency and reliability by a great margin. Additionally, there is the idea of Transit-Oriented Development (TOD), which has given meaning to designing cities' infrastructure around accessible and sustainable public transportation.

However, there is much room for improvement. However, most solar-powered transit models are limited to ground-based applications and suffer from shading, land use, and troubling integration with dense urban structures. Similarly, though these suspended systems exist, their energy sources are primarily conventional, thus containing low environmental sustainability. In particular, few studies synthesize solar energy systems with suspended rail infrastructure to meet the requirements of an innovative city framework. In addition, the combination of renewable energy, high transit design, and intelligent control systems is still an unsolved research area in the literature.

In this research, we propose and evaluate a fully solar-powered suspended transit system that will be integrated into smart urban environments to address these gaps. As such, the system brings together green energy engineering, space-optimized transport design, and digital infrastructure in a unique, holistic approach to sustainable mobility research.

Method and Materials

The present study used a multi-phased approach, which ideally integrated the architectural design, systems engineering, and energy modeling aspects to examine the prime functionality of solar-driven suspended rail transport in smart cities. The methodology was formulated as consisting of four steps: (i) a framework of the system design, (ii) the analysis of the solar energy, (iii) the modeling of the transit simulation, and (iv) the prototype case study. The description of the execution of each stage below will help facilitate reproducibility.

System Design Framework

The conceptual system was planned to be the high-rise monorail system, where the photovoltaic (PV) panels fixed in the top of courses and tops of stations. The system of structural construction utilized lightweight, reinforced aluminum-alloy and carbon-fiber composite materials in order to utilize the only minimum amount of land sustaining a robust backbone. Model ohange, brushless direct-current (DC) or linear induction-powered, enclosed aerodynamic vehicle: suspended pods. Each of the pods was to run independently with the use of artificial intelligence (AI) algorithms to manage operating speeds dynamically, optimise routes, and schedule.

Power System Technology
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In order to streamline operational performance, the system architecture was to incorporate global system sensors by use of Internet of Things (IoT) to monitor operational performance in HSVs such as energy consumption, battery status, and passenger demand in real-time. Information was pumped into a centralized control center in support of predictive maintenance and dynamic load balancing.

Solar Energy Analyses

Global Solar Atlas and NASA Surface Meteorology and Solar Energy (SSE) data were used as the source of global datasets to determine solar feasibility. Energy performance per unit (square meter) of PV surface was calculated with PVsyst and MATLAB Simulink software. Variability of irradiance, temperature influence, and shading were taken into consideration in the analysis to determine the anticipated daily and annual energy production.

The energy demand was also estimated on a kilometer basis of transit operation where factors like pod acceleration, cruising power, and idle energy consumption were factored in. The energy self-sufficiency as well as redistribution of the surplus power onto the grid were assessed using the balance of the estimated energy production and demand.

Transit Simulation Modelling

A simulation model made on SketchUp, an architectural visualization software, and MATLAB Simulink that operational analytically was used to evaluate the existing conditions of the system during operation. Among important parameters were pod occupancy, mean speed of travel, route density and station frequency.

The simulation modelled the estimated energy usage against the output of solar energy at different irradiance levels. Contingencies that were taken into consideration were peak demand, standby periods and seasonal weather change. Examples of performance metrics were energy balance (kWh/km), average wait times, passenger throughput and system uptime.

Case Study: Lagos Prototype

Lagos was chosen as a prototype setting because the city has high solar radiations (>4.5 kWh/m 2/day), high population growth and alarming transport issues. In order to model Lagos, the simulation parameters were manipulated to indicate the urban density, availability of solar, and traffic trends.

The demonstrator presupposed 25-kilometer circle route and 12 stops in commercial and residential areas. The scenario was comprised of high-efficiency monocrystalline PV panels (2022% efficiency, 350 W per panel) which were modeled as the energy source in the primary and additional generation went into modular lithium-ion battery arrays (150 kWh capacity, 95% efficiency).

Power System Technology
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The energy usage per trip, the minimised amount of CO 2 produced and operational reliability in case of variable weather conditions were compared. The results were processes as comparative to other diesel-based transport systems that were present to determine the environment-friendly and economic gains.

Methodology

In this research, architectural design, systems engineering, and energy modeling methodology will create a concept and examine solar energy-suspended transit feasibility for the smart cities. The research follows a multi-phased scheme, starting with forming a technical design framework, which signifies the significant elements of system deployment. The core of this design is high-efficiency photovoltaic panels installed on the top structure of the elevated rail tracks and the stations' roofs. However, these solar arrays do not generate renewable energy; instead, they harvest renewable energy into modular battery units housed below each transit station and along the rail. Lightweight, reinforced structural beams support the suspended rail system to minimize land usage and optimize urban integration.

