

# Metro Systems' Role in Reducing CO<sub>2</sub> Emissions in Urban Transport

Carlos Eduardo Sanches de Andrade<sup>1,\*</sup>

## Abstract

*To better understand the impact of metro systems on reducing CO<sub>2</sub> emissions in urban transport, a detailed analysis is required. This analysis should evaluate both the direct and broader effects of metro networks on the overall urban transportation system. It is crucial to quantify the actual contribution of metro systems in cutting CO<sub>2</sub> emissions by considering the entire transport network. The evaluation should include not only the emissions generated by metro operations but also the reductions achieved by decreasing reliance on higher-emission modes like cars, buses, and motorcycles. From an engineering perspective, metro systems can improve urban mobility efficiency by increasing passenger capacity, reducing traffic congestion, and enhancing the energy efficiency of public transport. Replacing private vehicles and buses with high-capacity rail systems can significantly lower per capita emissions and enhance air quality. Additionally, the energy source powering metro systems, particularly electricity from renewable sources, plays a crucial role in reducing the carbon footprint of urban transportation. This work aims to develop a comprehensive methodology for estimating CO<sub>2</sub> emissions, accounting for both the emissions directly produced by metro systems and the emissions avoided due to their operation. By integrating transport engineering concepts such as vehicle-kilometer reductions, energy efficiency measures, and modal shift effects, this methodology will assess the net environmental benefits of metro systems. The findings will highlight the key role metro systems can play in supporting sustainable, low-carbon urban transport systems, aiding in the planning and development of future infrastructure that balances environmental performance with high-quality service and connectivity.*

**Keywords:** Reducing CO<sub>2</sub> emissions, passenger transportation, transport sector, metros

## INTRODUCTION

By 2050, energy consumption in transport systems is projected to double, leading to a substantial increase in greenhouse gas (GHG) emissions unless effective mitigation measures are adopted. Road-based transport modes, such as cars, buses, and motorcycles, are key contributors to these emissions, with carbon dioxide (CO<sub>2</sub>) being the predominant pollutant. CO<sub>2</sub> emissions from transport significantly contribute to global warming and climate change. As urban populations expand and transportation demand grows, addressing the environmental consequences of these emissions becomes increasingly critical [1–4].

### \*Author for Correspondence

Carlos Eduardo Sanches de Andrade  
E-mail: carlos.sanches@ufg.br

<sup>1</sup>Professor, Federal University of Goiás, Faculty of Science and Technology, Estrada Municipal–Quadra e Área Lote 04–Bairro Fazenda Santo Antônio, CEP: 74.971-451, Aparecida de Goiânia, GO, Brazil

Received Date: September 03, 2024  
Accepted Date: September 26, 2024  
Published Date: September 28, 2024

**Citation:** Carlos Eduardo Sanches de Andrade. Metro Systems' Role in Reducing CO<sub>2</sub> Emissions in Urban Transport. Trends in Transport Engineering and Applications. 2024; 11(3): 19–22p.

In recent years, there has been a growing recognition of the need to curb transport-related emissions. Governments, urban planners, and policymakers are taking steps to develop sustainable transport solutions to address this issue. Many cities have set ambitious targets for reducing CO<sub>2</sub> emissions from transport. For example, New York City aims to cut emissions by 30% by 2030 compared to 2005 levels, while London has set a goal to reduce transport emissions by 60% by 2025 using 1999 levels as a baseline. Rio de Janeiro has

---

also introduced legislation to decrease emissions by 30% between 2010 and 2030. These initiatives highlight a global push towards developing sustainable urban transport systems that align with international climate objectives.

A key strategy for reducing transport emissions is improving public transportation systems, particularly metro networks. Metro systems can significantly reduce CO<sub>2</sub> emissions by providing a high-capacity, energy-efficient alternative to road transport. By encouraging a shift from private vehicles and buses to metro systems, cities can decrease congestion, enhance air quality, and reduce per capita emissions. However, a comprehensive analysis is required to fully understand the environmental benefits of metro systems, considering both the emissions generated by their operations and the emissions avoided by reducing reliance on more polluting forms of transport [5–8].

The goal of this study is to evaluate the overall impact of metro systems on CO<sub>2</sub> emissions in urban environments, focusing on both direct emissions from metro operations and the indirect emissions reductions achieved by replacing more polluting transport modes. By applying this methodology to various cities, the study aims to illustrate how metro systems can play a crucial role in lowering urban transport emissions and support efforts toward sustainable urban development.

### **CO<sub>2</sub> EMISSIONS PRODUCED BY METRO SYSTEMS**

CO<sub>2</sub> emissions from metro systems include all emissions generated through their operation. These emissions are categorized following the guidelines of the Intergovernmental Panel on Climate Change (IPCC) and the ISO 14064 standard for greenhouse gases. According to these standards, direct emissions (Scope 1) include emissions from sources such as generators, maintenance vehicles, and auxiliary equipment. Scope 2 covers indirect emissions from electricity consumption, while Scope 3, which is optional, includes other indirect emissions such as those from employee commuting and waste management [9, 10].

