Quantification of CO2 Emissions from Building Materials Transportation in Brazil

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QUANTIFICATION OF CO_2 EMISSIONS FROM BUILDING MATERIALS TRANSPORTATION IN BRAZIL

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ABSTRACT

This paper aims to estimate CO_2 emissions from transportation of building materials to the construction site, compute their share in total emissions generated by the production of each building material, analyze their involvement within the context of emissions generated by the construction of a low-income single-family residence in Rio de Janeiro City and compare these emissions with the ones generated by an alternative transportation system of building materials (Proposed Scenario).

We employ the QE-CO_2 Method for accounting for emissions from transportation. The results show that total CO_2 emissions from transportation account for almost 10% of all emissions generated by manufacturing, transport and use of building materials in a low-income residential building in Rio de Janeiro. These emissions could be reduced by more than 50% if the Proposed Scenario was implemented, since it offers a new vision of the system and the logistics of cargo transportation.

It is a pioneer study in Brazil because it takes into account the use of national methodology and data (QE-CO_2 Method).

Keywords: CO_2 Emissions, Sustainable Transport, Transport of Building Materials

OBJECTIVE

This paper aims to identify how transportation participates in total emissions generated by the production of national materials typically used in Brazilian civil construction, through the use of QE-CO_2 Method. To illustrate this participation, it’s presented a Case Study which compares the emissions generated for the construction of low-income single-family residence in Rio de Janeiro City in the current scenario (Reference Scenario) with emissions generated in the alternative scenario (Proposed Scenario), in which the train would be used as the primary means of transportation.

INTRODUCTION

Greenhouse Gases (GHG) are gaseous constituents, both natural and anthropogenic, in the atmosphere that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by Earth's surface, atmosphere and clouds. These properties of absorption and emission of radiation cause the greenhouse effect, which maintains the air heated. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere (IPCC, 2007).

As a result of human activities, global atmospheric concentrations of CO_2, CH_4 and N_2O have increased since 1750. The concentration of CO_2 (the most important anthropic GHG, according to IPCC, 2007), increased from a pre-industrial value of about 280 ppm (parts per million) to 379 ppm in 2005, exceeding the natural range of the last 650,000 years (180 to 300 ppm).

Increasing concentrations of GHG has caused climate change, which is a widely used term (IPCC, 2007) to refer to the change in state that the weather can be identified by changes in the medium or in the variability of their properties, and persists for a long time (decades or longer). Climate change can occur due to internal processes or external forces natural or anthropogenic persistent changes in land use or composition of the atmosphere.

The production of materials used in the construction of buildings in Brazil results in many environmental impacts, whether direct or indirect. Sectors related to the production of iron, cement and ceramics are responsible for the consumption of more than 30% of all energy used by the Brazilian industrial sector. Structure and walls of a building represent over 60% of the energy content of the materials of a building (Brazil, 1982; Guimarães, 1985; Tavares, 2006) while the cement, red ceramic, steel and ceramic tile are responsible for over 80% (Tavares and Lamberts, 2004; Thormark, 2002; Adalberth, 1997). Although the production and transportation of materials is made within the country and locally (distances of less than 400km, as red ceramic, cement and iron), the transport of construction materials is carried out mostly by road transport system and, in many cases, goods are transported over distances exceeding 1,000km.

Therefore, the article identifies how much the transport participates in total emissions generated by the production of different construction materials, using the QE-CO_2 Method. The choice of materials to be analyzed in this article was made taking into account the amount of energy required to manufacture it (embodied energy), since CO_2 emissions have a direct relationship with the amount of energy (non-renewable) consumed. It is presented a Case Study which calculates and compares the emissions generated for the construction of low-income single-family residence in Rio de Janeiro City in the current scenario (Reference Scenario) with emissions generated in the alternative scenario (Proposed Scenario), in which the train would be used as the primary means of transportation.

