QUANTIFYING AND MITIGATING NEIGHBOURHOOD TRANSPORTATION CO2 EMISSIONS THROUGH DATA-DRIVEN URBAN DESIGN

ALEKSEI KONDRATENKO[1], HOUSSAME EDDINE HSAIN[2], CESAR CHENG[3], RISHAN ANTONIO[4], MACIEJ NISZTUK[5], TEJAS CHAVAN[6], CAMIEL WEIJENBERG[7], and SAYJEL VIJAY PATEL[8]
[1,2,3,4,5,6,7,8] *Digital Blue Foam*
[1,2,3,4,5,6,7,8] *{aleksei|houssame|cesar|rishan|maciej|tejas|camiel|sayjel}@digitalbluefoam.com*
[1] *0000-0003-2436-2631*
[2] *0009-0002-6214-5080*
[5] *0000-0001-6520-5128*

Abstract. Urban areas are significant contributors to CO2 emissions, mainly due to transportation. In this paper, we introduce a novel data-driven tool that leverages urban design to mitigate transportation-related emissions. Our original contribution lies in the development of a comprehensive methodology and a digital analytics tool that applies global data to quantify neighbourhood transportation CO2 emissions and recommend mitigation strategies. Unlike other existing approaches that only present carbon emissions metrics for specific locations, our system uses a robust methodology that employs global data and can be applied to any neighbourhood in the world. A unique feature of our system is the application of the "15-minute city" concept, which assesses the accessibility of essential amenities within a specified travel time and the impact of a specific location on carbon emissions. The system queries, classifies, and filters nearby amenities, identifies those outside the 15-minute isochrone, finds potential car routes, and calculates the annual transportation CO2 emissions for the neighbourhood population. The tool evaluates the problem and suggests optimal facility placement, offering effective strategies for emission reduction. This dual functionality accelerates the urban design and decision-making processes. We validate our approach through case studies in Milan, Dubai, and Calgary, comparing our results with official data. Our tool empowers decision-makers with data-driven insights, paving the way for sustainable urban planning and significant reductions in transportation CO2 emissions.

Keywords. Transportation CO2 emissions, Urban Design, Data-driven, Neighbourhood Evaluation, Climate Risk Mitigation

ACCELERATED DESIGN, Proceedings of the 29th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2024, Volume 2, 435-444.

1. Introduction

Transportation is a significant contributor to global CO_2 emissions, accounting for 20% of the total emissions worldwide (Statista, 2022b) and up to 90% of it comes from the road transport in the developing countries like India (Timilsina & Shrestha, 2009). The primary source of these emissions is the combustion of fossil fuels, such as gasoline and diesel, in cars, trucks, ships, and airplanes. This combustion process releases carbon dioxide (CO_2), along with other pollutants like nitrogen oxides (NO_x) and particulate matter (PM). These emissions pose a major environmental concern due to their impact on air quality, global temperature, and public health. Given the urgency of the situation, there is a pressing need for effective reduction strategies. While the transition to Electric Vehicles (EVs) and the promotion of Public Transportation systems are commonly discussed, this paper introduces a third strategy that is often overlooked — sustainable urban planning. The premise is simple: if one doesn't need a car, one doesn't need to worry about its sustainable use.

In this paper, we present a novel, data-driven tool that leverages the principles of sustainable urban planning to mitigate transportation emissions. Our tool employs the "15-minute city" concept (Moreno et al., 2021), which promotes the development of mixed-use projects that consolidate residential, commercial, and recreational areas, thereby increasing urban density and reducing travel distance. By focusing on the accessibility of essential amenities within a 15-minute walking radius, our tool provides a comprehensive methodology for quantifying neighbourhood transportation CO_2 emissions and identifying ways to mitigate them.

Our significant contribution lies in the robust capabilities of our tool, which can be universally applied to any neighbourhood worldwide. This includes developing nations that may lack such local tools. The global applicability of our development marks a substantial advancement in sustainable urban planning, providing a universally accessible solution to a global issue.

2. Related studies

There are numerous studies related to the quantification of transportation CO_2 emissions of the neighbourhood and the impact of urban design on it. CO_2 emissions from transportation can be calculated using various models and methods, including average speed-based models, congestion-based models, and fuel consumption-based models (Zubair et al., 2023). Factors such as vehicle type, speed, fuel consumption, and air-quality measurements could be considered when calculating CO_2 emissions (Yaacob et al., 2020). Moreover, the formula for calculating CO_2 emissions from urban passenger transport has been developed (Cao et al., 2019). It includes variables such as transport mode, vehicle type, and energy consumption per ton-km.