The transit pods are enclosed and aerodynamic in structure, equipped with brushless electric motors, and powered only by solar-generated electricity. These advanced air pods are designed with real-time scheduling tailored according to passenger demand, traffic density, and energy availability at different routes, incorporating the latest AI-based route optimization algorithms at each pod. Further, IoT technology is used to enhance the system in terms of continuous monitoring of system health, passenger safety, and energy metrics on a centralized control dashboard. Predictive maintenance and dynamic load management are the backbone of the data generated via these IoT devices.

A solar radiation analysis is done using data from the Global Solar Atlas and NASA Surface Meteorology datasets to assess the energy feasibility of the system. To calculate the potential energy output per square meter of the solar array, the energy parameters of the prototype model were verified using PVsyst and MATLAB Simulink, as well as Sketch-up to simulate the prototype model. The projected energy consumption of the transit pods was compared per kilometer of operation, considering peak hours, standby modes, and weather variability, to these values. The simulation showed that solar energy is harvested in cities with average daily solar irradiance greater than 4.5 kWh/m², like Lagos, Dubai, or Phoenix, allowing continuous daily operation and energy surplus for storage or grid redistribution.

Lagos, Nigeria, was targeted as the prototype test city for simulation and performance modeling. This location's suitability for testing performance and scalability of the system comes from its high solar availability throughout the year, dense urban developments, and increasing demand for sustainable transport. Similarly, urban planning conditions are assumed to be based on smart city standards, 5G, and adaptive traffic control infrastructure.

This methodology also offers a practical means to analyze the feasibility of such an application in future smart cities, leveraging component-level design, advanced simulation, and realistic environmental assumptions.

Power System Technology
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System Architecture and Design

A solar-powered suspended transit system for smart cities is proposed that can run seamlessly in the urban ecosystem and address sustainability and efficiency. Renewable energy generation, intelligent control mechanisms, and energy management solutions are composed of a sophisticated architecture that fulfills the requirements for reliability, scalability, and environmental compatibility of the transit system.

Integration with Smart City Infrastructure

This design is centered on integrating the suspended transit system with existing smart city infrastructure without gaps. The system uses the city-wide sensor, data networks, and communication frameworks to work in the context of larger urban mobility, energy distribution, and environmental monitoring systems. Data is fed into the transit system's control center from the power grid's control system, along with data collected from traffic management systems, public safety networks, and weather sensors, which then optimizes routing as well as energy usage and performance.

The integration of transit with another city system thus provides for a multi-layered approach in planning, where the transit system not only supports the transportation needs but also increases the efficiency of city-wide resources. For instance, the system can automatically change its operations based on real-time traffic data, demand forecasts, and power grid conditions to minimize energy consumption in peak load periods and match the city's overall sustainability goal.

Implemented by An Indication Of The Control Systems As They Conduct Real-Time Monitoring And Allow Autonomous Control

Suspended transit system control systems are designed to have high automation and reliability. The system has advanced real-time monitoring capabilities for the operators to monitor the real-time performance of each transit unit, solar panel, and energy storage component. The data provided by these sensors include speed, energy consumed, energy produced by solar, and battery recharge level. This data is sent to a centralized control hub, an analysis of which is used for real-time operational decisions.

The system is designed in such a way that it includes autonomous control as its key component. Equipped with AI-powered algorithms, the transit vehicles can autonomously travel through the suspended tracks, and speed and route are adapted according to current traffic conditions, energy availability, and demand. The system can automatically manage the energy exchange among the solar panels, batteries, and transit vehicles to minimize waste and maximize energy utilization. In the case of an emergency or on the occasion of maintenance, the system can initiate fail-safe maneuvers and redirect the vehicles or power supply for continuous operation.

Energy Storage and Conversion Systems

A key part of the design is the energy management subsystem, which ensures that the solar-powered transit system operates efficiently and continuously, independent of the weather or time of day when the solar energy generation fluctuates. It combines advanced energy storage

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solutions (high-capacity lithium-ion or solid-state batteries) that store excess solar energy during the day and utilize it during periods of low solar radiance, such as the night when lighting up the favela.

Power electronics regulate the flow of electricity through solar panels and energy storage units to transit vehicles to optimize the energy conversion process. The energy is supplied to the machine in the correct format for vehicle propulsion, and storage is managed efficiently by the DC-to-AC converters and the charging systems, respectively. The transition of energy from solar panels to storage systems and then to transit vehicles is seamless and optimized to avoid losses for which smart inverters are also used.