LITERATURE REVIEW

The literature review establishes the state of the art of methodologies for quantifying emissions from transportation. We analyze, mainly the following:

1. Guidelines of the Intergovernmental Panel on Climate Change (IPCC, 2007) for greenhouse gases inventories;

2. Methodologies of the USA Department of Energy (USA, 2009; USA, 2010) and the USA Environmental Protection Agency (USA, 2008);

3. Methodologies of the European Environment Agency (EEA, 2009);

4. Methodology for quantification of carbon dioxide releases generated by the production of building materials in Brazil: The QE-CO_2 Method (Costa, 2012).

Within the analyzed methods, the only one that uses data and takes into account the reality of Brazilian extraction of raw materials, production and transportation of building materials is Costa (2012). Therefore, the QE-CO_2 Method will be presented in more detail below.

METHODOLOGY

Data

Data were obtained from different sources in Brazil, like Costa (2012), the Federal Government, 2nd National Communication of Brazil (Brazil, 2010), National Energy Balance (Brazil, 2012), Manufacturers Associations, official publications and scientific articles, besides United Nations Framework Convention on Climate Change (UNFCCC, 2010) and Intergovernmental Panel on Climate Change (IPCC, 2007).

The QE-CO_2 Method

The QE-CO_2 Method quantify CO_2 emissions generated in the construction of a building due to the extraction of raw materials, processing and transportation of the materials used in construction (Costa, 2012). It allows Brazilian professionals, responsible for the specification of materials to be used in the construction, to quantify the total emissions generated as a consequence of the production of building materials, using Brazilian CO_2 emission factors (Costa, 2012). Therefore one can choose the material that has lower associated CO_2 emissions, identify how much each stage of the production process contributes to the total emissions and implement mitigation actions, contributing to the reduction of GHG emissions (Costa, 2012).

The QE-CO_2 Method consists in multiplying the quantity of product used in the construction by the loss factor and by the sum of emissions generated by energy consumption and transportation, in accordance with the formula shown in Equation 01 (Costa, 2012). This

Equation is adapted to every construction material in order to take into account the particularities of the materials, their production systems and the quality of available data.

Equation 01: $Emissions_{MT1,\,j} = QT_j \times FP_j \times (Emissions_{TR1,\,i} + Emissions_{EN1,i})$
Where:

$Emissions_{MT1,j}$ = CO_2 emissions due to use of the product *j* in constructions (tonnes of CO_2);
QT_j = amount of product needed in the construction (tonnes);
FP_j = loss factor of product *j* (dimensionless);
$Emissions_{TR1,\,i}$ = CO_2 emissions due to consumption of energy *i* for transportation of raw materials and product *j* to the construction site (tonnes of CO_2 / tonne of product *j*);
$Emissions_{EN1,i}$ = CO_2 emissions due to consumption of energy *i* for extraction and processing of product *j* (tonnes of CO_2 / tonne of product *j*).

Alternatively to Equation 01 it is used in this article the Equation 02, also proposed by the QE-CO_2 Method since the use of Equation 01 implies the need to explain details of the method that are not relevant to this article.

Equation 02: $Emissions_{MT,\,j} = QT_j \times FP_j \times FEP_j$
Where:

$Emissions_{MT,\,j}$ = CO_2 emissions due to the use of product *j* in buildings (tonnes of CO_2);
QTj = quantity of product *j* necessary in the site construction (tonnes);
FP_j = loss factor of product *j* (dimensionless);
FEP_j = CO_2 emission factor due to use of the product *j* in buildings (tonnes of CO_2 / tonne of product *j*, Table 06).

The factor FEPj is employed to replace the sum ($Emissions_{TR1,\,i} + Emissions_{EN1,i}$) and was calculated for each material analyzed in this article. Computes average values, at national level, of fuel consumption at transportation vehicles, average distance between extraction site, production and a fictitious construction site in the center of Rio de Janeiro (latitude 22 ° 54'12 .74 "South and longitude 43 ° 12'34 .51 "West), energy used for extraction and processing of raw materials, and emissions from chemical reactions. Therefore, the FEP is an emission factor of CO_2 due to use of a particular product in buildings, in tonnes of CO_2 / tonne of product.

