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Carbon dioxide net avoided emissions by subway systems operation: Brazilian cases

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***Abstract*—Carbon dioxide emission increase can provoke huge environmental damages to the world. Transport sector is responsible for a significant percentage of global emission caused, basically, for fossil fuels consumption and electric energy generation. Thus, this paper aims to present the net avoided emissions concept applied to subway systems operation, analyzing the results which were found in Brazil particularly in Rio de Janeiro and Sao Paulo Subways systems.**

***Keywords*—avoided emissions, CO_2, metro rail, subway**

I. Introduction

The transport sector is responsible for 23% of energy-related greenhouse gas (GHG) emissions worldwide [1]. This sector is the main responsible for GHG emissions in different countries, such as Brazil [2], which has a 30% of energy consumed by transport sector. Carbon dioxide (CO_2) is the main GHG, so, researches usually use carbon dioxide equivalent (CO_2e) for measuring GHG emissions.

CO_2 emissions related to metro rail systems, such as subways are usually, smaller than emissions related to other modes of road passenger transportation, such as cars and buses - that consume fossil fuel, which are directly associated to CO_2 emissions. So, the transport sector of a large city tends to have a larger amount of emission if subways are not available to the population. If a subway is inexistent, population must use road alternatives to locomotion. Besides, without subways, it would have a larger number of road vehicles in the streets, what would enlarge the traffic and increase the fossil fuel consumption increasing the total amount of CO_2 emitted.

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So, the main question of this paper is: besides the benefits related to features of subways – such as, regularity, rapidity, reliability, could it contribute to CO_2 emission reduction? If it could, how much can the subway contribute?

Different studies all over the word have estimated the amount of avoided emissions by subway systems operation – which allows population to stop using means of transportation with higher emissions. The results indicate that subways can be an alternative to achieve the emission reduction. Thus, this paper aims to analyze how a subway system impacts in CO_2 emission of a large city, identifying how much the system can contribute to reduce emissions, showing this studies in Brazilian subways cases, in Rio de Janeiro and Sao Paulo.

Following this introduction, section 2 presents the net avoided emission concept related to subway system operation. In section 3, we present the methodological procedure and the results of its application in the two subway systems in Brazil, in the cities Rio de Janeiro and Sao Paulo. In section 4, we compare the results found in section 3. At the end, section 5 presents the main conclusions of this study.

II. Net avoided emissions by subway systems operation

Road transport is the main responsible for GHG emissions. Nevertheless, it is estimated a huge increase in its world fleet: it will be 3 or 4 times bigger than 2010, until 2050 [3]. The implementation and the improvement in subway systems can contribute to diminish the amount of emitted CO_2, since population would have an alternative to low capacity modes - such as cars, taxi and motorcycles - and medium capacity - such as buses and vans. The amount of not emitted CO_2 because of the decrease in usage of these low and medium capacity transport modes caused by the increase in subways usage is known as avoided emissions - in this case, it happens because there is an available subway system as an option to the citizens.

Avoided emissions by subway system operation must be calculated, mainly, using *mode shift* factor. This factor is associated to the fact that without a subway system operation, the cities would have a larger movement of other means of transport, which are more pollutant than subways. Just a non-existence of this system would increase the amount of emissions. The difference between the avoided and the produced emission will provide the net avoided emission.

This *mode shift* factor was suggested in an American Public Transportation Association (APTA) study, involving the whole public passenger transport system in New York City [4]. Nowadays, this concept is widely used in specific studies to subways.

APTA also identified *congestion relief* and *land use* factors. *Congestion relief* factor means that without a metro rail system, there would be a lot more vehicles in the street, increasing the traffic and causing a larger use of fossil fuels which would cause an increase in the emissions associated to the transport sector. *Land use* factor means denser land-use patterns provided by metro rail systems. This factor accounts for the indirect impacts of transit on reducing vehicle travel, including reduced trip lengths, facilitation of bicycle and pedestrian travel, trip chaining and reduced vehicle ownership. It is noteworthy these factors have a large influence in the amount of emitted pollutant.