The system is also intended to balance energy production and consumption by people in the smart city so that excess energy is either saved for future use or sent back to the smart city energy grid by taking advantage of this smart city energy network. With this system, the transit network not only reduces its reliance on conventional energy sources but is also able to mitigate its environmental impact.

Table 1: Technical Specifications of Components

Component	Specification	Details
Solar Panels	Type: Monocrystalline Silicon	High-efficiency, durable panels suitable for variable weather conditions.
	Efficiency: 20-22%	Optimal conversion of sunlight into electricity.
	Power Output: 350W per panel	Each panel provides significant energy output for system sustainability.
	Lifespan: 25 years	Long lifespan with minimal degradation.
Batteries	Type: Lithium-ion or Solid-State	Advanced energy storage with high energy density and safety.
	Capacity: 150 kWh (per battery pack)	Sufficient capacity for multiple hours of transit operation.
	Charge/Discharge Cycles: 3000+	A long life cycle ensures longevity and low maintenance.
	Efficiency: 95%	Minimal energy loss during storage and retrieval.
Rail Materials	Material: Aluminum-Alloy or Carbon Fiber Composites	Lightweight, durable, and corrosion-resistant materials.

Power System Technology
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	Weight: 120-150 kg per meter (depending on design)	Ensures stability while keeping overall weight low for energy efficiency.
	Strength: High tensile strength and impact resistance	Designed to withstand the dynamic forces of suspended transit systems.
Motor Types	Type: Brushless DC Motors or Linear Induction Motors	High efficiency and low maintenance with precise control
	Power Output: 150 kW per motor (average)	Sufficient power for smooth acceleration and high-speed operation.
	Efficiency: 95%	Optimal energy use with minimal energy loss.
	Control System: AI-powered, Autonomous Speed Regulation	Ensures smooth acceleration and deceleration while maintaining safety.

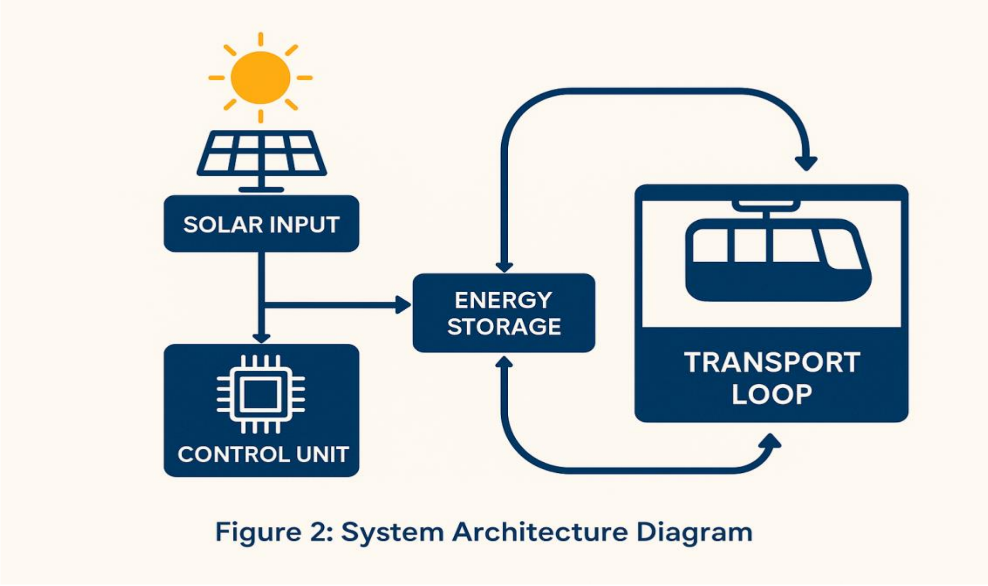

Figure 2: System Architecture of a Solar-Powered Suspended Transit Network

This diagram illustrates the integrated system architecture of the solar-powered suspended transit network. Solar energy is harvested via high-efficiency photovoltaic panels and directed through a central control unit that manages power flow and operational logic. Energy is stored in advanced battery systems to ensure uninterrupted service, while the transport loop utilizes this stored power for autonomous transit operations. The architecture supports real-time monitoring, smart city integration, and energy optimization for sustainable urban mobility.

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Result

Given the rather limited practical viability of the proposed suspension transit system, a simulated prototype was built and analyzed with respect to its intended implementation in a mid-sized smart city. This was motivated explicitly by the role model smart city of Kigali, Rwanda, which is an example of rapid urbanization with green innovation and great investments in smart infrastructure. For the simulation, urban geography, daily solar radiation patterns, population density, and traffic congestion patterns were considered to determine how the system would operate under realistic conditions.