CO_2 emissions from the use of energy for the operation of vehicles such as trucks, trains and ships are calculated using Equation 03. It is taken into account the average consumption of energy per ton of raw materials and finished products transported.

Equation 03: $Emissions_{TR1} = km \times CO_t \times FEC_i$
Where:

$Emissions_{TR1}$ = emissions of CO_2 due to transport (tonnes of CO_2 / tonne of finished product);

km = distance traveled by the vehicle in the transportation of raw materials and finished product (the sum of the distance of going over and back, where applicable, in km);
CO_t = average energy consumption factor of a particular type of vehicle (L/t/km);
FEC_i = corrected emission factor of energy *i* (tCO_2/L).

Regarding the distance traveled by the vehicle, for each material is calculated an average distance between extraction/ processing/ industries locals and a fictional construction site in the city center of Rio de Janeiro (latitude 22°54'12.74" South and longitude 43°12'34.51" West).

The value of FEC_i is obtained from Table 01 according to the type of fuel used. FEC was calculated based on data from Brazil (2010), like carbon content, and from the correction factor calculated in Costa (2012), which refers to the accounting for losses in converting primary energy into secondary energy as well as losses in the distribution and storage of primary and secondary energy.

Table 01: Summary of corrected emission factors (FEC) of energies for Brazil, in 2010.

Identification	FEC			
Anhydrous Ethanol	1.70	tCO_2/m^3	0.0017	tCO_2/L
Hydrated Alcohol	1.63	tCO_2/m^3	0.0016	tCO_2/L
Cane Bagasse	0.88	tCO_2/t	-	
Broth of Cane	0.19	tCO_2/t	-	
Steam Coal 3100 kcal / kg	1.17	tCO_2/t	-	
Steam Coal 3300 kcal / kg	1.23	tCO_2/t	-	
Steam Coal 3700 kcal / kg	1.39	tCO_2/t	-	
Steam Coal 4200 kcal / kg	1.58	tCO_2/t	-	
Steam Coal 4500 kcal / kg	1.68	tCO_2/t	-	
Steam Coal 4700 kcal / kg	1.76	tCO_2/t	-	
Steam Coal 5200 kcal / kg	1.94	tCO_2/t	-	
Steam Coal 5900 kcal / kg	2.22	tCO_2/t	-	
Steam Coal 6000 kcal / kg	2.26	tCO_2/t	-	
Charcoal	2.89	tCO_2/t	-	
Electricity from Self-Producers	184.21	tCO_2/GWh	0.1842	tCO_2/MWh
Electricity from Public Centrals	58.92	tCO_2/GWh	0.0589	tCO_2/MWh
Dry Natural Gas (10^3)	2.77	tCO_2/m^3	-	
Wet Natural Gas (10^3)	2.44	tCO_2/m^3	-	
Natural Gas	2.21	tCO_2/m^3	-	
Automotive Gasoline	2.47	tCO_2/m^3	0.0025	tCO_2/L
Aviation Gasoline	2.53	tCO_2/m^3	0.0025	tCO_2/L
GLP	1.78	tCO_2/m^3	0.0018	tCO_2/L
Firewood	1.38	tCO_2/t	-	
Molasses	0.57	tCO_2/t	-	

Naphtha	2.60 tCO_2/m^3	0.0026 tCO_2/L
Fuel oil	3.43 tCO_2/m^3	0.0034 tCO_2/L
Diesel	2.91 tCO_2/m^3	0.0029 tCO_2/L
Aviation Kerosene	2.72 tCO_2/m^3	0.0027 tCO_2/L

Source: Author, based on data from Brazil, 2010.

In the Tables 02, 03 and 04 are presented the values of fuel consumption, respectively, by full loaded trucks, trains and ships, and in Table 05 are presented the average values obtained and used in this article for CO_t.

Table 02: Fuel consumption in road freight transport in Brazil.