The amount of CO<sub>2</sub> emissions produced by metro systems varies depending on the energy source used to generate electricity in different regions. In countries like Brazil, where hydroelectric power dominates, emissions from electricity generation are generally low, as hydroelectric power accounts for over 80% of the country's energy supply. In contrast, many regions in Europe, Asia, and Oceania rely heavily on thermal power sources such as coal, oil, and gas, which result in higher emissions. To compare emissions between transport systems, it is useful to express CO<sub>2</sub> emissions per passenger-kilometer, which indicates the system's efficiency in terms of emissions [11–13].

### **CO<sub>2</sub> EMISSIONS AVOIDED BY METRO SYSTEMS**

In the absence of a metro system, cities would experience higher levels of road transport, such as cars, vans, buses, and motorcycles, resulting in increased CO<sub>2</sub> emissions. Metro systems reduce the demand for these more polluting modes of transportation by offering an alternative that can handle a large volume of passengers. This shift in travel behavior not only reduces the number of vehicles on the road but also improves traffic conditions, further lowering emissions from the remaining vehicles due to reduced congestion [14].

To calculate the CO<sub>2</sub> emissions avoided by a metro system, it is necessary to estimate the emissions that would have been generated if passengers had used other modes of transport. This requires determining which transport modes passengers would have relied on in the absence of the metro system and calculating the associated emissions. Understanding these avoided emissions is essential to evaluate the broader environmental benefits of metro systems in reducing road traffic and overall CO<sub>2</sub> emissions.

An avoided emissions model, developed by APTA [8], includes three key factors:

1. *Mode shift*: Without a metro system, other more polluting modes of transport such as cars, vans, buses, and motorcycles would be used, resulting in increased CO<sub>2</sub> emissions.

2. *Congestion relief*: Increased vehicle numbers on the road would lead to higher congestion levels, causing additional fuel consumption and thus higher emissions.
3. *Land use*: Metro systems encourage higher population density near stations, promoting walking and cycling, and reducing the need for long-distance car travel.

The total avoided emissions are calculated by summing the emissions avoided by each factor. The net avoided emissions are then determined by subtracting the metro’s emissions from the total avoided emissions. The “mode shift” factor is the most widely used method for calculating avoided emissions. This approach estimates the CO<sub>2</sub> emissions that would have been generated by other forms of transport if the metro system were not available. To do so, data on which transport modes passengers would use in the absence of the metro are collected, and the corresponding CO<sub>2</sub> emissions are calculated.

### THE CONTRIBUTION OF METRO SYSTEMS TO REDUCING EMISSIONS

The methodology outlined in this study includes the following components:

1. *Debit*: This refers to the emissions produced by the metro system, as determined through an inventory of GHG emissions.
2. *Credit*: This refers to the emissions avoided by the metro system's operation. Without the metro, passengers would be forced to travel by foot, bicycle, or more polluting modes of transport such as private cars, taxis, buses, vans, and motorcycles.

By comparing the debit (produced emissions) with the credit (avoided emissions), the net impact of the metro system on emissions can be evaluated. A positive net emission would indicate that the metro system leads to higher overall CO<sub>2</sub> emissions, which could occur in cities with a heavy reliance on thermal power sources or low ridership. Conversely, a negative net emission, where the credit outweighs the debit, would demonstrate that the metro system contributes to reducing the city's overall CO<sub>2</sub> emissions. Emissions produced and avoided by various metro systems were gathered from published reports, as displayed in Table 1.

The results of the analysis show that in all metro systems studied, the emissions avoided were significantly higher than those produced. Variations in the ratio of avoided to produced emissions can be attributed to differences in the scope and methodology used, as well as local energy matrices. For instance, in Lisbon and Porto, Portugal’s heavy reliance on imported energy, predominantly from fossil fuels (90% of primary energy), contributes to higher emissions [9]. In contrast, Brazil benefits from a cleaner energy matrix, with only about 10% of its electricity derived from thermal sources [6]. In the case of New York, the data encompasses the entire public transport system (including metro, trains, and buses), and considers all three emission-reducing factors (mode shift, congestion relief, and land use) in comparison to car use, while for the other cities, the focus was solely on metro systems using the “mode shift” factor.

The composition of the energy matrix for each metro system is a critical factor in determining net avoided emissions, as it directly influences the emissions produced. Additionally, passenger demand is a key element; metro systems need a sufficiently high occupancy rate to ensure that avoided emissions are substantial and exceed those produced.

**Table 1.** Results of avoided net emissions, in tCO<sub>2</sub>e, from the São Paulo, Rio de Janeiro, Lisbon, Porto and New York public transport systems.