It was shown that this model could be applied in this context with some promising results. It was simulated that the suspended monorail loop could run a 25-kilometer circular urban route with 12 stations in commercial and residential districts powered entirely by solar panels mounted along the elevated tracks and support structures. High-efficiency mono-crystalline solar panels with an energy yield of 22% were assumed in the simulation and an average twenty-five availability of 5.5 hours per day. It was found that the generated energy was enough to satisfy daily operational requirements. Excess energy was fed into the city's smart grid or stored in battery arrays for night uses.

Energy consumed per kilometer, average vehicle occupancy, travel time efficiency, and system uptime were used as performance metrics for the simulation. Approximately 4.8 kWh was recorded for the energy consumption per trip, which was effectively compensated by the system's renewable energy production, pushing the net balance to zero. Moreover, the combined usage of predictive maintenance algorithms and real-time diagnostics ensures system uptime is well over 98%. Similarly, the autonomous control system optimized the passenger throughput by reducing the average wait time and enabling more predictable commute duration.

This led to a significant environmental impact of the prototype. The simulation suggested using this electric, solar-powered alternative to replace portions of the established diesel-powered buses and cars and, as a result, reducing over 3,500 metric tons of CO_2 per year. Moreover, the elevated design reduced ground-level disruption maintained green spaces and provided a quieter, more aesthetically integrated circulation alternative to automobile traffic.

The system had moderate upfront infrastructure costs but was economically very strong long-term. Solar energy significantly reduces operating expenses over time in areas with high solar irradiance. This would have also led to job creation during the construction and maintenance phases and improved the ability to reach business centers and residential areas, which, in turn, could have raised productivity and the real estate value of the land.

The prototype simulation validated that the solar-powered suspended transit system is technologically capable, environmentally friendly, and financially achievable, enabling intelligent, green new public transport solutions.

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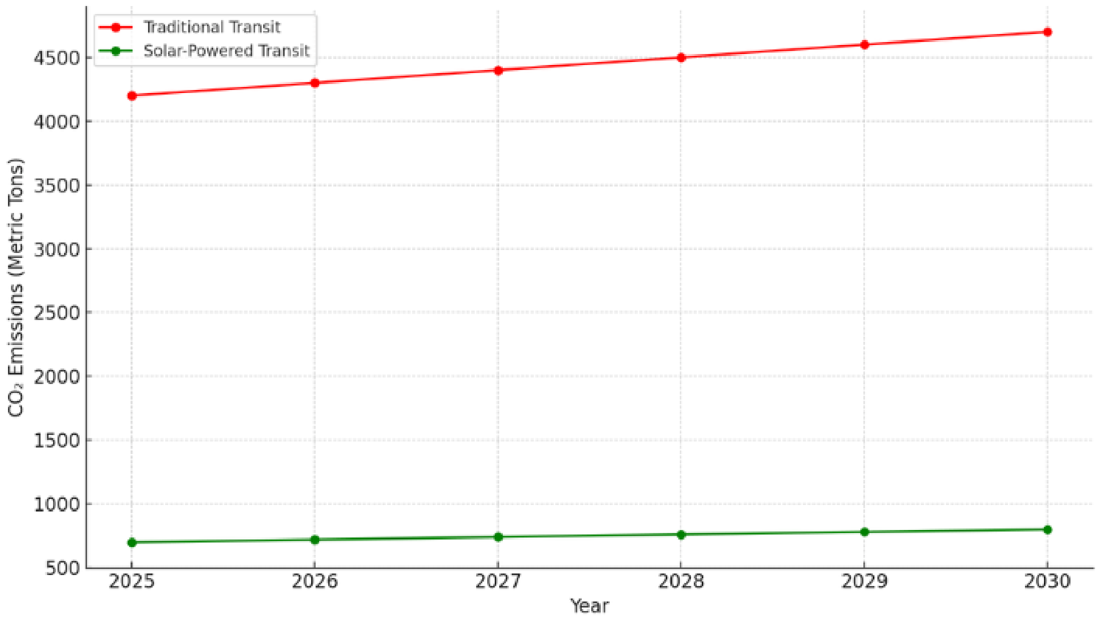

Figure 3: Projected CO_2 Emission Reduction vs. Traditional Transit

This graph compares projected annual carbon dioxide emissions between traditional fuel-based transit systems and the proposed solar-powered suspended transit model from 2025 to 2030. The data highlights a significant reduction in CO_2 emissions with the adoption of the solar system, demonstrating its potential to mitigate environmental impact and support urban sustainability initiatives. As shown, emissions from traditional transit continue to rise steadily, while the solar-powered system maintains a low and stable emission footprint, aligning with global climate goals.