A study in Beijing focused on the travel behaviour of urban residents and its impact on transportation emissions (Ma et al., 2015). It concluded that work related trips are the main cause of these emissions and job-housing spatial mismatch is one of its biggest driving factors. Another research performed in Guangzhou focused on resettlement housing neighbourhoods and examined the impact of the built environment on the carbon emissions of three travel purposes, including commutes, housework, and recreation. It found that neighbourhood environment had a significant total impact on CO2 emissions, which were mainly indirect effects through mediators such as car ownership or trip distance (Yang et al., 2018). Moreover, it concluded that diversification of the neighbourhood land use could significantly reduce transportation emissions. Other studies concluded that neighbourhoods where many jobs are located tend to generate fewer transportation emissions, mainly due to shorter commuting trips (Wang et al., 2017), and found that after the certain level of population density the reduction of neighbourhood emissions becomes insignificant (Hong, 2017).

Even though all these works quantified the effect of urban amenities on the neighbourhood's transportation emissions, they were applicable only for the particular location and conclusions as well as potential solutions could vary if the same methodology is applied in a different area, city or country. The holistic and generalised methodology to tackle this issue has not been found.

The work presented in this paper advances the outcomes of these studies by:

- Introducing a unified methodology for quantifying transportation emissions in urban areas that is applicable on a global scale.
- Enabling rapid comparison between the chosen location and global benchmarks to better understand the relative level of emissions.
- Providing recommendations for the relocation of existing amenities or the placement of new ones, optimized for emissions reduction.

3. Methodology

To mitigate transportation CO2 emissions through urban design, it is crucial to quantify the problem to devise the most effective solution. Based on our previous work (Cheng et al., 2022), we have developed methodology and analytics tool that can accomplish this for any neighbourhood globally. This approach includes the following steps:

- Select a location.
- Compute a 15-minute walking area (isochrone) for the selected location.
- Query nearby amenities from geospatial data providers.
- Classify these amenities into six key categories of essential neighborhood functions: Caring, Enjoying, Living, Learning, Supplying, and Working, as defined in the 15-minute city framework.
- Filter out any needed amenity that falls outside the 15-minute isochrone, and calculate the driving route to it from the input location.
- Based on route distance and travel time, calculate the annual transportation CO2 emissions for the entire population of the neighbourhood.

To ensure the analytical method is robust, we had to accurately estimate travel time and the exact route to be taken from the origin to the needed amenity. We used API from HERE (HERE Technologies, 2024) for this purpose. It provides calculation of car-specific routes, using real-time (traffic) and historical (traffic speeds) information. For example, a car route will follow highways that only cars can enter, avoid areas that are not compatible (like pedestrian zones), as well as respect road restrictions like one-way streets and time-dependent access like seasonal closures. The resulting number represents total transportation CO2 emissions caused by the neighbourhood's population in 1 year.

The quantification of neighbourhood CO2 emissions is an initial step in understanding the broader implications of these emissions. To provide context, these emissions can be compared either globally with other neighbourhoods worldwide, or locally with nearby areas. This analysis offers a clear perspective on how a neighbourhood compares to others in terms of transportation CO2 emissions.

However, merely understanding the problem is insufficient; strategies must also be developed to reduce these emissions. Traditional urban planning methods, which can take months or even years to develop and implement, are not conducive to the rapid pace of urban development and the urgent need to mitigate climate change.

Our research introduces a data-driven approach that leverages urban data to generate recommendations and simulate scenarios for urban transformation, while concurrently monitoring their potential impact on CO2 emissions. This approach allows for rapid response times and continuous monitoring, enabling the measurement of the outcomes of our actions and the adjustment of our strategies as necessary. In the subsequent sections of this paper, we will discuss a case study in which we applied our tactical urbanism strategies (Figure 1) for the data-driven repositioning of a critical amenity. This case study will also illustrate the practical application of our tool and its potential impact on reducing CO2 emissions.

