
Carlos Eduardo Sanches de Andrade, Márcio de Almeida D’Agosto

Abstract—The transport sector is responsible for a significant portion of global emissions of carbon dioxide (CO₂), due to the generation of electricity and the burning of fossil fuels required for the movement of vehicles. The measurement of such emissions, when held in grams of CO₂ per passenger-kilometer, enables more significant results, considering the passenger load. This work aims to analyze emissions from passenger transportation systems of integrated subways and buses, compared with private cars, establishing a procedure for calculating these emissions. The procedure was applied to Rio de Janeiro Subway and its fleet of buses, called Surface Subway, throughout 2012. The results obtained indicate that the electric trains of the system had an average emission of 4.5 grams of CO₂ per passenger-kilometer, a result ten times lower than the emission of buses, which in turn emitted three times less than the private cars. The integration of train and bus systems, thus, provided the city with significant reduction of carbon dioxide emissions produced by the transport system.

Index Term—CO₂ emissions; passenger transportation; subway

I. INTRODUCTION

The transport sector plays a large part in the emission of greenhouse gases (GHG) worldwide, accounting for about 23% of global emissions [1]. Ribeiro et al. [2] states that, over the past decade, GHG emissions from the transport sector have grown at rates higher than in any other sector that uses energy. In Brazil, the transport sector reached 48% of total emissions in the country, being the main responsible for emissions [3]. Carbon dioxide (CO₂) is the main greenhouse gas, being commonly used as a reference in the GHG emission measurements.

A way to avoid the growth of CO₂ emissions by the transport sector is to encourage the society to use public transportation systems, of high and medium capacity, as the subways and buses.

The total CO₂ emissions of the means of transportation occur, to a greater or lesser proportion, regardless of their occupancy rate. However, the higher the occupancy rate of the means of transportation, the lower the CO₂ emissions per kilometer travelled by passengers.

For more accurate information, it is important that the measurements of CO₂ emissions be carried out according to the mileage travelled by passengers, using to this end the measure grams of CO₂ per passenger-km (gCO₂ per pkm). Thus, it is possible to establish emission comparisons involving all means of passenger transportation.

The absence or inefficiency of high or medium-capacity transportation means makes the use of automobiles more and more intense, increasing congestion and, consequently, emissions from the transport sector. The average occupancy rate of cars is low when compared to the subways and buses, causing gCO₂ emissions per pkm in automobiles to be usually larger than the subways and buses’. The average occupancy rate of automobiles in Brazil is of 1.5 passengers per trip, while the subways’ is of 900 passengers per trip [4]. Thus, the transportation systems composed of integrated subways and buses occupy a prominent position as a solution of lower impact on CO₂ emissions by the transport sector.

The aim of this work is to present a procedure for calculating the emission in gCO₂ per pkm on the operation of subway systems and their integrated buses by applying the procedure proposed in Rio de Janeiro Subway and its bus fleet, called Surface Subway. Section 1 is an introduction, with a brief contextualization of the study and the establishment of the goal. Section 2 defines, in general terms, the issuance in gCO₂ per pkm in the operation of subway and bus systems, showing comparative results of emissions in these two transportation systems. Section 3 defines and presents the procedure proposed. Section 4 addresses the application of the procedure proposed in Rio de Janeiro Subway and in its bus fleet. Section 5 addresses the conclusions of the work.

II. CO₂ EMISSIONS IN THE OPERATION OF SUBWAY AND BUS SYSTEMS

The pkm measure is the most suitable in passenger transportation activity, being also commonly used for purposes of comparison of emission results between means of passenger transportation. It is more representative than the values of total emissions of vehicle travel, since it considers CO₂ emissions directly related to the amount of passengers transported. The pkm measure is obtained by multiplying the
corresponding total passengers transported in a particular preset period (daily, monthly or yearly) by the average extension of passenger trips based on origin-destination surveys of these trips.

Below you will find details about the emissions, in gCO\(_2\) per pkm, in the operation of subway and bus systems, as well as comparative results on the emissions of these two systems of passenger transportation.

\[A. \text{Emissions in gCO}_2 \text{ per pkm, in operation of subways}\]

CO\(_2\) emissions in the operation of subway systems occur mainly in the generation of electric power required for the operation of the subway trains. These emissions, called indirect emissions of CO\(_2\), by electricity, are produced by third parties [5], since that electricity is usually not generated locally by the subway system, but obtained from third parties, from the local electricity supply company.