	São Paulo	Rio de Janeiro	Lisbon	Porto	New York
Emissions produced	43,603	7,945	56,906	17,600	2,100,000
Avoided emissions	820,930	41,039	130,275	56,403	17,000,000
Result = Net emissions avoided	777,327	33,094	73,369	38,803	14,900,000
(%) Emissions avoided/produced	1,883%	516%	229%	320%	809%
Sources (References)	[10]	[11]	[12]	[13]	[14]

---

## CONCLUSIONS

In assessing the CO<sub>2</sub> impact of urban transport systems, it is important to recognize that metro systems help avoid emissions that would otherwise be generated by more polluting modes of transport. The proposed methodology, which calculates produced (debit) and avoided (credit) emissions, provides a way to measure the net impact of metro systems on a city's overall CO<sub>2</sub> emissions.

The energy matrix used to power metro systems plays a crucial role in the final outcome of this methodology, as it directly affects the produced emissions. Likewise, passenger demand is a significant factor, as higher occupancy rates lead to more significant avoided emissions, which need to surpass the produced emissions for the metro system to have a positive environmental impact.

The application of this methodology to the metro systems studied in this article demonstrates that all had negative net emissions, meaning that their operations positively impacted the city's overall CO<sub>2</sub> emissions during the years analyzed. Thus, metro systems generally outperform other transport modes in terms of reducing CO<sub>2</sub> emissions, making them a favorable option for mitigating urban transport-related emissions.

## REFERENCES

1. IEA – International Energy Agency. Transport, Energy, and CO<sub>2</sub>. [Online]. 2009. Available at <https://www.iea.org/publications/freepublications/publication/transport2009.pdf>
2. PlaNYC – New York City Plan. Reducing Greenhouse Gas Emissions in New York City. [Online]. 2011. Available at [http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/full\\_report\\_2007.pdf](http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/full_report_2007.pdf)
3. London Underground. London Underground Carbon Footprint. [Online]. 2009. Available at <http://www.tfl.gov.uk/assets/downloads/corporate/london-underground-carbon-footprint-2008.pdf>
4. Rio de Janeiro State Decree No. 43,216. [Online]. 2011. Available at <https://www.legisweb.com.br/legislacao/?id=159527>
5. ISO 14.064 – International Organization for Standardization. Greenhouse Gas Emissions. Geneva, Switzerland: ISO; 2007.
6. EPE – Energy Research Company. National Energy Balance. [Online]. 2012. Available at [https://ben.epe.gov.br/downloads/Resultados\\_Pre\\_BEN\\_2012.pdf](https://ben.epe.gov.br/downloads/Resultados_Pre_BEN_2012.pdf)
7. CoMET – Community of Metros. Energy Costs, Renewables, and CO<sub>2</sub> Emissions: Nova Phase 10 Case Study. London, UK: CoMET; 2008.
8. APTA – American Public Transportation Association. Recommended Practices for Quantifying Greenhouse Gas Emissions from Transit. [Online]. 2009. Available at <http://www.apta.com/resources/hottopics/sustainability/Documents/Quantifying-Greenhouse-Gas-Emissions-APTA-Recommended-Practices.pdf>
9. Lisboa e-Nova – Lisbon Municipal Energy-Environment Agency. An Energy-Environmental Strategy for the City of Lisbon. [Online]. 2010. Available at [http://www.cfn.ist.utl.pt/conf\\_energia/files/21\\_11\\_Apresentacao.pdf](http://www.cfn.ist.utl.pt/conf_energia/files/21_11_Apresentacao.pdf)
10. São Paulo Metro. Greenhouse Gas Emissions Inventory São Paulo Metro 2012. Cacilda Bastos Pereira da Silva, Sustainability Coordinator at São Paulo Metro. São Paulo, Brazil: São Paulo Metro; 2013.
11. Andrade CES, D'Agosto MA, Leal Júnior IC. Evaluation of the CO<sub>2</sub> reduction gain due to the availability of a subway system: application to the Rio de Janeiro Metro. *Transport J.* 2013; 21 (2): 5–12. Available at <https://revistatransportes.org.br/anpet/article/view/653>
12. Lisbon Metro. 2010 Sustainability Report. [Online]. 2011. Available at <http://www.metrolisboa.pt/wp-content/uploads/Relat%C3%B3rio-de-sustentabilidade2010.pdf>
13. Porto Metro. 2010 Sustainability Report. [Online]. 2011. Available at [http://www.metroporto.pt/PageGen.aspx?WMCM\\_PaginaId=17246](http://www.metroporto.pt/PageGen.aspx?WMCM_PaginaId=17246)
14. MTA – Metropolitan Transport Authority. Sustainability Report. [Online]. 2012. Available at <http://www.mta.info/sustainability/pdf/2012Report.pdf>