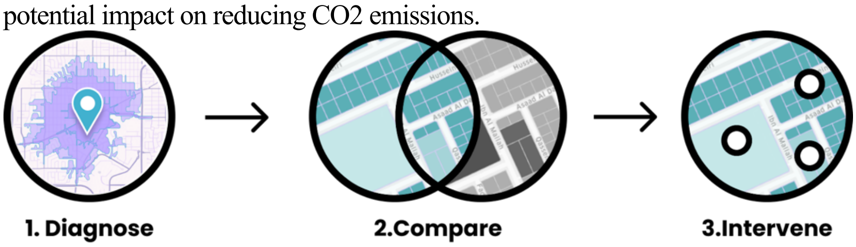

Figure 1. Methodology

4. Diagnose

To explore the potential of this methodology, we analysed three neighbourhoods: Brera, Milan; Jumeirah, Dubai, and Wood Crescent, Calgary. These three areas represent an incremental level of urban walkability and accessibility and therefore serve as a fair indication of a reliability of transportation CO2 emissions estimation performed by our tool. Figure 2, Figure 3, Figure 4 show a 15-minute isochrone with all found urban amenities within it (left) and found car routes to the needed (essential, but not found within the isochrone) amenities outside of it (right).

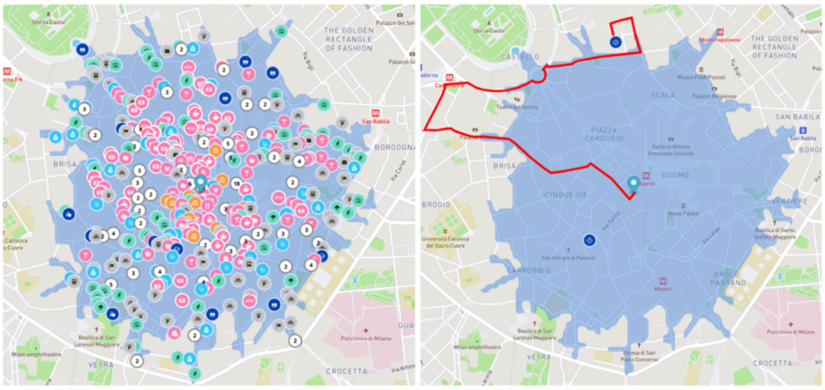

Figure 2. Isochrone, urban amenities, and car routes for Milan, Italy

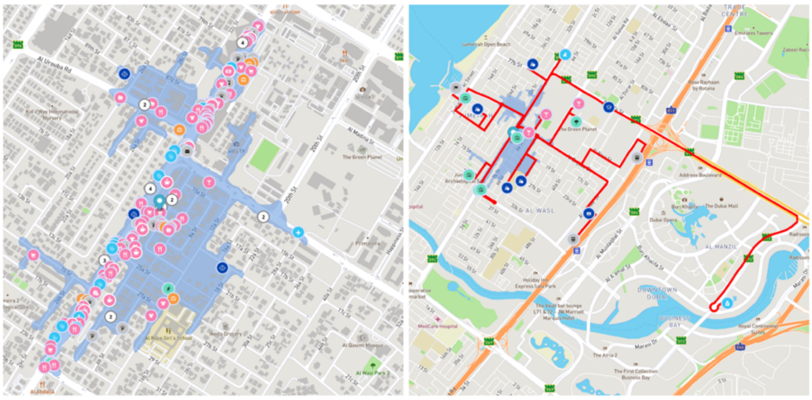

Figure 3. Isochrone, urban amenities, and car routes for Dubai, UAE

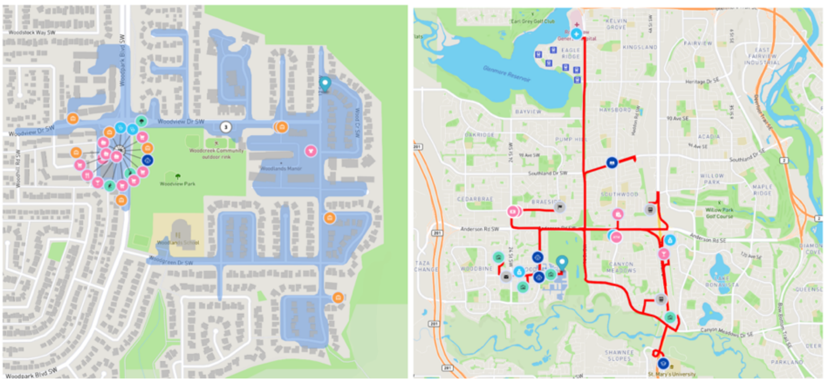

Figure 4. Isochrone, urban amenities, and car routes for Calgary, Canada

As Table 1 shows the analysis reveals significant disparities in transportation emissions resulting from car usage across these cities. Notably, per capita emissions in

Calgary are more than 20 times as high as those in Milan and more than two times as high as in Dubai. This discrepancy can be attributed to the contrasting availability of amenities within a 15-minute walking distance in these cities.