A large amount of electric power is required to provide the tractive force that moves the trains. As an example one can cite the London Underground, whose system’s electric power consumption reaches almost 3% of the total consumption of the city, using more than 1 TWh of electricity per year [6]. The New York City Subway consumes 3.4 TWh each year [7]. The subway of the city of Porto, in Portugal, consumed 0.52 TWh in 2012 [8], while the Subway of São Paulo consumed, in 2013, 0.58 TWh [9].

As the tractive force of the trains is responsible for much of the energy consumed in the subways, it is the biggest responsible for CO\(_2\) emissions in the operation of subways. The rest of the electric power consumed by the systems, called auxiliary power, aims to supply lighting and auxiliary equipment of the stations, such as: escalators, pumping, technical rooms, etc., including also other electric power consumptions of the subway company.

The generation of electric power for train traction considers only the emission related to the “fuel” of the subway system trains, which is the electric power. For the subways, according to Andrade and Bittencourt [10], the CO\(_2\) emission caused by generation of electric power for train traction is the most suitable for purposes of comparison of results with other means of transportation, when assessing the emission caused only by fuel consumption. The emissions of electric rail modes depend highly on the cleanliness of the electricity generated [11].

The values of CO\(_2\) emissions due to the generation of electric power used in subways show a great variation in results among the subway systems around the world, due to the different energy matrices used in each location. In most countries of Europe, Asia and Oceania, the thermal sources are predominant, with a mix of coal, oil and gas [12], which are the largest emission source types. Brazil is favored for using predominantly hydroelectric sources, which is considered a "clean" energy source, with low impact on CO\(_2\) emissions. In 2012, the hydroelectric source in Brazil represented 77% of the internal offer of national electric power [13].

Table I shows results of CO\(_2\) emissions, total and in pkm, due to the generation of electric power in three subways. It is possible to identify major differences in the results, as they depend on the amount of electrical power used by the systems and on factors such as: local energy matrix, energy efficiency, technology used, system’s age, system design, load of passengers (occupancy rate), the size of the system, the quantity of trains, intervals practiced and others.

<table>
<thead>
<tr>
<th>Subways</th>
<th>Total emissions in tons of CO(_2)</th>
<th>Emissions in gCO(_2) per pkm</th>
<th>Year</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lisbon</td>
<td>14,500</td>
<td>49</td>
<td>2012</td>
<td>[14]</td>
</tr>
<tr>
<td>Bilbao</td>
<td>16,638</td>
<td>28</td>
<td>2011</td>
<td>[15]</td>
</tr>
<tr>
<td>São Paulo</td>
<td>44,000</td>
<td>4</td>
<td>2012</td>
<td>[9]</td>
</tr>
</tbody>
</table>

The total CO\(_2\) emissions, by electricity, in the Subways of Lisbon and Bilbao are similar, while the values of emissions in gCO\(_2\) per pkm are quite different. These two subways have the same network extension, with 43 km, but have different demands of passengers a year, with 52 million/year in the Lisbon Subway [14] and 87 million/year in the Bilbao Subway [15], which justifies the better performance of the Bilbao Subway for less emission of CO\(_2\) per pkm, when compared to the Lisbon Subway.

\[B. \text{Emissions in gCO}_2 \text{ per pkm, in operation of buses}\]

The modal matrix of passenger traffic in large urban centers of Brazil shows 4% on rail systems, involving the subways and railroads, and 60% on bus [4]. This great use of buses in Brazil also occurs in several countries of the world, where, usually, the bus transportation stands out in relation to other systems, as in the countries of Latin America, where 43% of passenger transportation is done by bus [16].

Motor vehicles constitute worldwide the main source of air pollution in large cities, being this problem worsened in recent decades due to the increase in the fleet of road vehicles powered by fossil fuels, mainly gasoline C, used in automobiles, and diesel oil, used in buses, which are great emitters of CO\(_2\). According to the United Nations [17], road transport is responsible for the majority of current emissions and its estimated growth, since the forecast is that the global vehicle fleet is set to multiply three or four-fold in the next few decades.

