

Transport externalities of bus stations produced by Greenhouse Gas (GHG)

Córdova-Suárez, *M*^{1*}; Barreno-Ávila, *E*²; Villacrés-Cevallos, *P*³; Ruíz-Robalino, *O*¹

¹Universidad Técnica de Ambato, Facultad de Ciencia e Ingeniería en Alimentos, Ambato, Ecuador

²Universidad Técnica de Ambato, Facultad de Ingeniería Mecánica, Ambato, Ecuador

³Universidad Nacional de Chimborazo, Facultad de Ingeniería, Riobamba, Ecuador

Abstract. It is established that the interprovincial transportation in bus terminals of the Cities such as Ambato, Riobamba, Salcedo, Latacunga and Guaranda have contributed to the build-up of external costs of Greenhouse Gases (GHG) The climate change costs are calculated by multiplying the carbon emissions by the cost factor. To quantify the GHG emissions, this study has taken into account of both the direct and indirect sources of the Greenhouse Gas Protocol (GHG), as well as the ISO 14064.1: 2006 standard. In view thereof, it was found that the 11 bus terminals of the five cities, namely Latacunga, Riobamba Salcedo, Ambato, Guaranda-which accounts for around 3225 buses, had accounted for the emissions of 25,746.8 tCO₂eq, 37,404.6 tCO₂eq, 8,762.7 tCO₂eq, 92,364.9 tCO₂eq, 31,990.3 tCO₂eq, respectively. Simply, the average load of such pollution produced per vehicle was 60.8 tCO₂eq. and the total emissions were 196,269.3 tCO₂eq with an estimated GHG contamination cost of €27,477,702 per year.

1 Background

Externalities are created when the final product production, the expected good or service and the associated pollutant emissions, produces a negative effect on another agent without receiving any compensation [1]. In other words, this produces a loss of social wellbeing due to lack of contaminant-free air.

In Latin America, direct climate change transformations have been observed whereby, the temperature is increasing at the rate of average of 0,1°C every ten years because of the Greenhouse gas emissions (GHG) [2]. This is forcing countries to take measures by prioritizing social sectors so that problems can be mitigated ; issues such premature deaths of more than two million people per year [3] and also the costs generated by non-pollution efforts

Current bus transportation needs require the use of heavy vehicles that move continuously that run on the diesel engines.[4] The use of this type of vehicle has produced quite an impact on the environment by emitting pollutants into the air. [5]. The transportation sector has a direct impact on the accelerated growth of greenhouse gas (GHG) emissions, which cause climate change. [6].

The interprovincial bus stations infrastructures have met the requirements to satisfy the needs of the embarkation and disembarkation passengers [7]. Yet, these activities have accumulated GHG emissions from direct and indirect sources polluting the environment as a result. Once the emissions are quantified, thereby identifying the most relevant sources can the areas of emission reduction and efficiency increase can be prioritized.

The climate change externalities' costs can be calculated by multiplying the emissions of carbon dioxide equivalent in tons of one year (tCO₂eq) by a cost factor. First, it is necessary to determine (CO₂) carbon dioxide emissions, (NO_x) nitrogen oxides and (CH₄) methane according to the Greenhouse Gas Protocol (GHG) guidelines and the ISO 14064.1: 2006 standard.

In market economies where the economic resources' scarcity is not clearly shown, the direct quantification of these externalities is estimated by policymaker asking for a value to be paid in favour of environmental improvement or a compensation [8]. The estimation methodology for the non-contamination cost calculation which is used to consider the costs of goods through its used or unused economic value, and the determination of the externality economic value has become an essential part of the socio-environmental economy in business activities [9].

As the Ecuadorian highlands bus stations agglomerate a significant number of buses, people and resource consumption resulting in the generation of GHG its pollution costs will, therefore, be analysed.

2 Methodology

The methodology is illustrated in the flow chart in figure 1.

2.1 Greenhouse Gas (GHG) measuring equipment

The Bacharach ECA 450 analyzer was used to measure the efficiency of combustion gases and environmental emissions, (see figure 2) following the methodology of Boruta, Imiolek

* Corresponding author: ma.cordova@uta.edu.ec

(Boruta et al., 2013). This equipment measures and displays the oxygen percentage (O₂) and the concentration of carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO₂) and sulfur dioxide (SO₂) of flue gases.

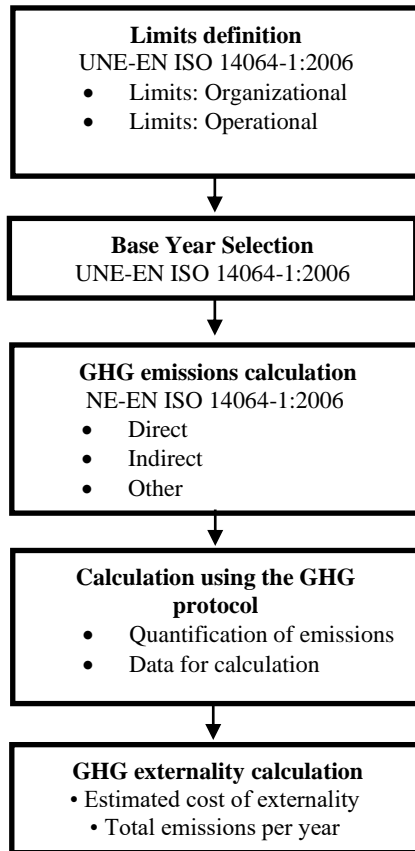


Fig. 1. Bus stations' GHG externalities assessment flowchart.