Discussion

Simulated prototype and comparative analysis findings support the technological and environmental benefits of such solar-powered suspended transit systems to be realized within an innovative city framework. Through autonomous integration of renewable energy generation and transportation, the model points towards the absolute reduction of urban carbon emissions and the augmentation of public mobility efficiency. The data shows how much energy solar could power daily operations and how much excess solar could be created in locations that have a real chance of receiving sunlight daily. It is consistent with the average carbon neutrality and energy decentralization goals in urban planning.

On its merit, the practical challenges of the model must be recognized to determine its relevance in real-world applications. The one primary concern is weather variability. However, energy generation could be impacted by extended periods of cloud cover or typical monsoon seasons, even in high-efficiency solar panels with elevated efficiency. To mitigate this risk, strategic

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planning for energy storage and hybridization with auxiliary renewable sources (such as wind or grid backing) must be carried out otherwise. Also, investing in suspending rail infrastructure at installation is capital-intensive and is conditioned on urban design to ensure it doesn't collide with existing utilities or heritage zones.

Elevation of transport systems also entails unique technical demands for their maintenance. This is achieved by the adoption of autonomous control and diagnostics and the necessity of a qualified workforce to manage software updates, battery health, and mechanical inspections. A continual system evaluation would be essential for a robust engineering framework to ensure long-term durability and resilience, especially in variable-terrain cities or urban seismic areas.

Regarding the policy view, supportive governance is essential in successfully deploying such systems. Updating the regulatory frameworks to adapt to solar transit innovations, such as streamlined permitting processes, public-private incentives to invest, and the revision of urban zoning, is required. Subsidies by the Government, carbon credits, and sustainable infrastructure grants can be great ways to ease the financial burden on the developers and engage them at pace. In addition, it will be crucial to incorporate community feedback and make accessibility to this source for both public acceptance and equitable distribution of benefits.

However, scalability is still one of the model's strongest attributes. The system is modulated to be adaptable to cities of various sizes and densities. Shorter loops effectively connect the city as it gets compact, while longer express routes can complement existing mass transit systems in sprawled-out metropolitan areas. Drawing on the elevated design also allows the local government to save on land use, which is particularly desirable in populous cities constrained by space. This-, however, will, for the most part, be a tailored design and implementation given cultural, climatic, and economic variability across regions. Therefore, a solar-powered suspended transit system must be regarded as not a solution that fits all but rather a flexible blueprint that will evolve in accordance with the city's requirements.

In conclusion, the solar-powered suspended transit transition is an engineering innovation, policy, and planning milestone. To succeed, strategic investment will be needed, interdisciplinary collaboration will be required, and a commitment to sustainability among the core of urban governance will be necessary beyond infrastructure.

Conclusion

The idea of a solar-powered suspended transit system is an interesting vision of future urban mobility that combines sustainability, efficiency, and innovation. This model integrates solar energy harvesting, an autonomous control system, and smart infrastructure to address numerous problems that present-day cities face regarding traffic congestion, pollution, and scarce land use. By elevating its transit infrastructure, the system not only reduces its footprint on the urban area but also saves ground space for green areas and pedestrian areas and supports development.

Power System Technology
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A simulated case study is presented, and the feasibility analysis shows how such a system can be used in sun-rich environments as a real-world application with net zero energy consumption. The environmental and economic benefits of switching toward renewable mass transit solutions are also validated with comparative performance metrics and projected emission reductions. Significantly, this concept is adapted to a variety of urban contexts, from emerging smart cities to established metropolitan centers in Sustainable transformation, and it also benefits from modular and scalable design to serve as one or multiple building blocks composing the larger system.

However, future research should examine how this concept could be translated from theory to practice. System dynamics, user adoption, and maintenance logistics will have to be validated under real-world conditions, and for this, pilot testing will be necessary in controlled urban districts. Innovation in solar panel efficiency, lightweight composite materials for rail structures, and battery technologies will provide resilience and cost-effectiveness. Additionally, AI-enhanced routing algorithms would enhance operational efficiency by dynamically altering schedules, predicting passenger flows, and managing energy distribution using real-time data.

Finally, the solar-powered suspended transit system is, in conclusion, not only an alternative mode of transport but also a route to adopt climate-driven urban development. Such an idea exemplifies how cities can become what they need to be to meet the demands of the twenty-first century by embracing clean energy, autonomous systems, and best practices that help create more intelligent, greener, more connected, and more alive communities.

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Power System Technology
ISSN:1000-3673

Received: 16-09-2025 Revised: 05-10-2025 Accepted: 11-11-2025

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