The calculation of CO\(_2\) emissions by the buses is done according to the amount of liters of fuel burnt, usually diesel oil, which is multiplied by an average emission factor. Emission values, in gCO\(_2\) per pkm, for buses, depend heavily on passenger load. In Brazil, considering the maximum capacity of the buses, with 80 passengers, the emission average is 16 gCO\(_2\) per pkm [4], while the buses of the city of São Paulo emit 64 gCO\(_2\) per pkm, considering the average load on the buses [9]. Table II shows the emission results of buses of some cities in the world, considering their average capacity.
Table II

CO₂ Emissions of Buses in the Cities of Almada, Adelaide, Birmingham and Washington

<table>
<thead>
<tr>
<th>Countries</th>
<th>Cities</th>
<th>Emissions in gCO₂ per pkm</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portugal</td>
<td>Almada</td>
<td>85</td>
<td>[18]</td>
</tr>
<tr>
<td>Australia</td>
<td>Adelaide</td>
<td>140</td>
<td>[19]</td>
</tr>
<tr>
<td>England</td>
<td>Birmingham</td>
<td>186</td>
<td>[20]</td>
</tr>
<tr>
<td>USA</td>
<td>Washington</td>
<td>202</td>
<td>[21]</td>
</tr>
</tbody>
</table>

C. General comparative results of emissions, in gCO₂ per pkm, of the subways and the buses

Different researches indicate that the subway systems that use electric power from less polluting sources take advantage over other means of transportation in a comparison of emission in gCO₂ per pkm. Andrade et al. [22] conducted a study on the contribution to reducing CO₂ emissions by rail systems, concluding that in all the approaches of emissions, these systems show that, in general, worldwide, they are a good alternative for passenger transportation of low CO₂ emission. The transport authority of the city of London conducted a study that shows the emission per pkm of various transportation systems. This comparison proves the better performance of the subways regarding lower CO₂ emissions. While the London Underground emits 50 gCO₂ per pkm, London buses emit 80 gCO₂ per pkm, and automobiles emit 110 gCO₂ per pkm, considering the average passenger capacity [23].

In 2011, a study was carried out in Europe to identify the average values of emissions, in gCO₂ per pkm, of the various types of passenger transportation in 27 countries in Europe. The emission results, in gCO₂ per pkm, showed a value of 109 for road transport, whereas for subways it was 41 [24]. Another example of comparison between subways and buses from the European continent is a result from the city of Bilbao, Spain, where the buses emit 5 times more (135 gCO₂ per pkm) than the subway system (25 gCO₂ per pkm) [25].

The emission averages, in 2010, in the United States [18], in gCO₂ per pkm, by the subways and buses are: 62 for the subways and 180 for the buses, considering the average capacity of the systems. It is noted that emissions by buses are almost 3 times higher than those by subways. This survey also revealed the average occupancy rates of these two systems across the country, which shows 47% occupancy for subways and 28% for buses. If the maximum passenger loads were considered, the subway would still have the lowest emission values, in gCO₂ per pkm, with 31 for subways and 51 for buses [18]. Fig. 1 shows examples of results of bus, subway and car emissions in four cities in the United States.

It was noted that, among all American cities, in only one of them, Baltimore, the subway presented an emission value greater than that of the bus. This is because there was a low rate of use in the Baltimore Subway, with only 17 percent of average occupation, justifying the emissions being higher than those of the buses in the city of Baltimore, which have 34% of average occupation rate [18].

In Oceania, the Urban Transport Government of Australia conducted a study in 2009 on CO₂ emissions in the transportation systems of the city of Melbourne, finding, for the subways and buses, respectively, 145 and 159 gCO₂ per pkm [26].

A high value is found, above average, in the emission by Melbourne Subway. This is because Australia has an energy matrix constituted basically of thermal sources, based on coal, which is the thermal source with largest emission [27], making Australia the 5th country in the world in the production of coal and the 2nd country in the world in the export of coal [28]. The generation of electric power in Australia raises the result of CO₂ emission as compared to other countries that have energy matrices with less thermal sources. As a result, the CO₂ emission values of the subway and buses in the city of Melbourne remain so close.

III. PROCEDURE FOR CALCULATION OF EMISSION, IN GRAMS OF CO₂ PER PKM, IN THE OPERATION OF SUBWAYS AND THEIR BUS FLEET

Some subway systems possess and administer a bus fleet, either their own fleet or a leased one, to complement part of the itineraries, not supplied by the train network. Often, the use of these buses is covered by a single subway fee. As examples, we can mention the subway systems of five cities: a) Delhi - it has several own minibus lines, with capacity for up to 30 people per vehicle. As in the Delhi subway trains, the value of the minibus fee varies according to the mileage travelled by users [29]; b) New York - it has free bus lines for its users by using the Metro Card pass, which offers a price per trip lower than the unitary fee of New York Subway [30]; c) Paris - it has free transfer for its users between zones I to V, during a period of 2 hours by use of the Paris Visit Pass [31]; d) Rio de Janeiro - it has two bus lines administered by the subway system with no fee [32]; and e) Santiago - where it is
possible to make free integration with up to two consecutive bus lines, during the period of 2 hours by use of the Targeta Bip pass [33].