Regarding the *mode shift* factor, it consists in estimating the amount of GHG emitted by other means of transport when they absorb the daily subways demand. So, it is necessary to survey which transport mode each user would use if there were no subway system and estimating the amount of emitted CO_2 for the selected means of transport. According to Florida Department of Transportation (FDT) there are 4 most common ways to estimate the avoided emissions by *mode shift* factor use [5].

a) To simulate effect of subway absence in travel demand models.

b) To examine trips behavior during long interruptions of metro rail system, such as strikes.

c) To make a survey with users about their travel preferences.

d) To use a set of patterns based on population size.

It is possible to establish different calculation methodologies to get the net avoided emissions result, which value depends on what will be considered for calculating the emissions produced by the subway.

Generally, the source of emissions produced by subway is the generation of electric power for train traction. It is related to the *fuel* of the subway system trains, which is the electric power. For the subways, 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 caused emission only by fuel consumption [6].

Net avoided emissions are calculated by the difference between subway's produced emission and subway's avoided emission. Analyzing the result, it is possible to determine if the subway system has a positive or a negative net emission. A positive net emission means that the system emits more than avoids. A negative net emission means that the system operation compensates the amount of produced emissions and still avoids a specific amount of emission - which is quantified in tons of carbon dioxide equivalent (tCO_2e).

III. Brazilian cases of net avoided emissions by subway systems operation

Studies about the amount of produced and avoided emissions by subway systems operation were done in Brazilian subways, specifically in Rio de Janeiro and Sao Paulo.

A. *Net avoided emissions by Rio de Janeiro Subway*

In the study published by Andrade et al. [7], the result of avoided emissions by the operation of the Rio de Janeiro Subway was calculated for 2011. The methodological procedures used to calculate the avoided emissions result considered just the *mode shift* factor. It was done in 4 steps:

Step 1: Determination of users' choice regarding what would be used (private cars, taxis, motorcycles, buses and vans, for instance) if did not exist subway in Rio de Janeiro. The data were obtained though a survey conducted by an independent agency together all users of the Rio de Janeiro Subway.

Step 2: Determination of the number of passenger kilometers (or passenger-mile) of each means of transport chosen by users.

Step 3: Determination of the additional amount of vehicle-km (or vehicle-mile) corresponding to each mode of transport and each type and quantity of fuel used (gasoline, ethanol, diesel and natural gas).

Step 4: Determination of the additional emission produced by each mode of transport and each fuel type.

The methodology used in that study [7] considered the passenger-km of each mode of transport chosen relating it to the peak time. The authors assume that, conservatively, in the other times during the day, the demand would be absorbed by spare capacity in other modes of transport, generating no need for additional vehicle-km.

The GHG inventory from the Rio de Janeiro Subway [8] includes the direct emissions results (Scope 1), the indirect emissions from the use of electricity (Scope 2) and other indirect emissions (Scope 3), as defined in ISO 14064 [9].

In this study, produced emissions from the Rio de Janeiro Subway includes only the generation of electric energy required for the movement of trains (traction force). It represents 70% of the whole results from the Scope 2 in the GHG inventory from the Rio de Janeiro Subway [8]. Table I presents the results obtained in the studies of produced emissions [8] and avoided emissions [7] by the Rio de Janeiro Subway system, in 2011, allowing the calculation of net avoided emissions.

TABLE I. PRODUCED, AVOIDED AND NET AVOIDED GHG EMISSIONS IN RIO DE JANEIRO SUBWAY – 2011 [7, 8]

Produced emissions, considering just the emissions related to electric energy production applied in the trains movement	5,561 tCO_2e
Avoided emissions, considering just the *mode shift* factor	41,039 tCO_2e
Net avoided emissions	- 35,478 tCO_2e

The relationship between the produced emission and the avoided emission by Rio de Janeiro Subway indicates that, to each ton of GHG emitted by the system, considering the GHG inventory of this system made in 2011, about 7 tons were avoided.

B. *Net avoided emissions by Sao Paulo Subway*

Sao Paulo Subway calculates and publishes in its sustainable reports the results of net avoided emissions, taking into account the social benefits related to its operation. In this report, they show the net avoided emissions resulted from Sao Paulo Subway operation [10], based in an own specific methodology which analyzes the *mode shift* factor and the *congestion relief* factor.

The produced emissions are related only to electric energy generation required to trains movement (trains traction force). Table II presents the results found in studies about net avoided emissions in Sao Paulo Subway in 2013.