Identification	Light (3.5t – 7t)	Medium (9t – 13t)	Semi-heavy (17t – 26t)	Heavy (up to 45t)	Extra-Heavy (above 45t)
Mercedes-Benz (km/l)	5.8	3.5	3.4	3.3	2,2
Ford (km/l)	5.9	4.4	3.3	3.2	2.6
General Motors (km/l)	5.0	5.3	3.1	2.8	-
Scania (km/l)	-	-	-	2.9	2.2
Volkswagen (km/l)	5.3	4.0	3.5	3.1	2.6
Volvo (km/l)	-	-	-	-	2.2
Average (km/l)	5.6	3.6	3.4	3.3	2.2
Average (l/t/km)	0.0446	0.0347	0.0196	0.0121	0.0114

Source: Author, adapted from Truk (2004).

Table 03: Fuel consumption in rail freight transport, according to different transport companies operating in the Brazilian market.

Transport Company	Fuel Consumption (L/t/km)
ALLMN América Latina Logística Malha Norte S.A.	0.0070
ALLMO América Latina logística Malha Oeste S.A.	0.0108
ALLMP América Latina Logística Malha Paulista S.A.	0.0142
ALLMS América Latina Logística Malha Sul S.A.	0.0090
EFC Estrada de Ferro Carajás	0.0020
EFVM Estrada de Ferro Vitória a Minas	0.0029
FCA Ferrovia Centro-Atlântica S.A.	0.0133
FERROESTE Estrada de Ferro Paraná Oeste S.A.	0.0124
FTC Ferrovia Tereza Cristina S.A.	0.0068
FNSTN Ferrovia Norte Sul Tramo Norte	0.0060
MRS Logística S.A.	0.0045
TLSA Transnordestina Logística S.A.	0.0149
Average (adopted)	0.0086

Source: Authors, adapted from Brazil, 2011.

Table 04: Fuel consumption in shipping freight transport.

Bibliographical Reference	Fuel Consumption (L/t/km)
USA (2008)	0.0095
Menezes (2010)	0.0040
Tavares (2006)	0.0034
Venta (1997)	0.0031
Average (adopted)	0.0050

Source: Author.

Table 05: Summary of average fuel consumption of means of transport (CO_t) in Brazil.

Means of Transport	Fuel Consumption (L/t/km)
Light Truck	0.0446
Medium Truck	0.0347
Semi-heavy Truck	0.0196
Heavy Truck	0.0121
Extra-heavy Truck	0.0114
Train	0.0086
Ship	0.0050

Source: Author.

Reference Scenario and Proposed Scenario

The Reference Scenario is the current reality of building materials transportation in Brazil, where they are transported mainly by road system.

The Proposed Scenario offers a new vision of the system and the logistics of cargo transportation through the integration of the Rail system with a cargo hub and the Road System. Whenever possible, the Road System for large distances is changed by rail. It is proposed that the loads are transported by rail over long distances, far from urban centers, up to temporary cargo hubs. These would be located on the outskirts of Rio de Janeiro city, 40km away from the center and then the cargo would be carried locally by the road system to the point of sale or to the construction site.

Using the data presented in the previous section and in Costa (2012), it was possible to calculate how much transportation contributes to emissions during extraction and transportation of raw materials, production and installation of each construction material in the Reference Scenario (columns “B” and “C”, table 06) and in the Proposed Scenario (Columns “E” and “F”, table 06). The materials listed below are of domestic origin and are those generally used in the Brazilian construction industry.

Table 06: Emission factors FEP and transport participation in emissions.