A. Procedure for calculation of emission, in gCO₂ per pkm, in the operation of subways

The proposed procedure for calculating the emissions, in gCO₂ per pkm, in the operation of subways should be applied monthly, so as to reach an annual result, and should follow the following steps:

1. Determine the traction power (including energy losses) monthly consumed by the subway, in MWh.
2. Find the monthly average factor of electric power generation, defined by the regulatory agency, in tCO₂/MWh. This factor can be regional or national, depending on the characteristics of the generation and distribution of electric power. This average factor released by the regulatory agency must be used when the goal is to quantify emissions from electric power generated, serving, therefore, to inventories in general, corporate or otherwise [34].
3. Multiply the monthly traction power consumed by the subway system by the monthly average factor of electric power generation established by the regulatory agency, which will result in total emissions, in that month, in tCO₂.
4. Turn the result of the total emissions, in tCO₂, into gCO₂ by multiplying it by 1,000,000.
5. Determine the quantity of monthly pkm of the subway system by using the data from the monthly demand multiplied by the average extension of the passenger trips, based on origin-destination surveys on these trips.
6. Divide the result of total emissions, in gCO₂, by the pkm result for the month assessed. Then, the monthly result of total emissions, in gCO₂ per pkm, is found for the operation of a subway system.
7. The annual emission result, in gCO₂ per pkm, in the subway operation, is obtained by dividing the sum of the total monthly emissions, in gCO₂, by the sum of the monthly results of pkm.

B. Procedure for calculation of emissions, in gCO₂ per pkm, in the operation of the bus fleet of the subway systems

The proposed procedure for calculating the emissions, in gCO₂ per pkm, in the operation of bus fleet of subway systems should be applied monthly, so as to reach an annual result, and should follow the following steps:

1. Find the total monthly mileage traveled by the entire bus fleet of the subway system.
2. Determine the total monthly fuel consumption of the bus fleet of the subway system, based on the information of the total monthly mileage rates. For this purpose, the average efficiency of the fuel used by the bus, in liter per km, must be found.
3. With the total fuel consumption, in liters, of the bus fleet of the subway system, this result must be multiplied by the average emission factor, in kgCO₂ per liter, of the fuel used in the buses. That leads to the result of the total emissions, in kgCO₂, of the bus fleet of the subway system.
4. Turn the general result of the total emissions, in kgCO₂, into gCO₂ by multiplying it by 1,000.
5. Determine the result of monthly pkm of the bus fleet in the subway system by using the data from the monthly demand of the bus fleet multiplied by the average extension of passenger trips based on origin-destination surveys on these trips.
6. Divide the monthly result of total emissions, in gCO₂, by the monthly pkm result of the bus fleet. Then, the monthly result of emissions, in gCO₂ per pkm, is found for the operation of the bus fleet of the subway system.
7. The annual emission result, in gCO₂ per pkm, in the operation of bus fleet of the subway system, is obtained by dividing the sum of the total monthly emissions, in gCO₂, by the sum of the monthly results of pkm.

IV. APPLICATION OF THE PROCEDURE TO RIO DE JANEIRO SUBWAY AND ITS BUS FLEET

The subway network of Rio de Janeiro - MetrôRio - is 42 km long, with two lines and 36 stations, with an annual demand of about 186 million users. In addition to this network, which is serviced by the subway trains, there is an extension of the network done by MetrôRio’s exclusive buses, called Surface Subway, reaching important neighborhoods of the city, which are not served by the trains of the system. Thus, the users can complete their trip without paying anything extra for this service, because it is free, already included in the system’s standard fee [32]. The bus fleet of the Surface Subway has 32 buses, distributed in two lines. One bus line departs from the line 2 terminal of the subway and the other line departs from the line 1 terminal.

A. Application of the procedure in the operation of Rio de Janeiro Subway trains

MetrôRio has made available the monthly data of passenger-km and traction power consumptions (including energy losses) of the trains in the year 2012. Table III presents the data collected, required for the application of the proposed procedure and the results of emissions.