TABLE II. PRODUCED, AVOIDED AND NET AVOIDED GHG EMISSIONS IN SAO PAULO SUBWAY - 2013 [10]

Produced emissions, considering just the emissions related to electric energy production applied in the trains movement	42,000 tCO_2e
Avoided emissions, considering the *mode shift* factor and the *congestion relief* factor	862,000 tCO_2e
Net avoided emissions	- 820,000 tCO_2e

The relationship between the produced emission and the avoided emission by Sao Paulo Subway indicates that, to each ton of GHG emitted by the electric energy generation required in 2011, about 20 tons were avoided.

IV. Comparative analysis of the net avoided emissions by the subway systems

Table III summarizes the existing results and the methodologies adopted to calculate the avoided emissions in the two studied cases. The results indicate that, in the cities analyzed, the amount of emissions avoided by subway operation were much bigger than the emissions produced by the system. It proves that the subway systems are important alternatives to diminish the increasing amount of emitted CO_2 by transport sector in Brazil.

TABLE III. NET AVOIDED EMISSIONS, IN TONS OF GHG, OF RIO DE JANEIRO AND SAO PAULO [7, 8, 10]

	Rio de Janeiro Subway	**Sao Paulo Subway**
Base year of emissions	2011	2013
Produced emissions	Energy to trains movement (traction power)	Energy to trains movement (traction power)
	5,561 tCO_2e	42,000 tCO_2e
Avoided emissions	*mode shift*	*mode shift + congestion relief*
	41,039 tCO_2e	862,000 tCO_2e
Result = net avoided emissions	- 35,478 tCO_2e	- 820,000 tCO_2e
Number of tons avoided / 1 ton emitted	7.4	20.5

The energy matrix structure is essential to determine the net avoided emissions' final result because it affects directly the produced emission. Subway demand is also another factor relevant for its result since it is necessary that the system occupation rate is not low in order to obtain relevant values to the avoided emission which must be bigger than the produced emission.

In Brazil, the largest part of energy is generated by hydroelectric sources, which are *clean* sources with a slight impact in GHG emissions. There is a smaller usage of thermal sources in Brazil, where the hydroelectric represents 77% of national energetic matrix while thermal source is responsible for 13% [11]. Considering this fact, Brazilians subways tend to contribute more to diminish the emissions in transport sector.

Sao Paulo Subway results are due to the inclusion of *congestion relief* factor in the avoided emissions calculation which contributed positively to the net avoided emission final result in this city.

V. Final considerations

This study proposal consisted in evaluate the net avoided emissions by subway systems operation. So, the objective was achieved through the results presented and their comparative analysis. It was analyzed the amount of GHG emissions produced and avoided by subway systems operations in two Brazilian cities: Rio de Janeiro and Sao Paulo. The results are dependent of the methodology used to calculate the emissions and the factors considered. In Rio de Janeiro the methodology was conservative and was implemented only for *mode shift* factor while in Sao Paulo was used another methodology that considered also the *congestion relief* factor.

Despite the differences in the adopted methodologies, it appears that even in the most conservative methodology - Rio de Janeiro Subway - the subway proved to be a sustainable transport mode. We found that these systems have important contributions to the reduction targets achievement, which vary from 7.4 to 20.5 tCO_2e avoided to each ton produced.

It is reasonable to consider that, in general, implantation of other rail systems, electricity powered, around the world, would avoid a certain quantity of CO_2 emissions in the

transport system. This is particularly true for countries where electricity generation is based on hydroelectric and other *clean* sources. The subway and rails systems have a smaller impact in GHG emission than the most road transport vehicles.

We conclude that authorities should establish an integrated transportation plan, where metro rail systems be evaluated not only as mass transit but also as a possible solution to mitigate CO_2 emissions by the transport system.

The proposal for new studies is to establish and to apply a new avoided emissions methodology for subway systems that considers the *land use* factor, as conceived by APTA. So far all the elements (*mode shift*, *congestion relief* and *land use*) would be considered. This approach would provide a more adequate standardization for comparison with other means of transport.

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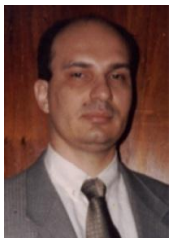

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