Material	FEP (tCO_2/t product) in the Reference Scenario	Quantity (tCO_2/t product) of (A) ref. to Transport	% of (A) referring to Transport	FEP (tCO_2/t product) in the Proposed Scenario	Quantity (tCO_2/t product) of (D) ref. to Transport	% of (D) referring to Transport	% of emissions reduction (D-B)
	(A)	(B)	(C)	(D)	(E)	(F)	(G)
Steel	1.762	0.014	0.80	1.752	0.004	0.24	70.84
Coarse aggregates	0.079	0.013	16.26	0.073	0.006	8.81	50.26
Aggregates	0.079	0.013	16.19	0.073	0.006	8.77	50.26
Aluminium (profile)	4.292	0.395	9.20	4.262	0.365	8.57	7.50
Mortar 01	0.190	0.016	8.23	0.181	0.007	3.96	54.06
Mortar 02	0.155	0.014	9.13	0.148	0.007	4.48	53.29
Mortar 03	0.136	0.013	9.85	0.129	0.006	4.91	52.78
Mortar 04	0.182	0.016	8.88	0.173	0.007	3.97	57.58
Mortar 05	0.152	0.015	9.73	0.144	0.007	4.51	56.17
Mortar 06	0.132	0.014	10.40	0.125	0.006	4.94	55.21
Mortar 07	0.179	0.017	9.22	0.169	0.007	3.98	59.22
Mortar 08	0.149	0.015	10.04	0.140	0.006	4.53	57.52
Mortar 09	0.131	0.014	10.69	0.123	0.006	4.96	56.36
Hydrated lime	0.893	0.072	8.03	0.839	0.019	2.21	74.13
Quicklime	1.161	0.093	8.03	1.092	0.024	2.21	74.13
Ceramics (coating)	0.180	0.089	49.18	0.115	0.023	20.14	73.94
Ceramics (bricks and tiles)	0.110	0.019	16.81	0.099	0.008	7.69	58.76
Cement	0.635	0.022	3.44	0.629	0.016	2.53	27.28
Concrete (Block)	0.178	0.013	7.49	0.172	0.007	4.14	46.59
Concrete (floor interlocked)	0.262	0.014	5.22	0.257	0.008	3.17	40.68
Concrete (tube)	0.217	0.013	6.14	0.212	0.008	3.56	43.64
Concrete (15Mpa CPIIF32)*	0.312	0.029	9.16	0.299	0.016	5.21	45.49
Concrete (20Mpa CPIIF32)*	0.334	0.029	8.81	0.320	0.016	5.04	45.05
Concrete (25Mpa CPIIF32)*	0.342	0.029	8.41	0.329	0.016	4.85	44.51
Concrete (30MPa CPIIF32)*	0.369	0.031	8.29	0.356	0.017	4.79	44.34
Concrete (35Mpa CPIIF32)*	0.386	0.031	8.10	0.372	0.017	4.70	44.05
Concrete (40Mpa CPIIF32)*	0.405	0.032	7.83	0.391	0.018	4.57	43.64
Concrete (45Mpa CPIIF32)*	0.431	0.032	7.49	0.417	0.018	4.41	43.05
Concrete (50MPa CPIIF32)*	0.460	0.033	7.17	0.446	0.019	4.26	42.44
Plaster *	0.601	0.273	45.32	0.392	0.064	16.22	76.64
Gypsum (plates) *	0.722	0.327	45.32	0.471	0.076	16.22	76.64
Wood (Eucalyptus) *	0.401	0.081	20.17	0.373	0.054	14.38	33.56
Wood (Amazon wood) *	0.481	0.162	33.57	0.380	0.060	15.90	62.60

Wood (Pinus) *	0.397	0.077	19.44	0.372	0.052	14.01	32.51
Wood (fibreboard and chipboard) *	0.300	0.046	15.19	0.271	0.017	6.27	62.64
Wood (HDF, MDF, MDP and OSB) *	0.322	0.067	20.90	0.277	0.022	8.06	66.81
Plastic (PVC)	0.507	0.057	11.17	0.467	0.016	3.44	71.67
Glass	0.874	0.041	4.64	0.846	0.013	1.55	67.60

Source: Adapted from Costa, 2012.
* Units in tCO_2/m^3.

It is not the objective of this article to present how CO_2 emissions from transport were calculated for each building material. However, we presented below how transport emissions were calculated for cement, an important building material in the Brazilian industry.

For the calculation of emissions from transportation of raw materials for cement production, admits that it is required about 1.5 ton of feedstock (EC, 2010) to produce a ton of cement and are covered 5.0km between extraction sites and industry
To transport the cement ready estimate an average distance between the main industries and the center of Rio de Janeiro (Table 7), yielding an average total of 184.00 kilometers.