Monthly results of total emissions were found to be up to 4.4 times higher from a month to another. By comparing the months of Jan/12 and Nov/12, similar results are observed in traction power consumption and pkm, but with a big difference in the values of total emissions, this being due to an increased use of thermal sources in power generation in Nov/12, proving the high value of the average emission factor for this month, which was the highest in 2012.
In 2012, the average emission in the operation of MetrôRio’s trains was 4.5 gCO₂ per pkm. If compared to the results of emissions in other subway systems already presented in this work, it is evidenced that MetrôRio has low emission.

This occurs mainly due to Brazilian energy matrix, composed basically of hydroelectric plants, in addition to the adequate system occupation rate, which, according to MetrôRio [32], was of 50% throughout 2012, representing approximately 865 passengers inside a train in each trip. Differences are noticed in monthly results, ranging from 2.1 to 9.0 gCO₂ per pkm. From Sep/12 to the end of the year, the monthly results in gCO₂ per pkm remained above the annual average, mainly due to the increase in the emission factors released by the Brazilian Government in the last four months of 2012, motivated by greater use of thermal sources during this period. Automobiles in Brazil emit 127 gCO₂ per pkm [4], which demonstrates the good performance regarding CO₂ emission by MetrôRio.

**B. Application of the procedure in the operation of the Surface Subway buses of Rio de Janeiro Subway**

The application of the procedure proposed in this work is shown in table IV, which displays the result of the total emissions of CO₂, in addition to emission in gCO₂ per pkm, in the operation of the MetrôRio’s buses.

It is verified that, in 2012, the average emission in the operation of the two MetrôRio’s bus lines was 46 gCO₂ per pkm. According to MetrôRio the average occupancy rate of these buses in 2012 was 47% [32].

### Table III

**CO₂ Emissions in the Operation of MetrôRio Trains in 2012**

<table>
<thead>
<tr>
<th>Months</th>
<th>Traction power (in MWh)</th>
<th>Government's Emission Factor (in tCO₂/MWh)</th>
<th>Pkm</th>
<th>Emissions in gCO₂/pkm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan/12</td>
<td>11,626</td>
<td>0.0294</td>
<td>160,875,859</td>
<td>2.1</td>
</tr>
<tr>
<td>Feb/12</td>
<td>11,668</td>
<td>0.0322</td>
<td>166,823,976</td>
<td>2.3</td>
</tr>
<tr>
<td>Mar/12</td>
<td>11,813</td>
<td>0.0405</td>
<td>180,577,528</td>
<td>2.6</td>
</tr>
<tr>
<td>Apr/12</td>
<td>10,943</td>
<td>0.0642</td>
<td>156,885,831</td>
<td>4.5</td>
</tr>
<tr>
<td>May/12</td>
<td>11,866</td>
<td>0.0620</td>
<td>178,363,796</td>
<td>4.1</td>
</tr>
<tr>
<td>Jun/12</td>
<td>11,454</td>
<td>0.0522</td>
<td>161,865,005</td>
<td>3.7</td>
</tr>
<tr>
<td>Jul/12</td>
<td>11,925</td>
<td>0.0394</td>
<td>175,907,290</td>
<td>2.7</td>
</tr>
<tr>
<td>Aug/12</td>
<td>12,294</td>
<td>0.0460</td>
<td>189,090,840</td>
<td>3.0</td>
</tr>
<tr>
<td>Sep/12</td>
<td>11,224</td>
<td>0.0783</td>
<td>168,104,302</td>
<td>5.2</td>
</tr>
<tr>
<td>Oct/12</td>
<td>12,033</td>
<td>0.0984</td>
<td>182,993,862</td>
<td>6.5</td>
</tr>
<tr>
<td>Nov/12</td>
<td>11,837</td>
<td>0.1247</td>
<td>164,354,114</td>
<td>9.0</td>
</tr>
<tr>
<td>Dec/12</td>
<td>13,095</td>
<td>0.1168</td>
<td>170,690,301</td>
<td>9.0</td>
</tr>
<tr>
<td>2012</td>
<td>141,778</td>
<td>0.0653</td>
<td>2,056,532,704</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Source: [32, 34]