In Milan’s Brera neighbourhood, a substantial number of amenities are located within the walkable isochrone. Even those outside this range are reasonably accessible, thanks to the municipality’s prioritization of pedestrians and public transport over cars (Pucci, 2017). This compact urban design ensures that most amenities are within walking distance for locals, leading to lower CO2 emissions. Conversely, Calgary’s Wood Crescent neighbourhood follows a sparse urban design strategy (Choi, 2018), with clear separation between non-residential and residential buildings. This results in fewer amenities within walking distance and necessitates longer car trips to reach those located further away. Consequently, this spatial arrangement contributes to much higher CO2 emissions due to the greater reliance on cars for accessing essential services. Finally, in Dubai’s Jumeirah neighbourhood, the urban design and amenity distribution also play a significant role in transportation emissions. Even though a lot of amenities are present within the walking area, most of them belong to the "entertainment" class. This non-uniform land use necessitates the use of cars, leading to much higher CO2 emissions than in Milan.

	Brera, Milan	Jumeirah, Dubai	Wood Crescent, Calgary
Isochrone area (km2)	1.37	0.48	0.31
Population	10,400	3,800	2,533
Neighbourhood transportation CO2 emissions per year (ton)	300	1,200	1,900
Transportation CO2 emissions per capita (ton)	0.03	0.31	0.75

Table 1. Comparison between the neighbourhoods in Milan, Dubai, and Calgary

To validate the results of the study, we compared the official values of car-generated emission per capita by country with our results. We took a data for a CO2 road transportation emissions per country (Statista, 2018). To get benchmark values of car emissions in urban areas, we multiplied this number by 0.5 (cars cause around 50% of total road emissions (Statista, 2022a)) and 0.7 (70% of car trips occur in urban areas (Center for Sustainable Systems, 2023)). Table 2 shows the result of validation. Our estimate is the closest in a car-dependent neighbourhood in Calgary since this area seems to represent the typical urban space in Canada. While the difference is bigger in Dubai where the Jumeirah neighbourhood is much more walkable than a typical urban area in UAE. Finally, the biggest difference is found in Milan, where the Brera neighbourhood is fully walkable which leads to almost zero transportation emissions. Moreover, the accuracy of the study will be improved in the future when the public transport network and different types of vehicle's fuel will be added to the CO2 emissions' calculation.

	Benchmark for a country (tons)	Our estimate (tons)
Brera, Milan (Italy)	0.54	0.03
Jumeirah, Dubai (UAE)	1.25	0.31
Wood Crescent, Calgary (Canada)	1.41	0.75

Table 2. Validation of transportation CO2 emissions per capita

5. Compare

To accelerate the process of urban design and decision-making, it is essential to provide context to the obtained value of transportation CO2 emissions. This allows a clear understanding of how the neighbourhood under consideration performs in comparison with global benchmarks.

For instance, Rutland Park in Calgary generates higher levels of CO2 emissions compared to other neighbourhoods in Europe, Asia, and America (Figure 5). A quick comparison reveals that this neighbourhood is more car-dependent than others, generating 10 times more emissions than Midtown Manhattan and 3 times more emissions than Dhoby Ghaut in Singapore. This neighbourhood's emission levels are very close to those of Los Angeles, a city known for its poor connectivity and car dependence.

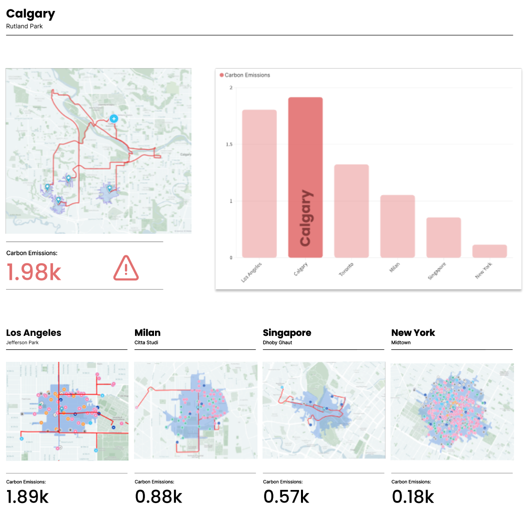

Figure 5. Comparison between different cities with 15-minute walking isochrone (blue) and car routes (red) for each of them. Rutland Park neighbourhood in Calgary has higher transportation emissions then neighbourhoods in Los Angeles, Milan, Singapore, and New York