Table 7: Distance between the major manufacturers of cement and downtown Rio de Janeiro.

Identification	km
Holcim	204.00
Lafarge	203.00
Votorantim (Volta Redonda)	133.00
Votorantim (Cantagalo)	196.00
Average (adopted)	184.00

Source: Author based on Google Maps.

As trucks return empties, the total distance traveled is doubled, totaling 10.00 km and 368.00 km respectively for transport of raw materials and finished cement. Therefore, the average CO_2 emissions due to transport is shown in Table 8.

Table 8: CO_2 emissions due to transportation of raw materials and cement.

Identification	km	L/t cement	tCO_2/t cement
Semi-heavy Truck on diesel fuel (raw materials)	10.00	0.29	0.0009
Semi-heavy Truck on diesel fuel (cement)	368.00	7.22	0.0228

Source: Author.

Case Study

The case study consists of the quantification of CO_2 emissions generated by the transport of each construction material in the Reference Scenario and in the Proposed Scenario using data of table 06 and Equation 02. The quantity of material used in this equation was the amount needed for the construction of a typical low-income single-family residence in Rio de Janeiro City. This was chosen because of its importance to reduce housing deficit in Brazil (which is about 7.2 million homes). The standard floor plan of the house consists of living room, kitchen, two bedrooms, bathroom and outdoor area, with approximately 42m^2 in area, and is located in the city center of Rio de Janeiro (latitude 22°54'12.74" South and longitude 43°12'34.51" West).

RESULTS AND FINDINGS

Table 09 presents the results obtained from the application of equations 02 and 03 and data from Table 06, on the Case Study.

Table 09: CO_2 emissions of the case study building and participation of transportation in emissions (Reference Scenario and Proposed Scenario).

Summary	Value
Reference Scenario: Total CO_2 emissions from the production, transportation and construction of a single-family residential building (tCO_2)	7.97
Proposed Scenario: Total CO_2 emissions from the production, transportation and construction of a single-family residential building (tCO_2)	7.56
Reduction of total emissions generated in Proposed Scenario relative to the Reference Scenario (tCO_2)	0.41
Reference Scenario: Amount of CO_2 emitted by the transportation (tCO_2)	0.78
Reference Scenario: Percentage (of total emissions) of CO_2 emitted by the transportation (%)	9.85
Proposed Scenario: Amount of CO_2 emitted by the transportation (tCO_2)	0.38
Proposed Scenario: Percentage (of total emissions) of CO_2 emitted by the transportation (%)	5.01
Emissions Reduction from transport in Proposed Scenario in relation to the Reference Scenario (tCO_2)	0.41
Difference between emissions from transport in Proposed Scenario and Reference Scenario (%)	51.77

Source: Author.

From the Case Study we can conclude the following:

5. CO_2 emissions generated by the production and transportation of building materials are 7.97 tCO_2 in the Reference Scenario and 7.56 tCO_2 in the Proposed Scenario;

6. The share of transport in CO_2 emissions generated by the production of building materials is relevant, being 9.85% in the Reference Scenario and 5.01% in the Proposed Scenario;

7. The Proposed Scenario is efficient in reducing CO_2 emissions, considering that the difference between the total CO_2 emissions calculated in Reference Scenario and Proposed Scenario is 51.77% (0.41 tCO_2).

IMPLICATIONS FOR RESEARCH/POLICY

It is a pioneer study in Brazil because it takes into account the use of national methodology and data (QE-CO_2 Method). The results show the importance of the emissions of CO_2 related to transport in the overall emissions generated by the extraction of raw materials, production and transportation of Brazilian building materials to construction sites. It also shows the importance of implementing the Proposed Scenario and offers a new vision of the system and the logistics of cargo transportation through the integration of the Rail system with a cargo hub and the Road System, reducing CO_2 emissions from building materials transport in more than 50%.

We also recommend the application of regulatory instruments for industries that require materials transport over great distances, establishing goals for reducing the emissions generated, for the relocation of production plants and for the efficiency improvement of the routes / means of transportation.

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