### Table IV

**Emissions in the Operation of MetrôRio’s Buses in 2012**

<table>
<thead>
<tr>
<th>Months</th>
<th>Mileage traveled (in kilometers)</th>
<th>Total emissions from the bus fleet (in gCO₂)</th>
<th>Pkm</th>
<th>Emissions in gCO₂/pkm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan/12</td>
<td>121,348</td>
<td>140,922</td>
<td>2,686,318</td>
<td>52</td>
</tr>
<tr>
<td>Feb/12</td>
<td>106,102</td>
<td>123,356</td>
<td>2,638,953</td>
<td>47</td>
</tr>
<tr>
<td>Mar/12</td>
<td>111,166</td>
<td>129,689</td>
<td>3,260,833</td>
<td>40</td>
</tr>
<tr>
<td>Apr/12</td>
<td>102,326</td>
<td>116,831</td>
<td>2,727,308</td>
<td>44</td>
</tr>
<tr>
<td>May/12</td>
<td>109,379</td>
<td>127,043</td>
<td>3,085,043</td>
<td>41</td>
</tr>
<tr>
<td>Jun/12</td>
<td>104,383</td>
<td>121,220</td>
<td>2,740,898</td>
<td>44</td>
</tr>
<tr>
<td>Jul/12</td>
<td>125,095</td>
<td>145,273</td>
<td>2,802,873</td>
<td>52</td>
</tr>
<tr>
<td>Aug/12</td>
<td>120,193</td>
<td>139,580</td>
<td>3,100,684</td>
<td>45</td>
</tr>
<tr>
<td>Sep/12</td>
<td>108,189</td>
<td>125,641</td>
<td>2,655,767</td>
<td>47</td>
</tr>
<tr>
<td>Oct/12</td>
<td>118,949</td>
<td>138,136</td>
<td>2,996,457</td>
<td>46</td>
</tr>
<tr>
<td>Nov/12</td>
<td>110,045</td>
<td>127,796</td>
<td>2,645,088</td>
<td>48</td>
</tr>
<tr>
<td>Dec/12</td>
<td>114,519</td>
<td>132,992</td>
<td>2,536,125</td>
<td>52</td>
</tr>
<tr>
<td>2012</td>
<td>1,352,521</td>
<td>1,570,688</td>
<td>33,876,346</td>
<td>46</td>
</tr>
</tbody>
</table>

Bus fuel=diesel; Efficiency of the buses=2.30 km/l; Bus emission factor=2.671 kgCO₂/l. Source: [32, 35]

### CONCLUSIONS

The objective of this study was achieved through the comparative analysis of general results of CO₂ emissions from subways, buses and cars and through the proposition and application of a procedure for calculating the emission of a subway system and its bus fleet. The comparative analysis showed that the subway mode, in general, is a transportation solution with lower CO₂ emissions per passenger-km than other means of transportation like buses and cars. The buses usually emit less than the cars. However, it is possible for the subways to emit amounts of CO₂ that are close to or higher than those of buses, as in the case of the Baltimore Metro. The bus may also have an emission higher than the emission of automobiles. This occurs when the subway or bus system does not present a proper occupancy rate, causing emissions, in gCO₂ per pkm, to become high. Another reason is the use of an energy matrix based on thermal sources for generation of energy to be used by the subway system, as in Australia, where the results of emission of subways, buses and cars are similar.

The application of the procedure proposed to Rio de Janeiro Subway and its bus fleet throughout the year 2012 revealed that, inside this system, the subway has an emission (4.5 gCO₂/pkm) about 10 times lower than that of the buses (46 gCO₂/pkm), with similar occupancy rate (50% to subway and 47% to buses). Buses, in turn, emit almost 3 times less than the Brazilian automobiles (127 gCO₂/pkm). The proper occupancy rate of MetrôRio and its bus fleet, coupled with little use of thermal sources in the energy matrix of generation of electricity powering the trains, enabled these results.

A limiting factor in the study developed here lies in the influence of passenger load and traffic congestion on the fuel consumption of the buses. Since average values of efficiency are used, the actual emission values at rush hours are actually
larger than those calculated. However, data on engine operating modes in situations of great load and congestion are scarce in Brazil and in the world.

As an idea for new studies we suggest that a study be carried out to learn about the differences in results in CO₂ emissions in the operation of trains and buses, for a 2-hour period during rush hour and for a 2-hour period off-peak, in order to quantify the differences in the results of emissions according to the time of the day, investigating the influence of occupancy rate throughout the times of operation.

REFERENCES


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