A local analysis of the district can help determine if the area as a whole is underserved by key services and would therefore benefit from introducing or repositioning facilities to serve the population and decrease emissions for this area of the city. Our local analysis shows that four neighbourhoods in the west side of Calgary are generating high levels of transportation CO_2 emissions due to low accessibility to key amenities (Figure 6). In the next chapter we examined trips to hospitals to understand the impact of positioning a new facility closer to this area of the city.

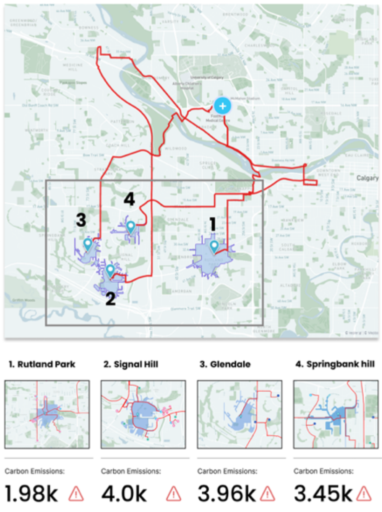

Figure 6. Comparison between different neighbourhoods in Calgary. Rutland Park has the lowest transportation emissions among others. 15-minute walking isochrones (blue) and car routes to the closest hospital facility (red) are shown.

6. Intervene

The developed tool provides a list of the most critical facilities missing in the area, along with the corresponding CO_2 emissions generated by residents undertaking long trips to meet their needs. Once these facilities are identified, we can simulate scenarios for repositioning or introducing new ones.

In the subsequent analysis, four potential locations for a hospital are identified. Calculations are performed for each potential location to determine which one generates the least emissions, thus having the most significant impact on improving residents' access to healthcare facilities in this specific area of Calgary. The simulation illustrates the potential impact of a new facility in this area. The bottom right chart of Figure 7 compares the environmental impact for each of the potential locations. Location 2 proves to be the most central to serve this area of the city and achieves the greatest CO_2 reductions.

By positioning the new hospital in this area, we could reduce emissions by more than half for the neighbourhoods in the west side of Calgary. The top right chart of Figure 7 shows the amount by which CO_2 emissions are reduced for each of the neighbourhoods. Similarly, we can simulate new locations for other key facilities like libraries or schools and measure the impact of repositioning these facilities to better serve the city and its residents. This approach provides a data-driven method for urban planning, offering a practical solution to reduce CO2 emissions and improve the quality of life for residents.

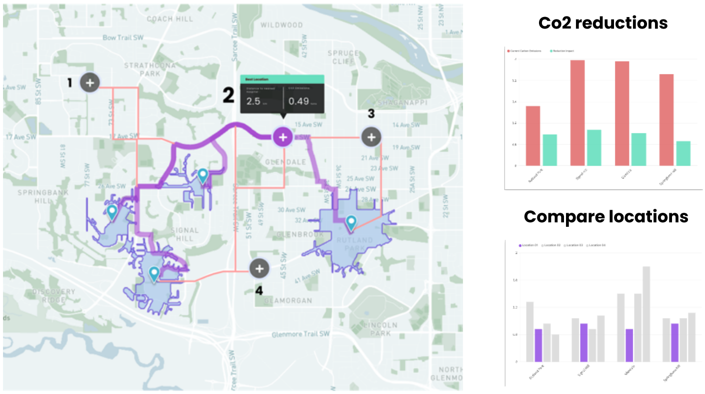

Figure 7. Identification of the best location for a new hospital. Car routes to the best location are shown in purple.

7. Conclusions and Future Studies

Transportation is a major contributor to climate change, and the adoption of sustainable urban design strategies, such as the "15-minute city" concept, is critical in addressing this pressing issue. This paper presents a data-driven tool that aids cities in transitioning towards a more sustainable future. It allows decision-makers to make informed choices, backed by comprehensive data analysis, to optimise urban planning, reduce transportation emissions, and promote environmentally friendly practices. The efficiency of this tool can speed up urban design and decision-making, which is crucial given the urgency of our current climate problem.

While our current development provides valuable information for reducing neighbourhood transportation CO2 emissions, there are ways to enhance its effectiveness. At present, we assume that all trips outside of the walking area will be made by car. Future iterations of our tool will adequately represent the diversity of transportation modes including public transportation routes as an alternative to car driving. Moreover, we will consider the alternative of using EVs instead of typical cars, depending on the EV usage rate in a country. These enhancements will further refine our tool and contribute to the global effort to combat climate change.

References

Cao, X., Ouyang, S., Liu, D., & Yang, W. (2019). Spatiotemporal patterns and decomposition analysis of CO2 emissions from transportation in the Pearl River Delta. Energies, 12(11). https://doi.org/10.3390/en12112171

Center for Sustainable Systems, U. of M. (2023). Personal Transportation Factsheet. https://css.umich.edu/publications/factsheets/mobility/personal-transportation-factsheet

Cheng, C., Li, Y., Deshpande, R., Antonio, R., Chavan, T., Nisztuk, M., Subramanian, R.-N., Weijenberg, C., & Patel, V. (2022). REALTIME URBAN INSIGHTS FOR BOTTOM-UP 15-MINUTE CITY DESIGN. POST-CARBON, Proceedings of the 27th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), 435–444.

Choi, K. (2018). The influence of the built environment on household vehicle travel by the urban typology in Calgary, Canada. Cities, 75, 101–110. https://doi.org/10.1016/j.cities.2018.01.006

HERE Technologies (2024). HERE Routing. Retrieved February 13, 2024, from https://www.here.com/docs/category/routing

Hong, J. (2017). Non-linear influences of the built environment on transportation emissions: Focusing on densities. Journal of Transport and Land Use, 10(1), 229–240. https://doi.org/10.5198/jtlu.2017.815

Ma, J., Liu, Z., & Chai, Y. (2015). The impact of urban form on CO2 emission from work and non-work trips: The case of Beijing, China. Habitat International, 47, 1–10. https://doi.org/10.1016/j.habitatint.2014.12.007

Moreno, C., Allam, Z., Chabaud, D., Gall, C., & Pratlong, F. (2021). Introducing the "15-Minute City": Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities. Smart Cities, 4(1), 93–111. https://doi.org/10.3390/smartcities

Pucci, P. (2017). Mobility behaviours in peri-urban areas. the Milan Urban Region case study. Transportation Research Procedia, 25, 4229–4244. https://doi.org/10.1016/j.trpro.2017.05.227

Statista. (2018). Road transportation carbon dioxide emissions per capita worldwide in 2018, by select country. https://www.statista.com/statistics/1201243/road-transport-sector-per-capita-co2-emissions-worldwide-by-country/

Statista. (2022a). Distribution of carbon dioxide emissions produced by the transportation sector worldwide in 2022, by sub sector. https://www.statista.com/statistics/1185535/transport-carbon-dioxide-emissions-breakdown/

Statista. (2022b). Distribution of carbon dioxide emissions worldwide in 2022, by sector. https://www.statista.com/statistics/1129656/global-share-of-co2-emissions-from-fossil-fuel-and-cement/

Timilsina, G. R., & Shrestha, A. (2009). Why Have CO 2 Emissions Increased in the Transport Sector in Asia? Underlying Factors and Policy Options. http://econ.worldbank.org.

Wang, Y., Yang, L., Han, S., Li, C., & Ramachandra, T. V. (2017). Urban CO 2 emissions in Xi'an and Bangalore by commuters: implications for controlling urban transportation CO 2 emissions in developing countries. MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE, 993–1019. https://doi.org/https://doi.org/10.1007/s11027-016-9704-1

Yaacob, N. F. F., Yazid, M. R. M., Maulud, K. N. A., & Basri, N. E. A. (2020). A review of the measurement method, analysis and implementation policy of carbon dioxide emission from transportation. In Sustainability (Switzerland) (Vol. 12, Issue 14). MDPI. https://doi.org/10.3390/su12145873

Yang, W., Wang, S., & Zhao, X. (2018). Measuring the direct and indirect effects of neighborhood-built environments on travel-related CO2 emissions: A structural equation modeling approach. Sustainability (Switzerland), 10(5). https://doi.org/10.3390/su10051372

Zubair, M., Chen, S., Ma, Y., & Hu, X. (2023). A Systematic Review on Carbon Dioxide (CO2) Emission Measurement Methods under PRISMA Guidelines: Transportation Sustainability and Development Programs. Sustainability, 15(6), 4817. https://doi.org/10.3390/su15064817