Fig. 2. GHG Bachacach ECA 450 measuring equipment.

2.2 Sample Size Determination

A stratified sample was computed [10] with proportional fixation to separate the pollution into exclusive segments, in which the homogeneity and minimum variance are analyzed. For this investigation, a sample of 3225 buses with a 95% confidence level is considered. Later, the sample was then classified according to the European Emission Standard by considering the manufacture year. See table 1.

Table 1. European emission standard application range

Tier	Standard Implementation Date	Vehicle Manufacturing Year
Euro I	December 31, 1992	1994-2000
Euro II	January 1, 1997	2001-2010
Euro III	January 1, 2002	Since 2011
Euro IV	January 1, 2007	No aplica
Euro V	January 1, 2011	No aplica
Euro VI	September 1, 2015	No aplica

Note: The first three categories are considered homologated in Ecuador according to the National Transit Agency. This is an adaptation from [11]

2.3 Calculation of GHG emissions

To begin with, according to the EURO standard (TOTAL, 2015), the land transport classification by city has three categories: EURO I, EURO II, EURO III. For the gas emissions quantification, (Galarza Baldeón, 2016) -1: 2006 It will carry out the following actions: define limits, select the base year, identify the emissions and finally quantify the emissions using the Greenhouse Gases Protocol (GHG).

2.3.1 Calculation of direct GHG emissions (scope I)

GHG emissions which generated by vehicles in the bus stations are considered. [12].

2.3.2 Calculation of indirect GHG emissions (scope II)

Under this scope, GHG emissions generated by bus stations' energy consumption, GHG emissions generated by bus stations' energy consumption are established. The data collection method is used for scope II emissions [13] according to figure 3.

2.3.3 Calculation of indirect GHG emissions (scope III)

With regard to this area, those GHG generation sources which do not belong to this case study, (such as the interprovincial transport buses occupying the bus station), are considered. [14]. To proceed, the main data such as the manufacture year, service operator brand and name are vital.

Following the quantification methodology (see figure 4) and according to the GHG protocol, it is necessary to know: the type of fuel, the amount of fuel consumed and price.

2.4 Calculation of emission factors.

CO₂ carbon dioxide emission factor

It starts by determining the % CO₂ and applying equation 1.

$$[CO_2] = (\% CO_2 * DA * CS) / (TC * 100) \tag{1}$$

[CO₂]= CO₂ concentration (kg/year)

DA=Air density (kg/L)

CS= Probe flow (L/min)

TC= Combustion time (day)

Afterwards, the emission factor is calculated utilizing the application described in equation 2

$$FE(CO_2) = \frac{[CO_2]}{n_A} \quad (2)$$

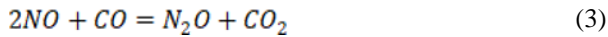
FE(CO₂)= emission factor de CO₂ (kgCO₂/TJ)

DA= activity data (TJ)

The air density was calculated considering an uncertainty of + - 1°C as ambient temperature and + - 0,1 hPa as atmospheric pressure .[15]

Nitrous Oxide Emission Factor N₂O

It is calculated using the stoichiometric equation of N₂O formation [16]:



With equation 4, the final N₂O (N₂O_f) was determined as follows:

$$[N_2O]_f = \frac{[NO_{medición}] * [N_2O]}{[NO] * 1000} \quad (4)$$

Donde:

[NO_{medición}]= NO concentration of the measurement (g/year)

[N₂O]= mass of N₂O (g/year)

[N₂O]_f= mass of final N₂O (Kg/year)

Next, the emission factor of N₂O is determined using equation 5.

$$FE(N_2O) = \frac{[N_2O]_f}{n_A} \quad (5)$$

Where:

FE (N₂O)= emission factor de N₂O (kg/TJ)

[N₂O]= mass of N₂O (g/year)

DA= activity data (TJ)

2.5 GHG emission calculation

The GHG emission considering both direct and indirect sources is calculated with equation (6):

$$EGEI = \frac{DA * FE}{1000} \quad (6)$$

Where:

EGEI= GHG emission (tCO₂)

DA= activity data (TJ)

Considering the potential of global warming [17] The total emissions in tons of CO₂ equivalent to a year CO₂-eq are determined with the equation (7).

$$ECO_{2-eq} = DE * PCG \quad (7)$$

Where:

ECO_{2-eq}= GHG emission in (tCO_{2-eq})

DE= emission data of CO₂, N₂O and CH₄ (TJ)

PCG= Global warming potential at 100 years (tCO_{2-eq})

2.6 Calculation of the externality cost due to GHG emissions

From the recommended values to the calculation of the global warming cost, the most commonly used methods recommend to consider the values between 1 €/tCO₂ and 140 €/tCO₂. Although the most used methodology considers the avoided costs, the estimation hypotheses are very sensitive. In fact, there are already many considerations such as the discount rate, the potential for impact, the function of the damage, the pace of climate change, the impacts on the ecosystem. In other words, for the consideration of the damage aggregation, the shadow cost will be considered [18], not only because its value does not give intervals, but also this is the most updated data.

Lastly, the shadow pricing methodology is used to estimate a comparison point among the costs obtained in the countries of the European Community, which uses the value of 140€/tCO₂ [19]

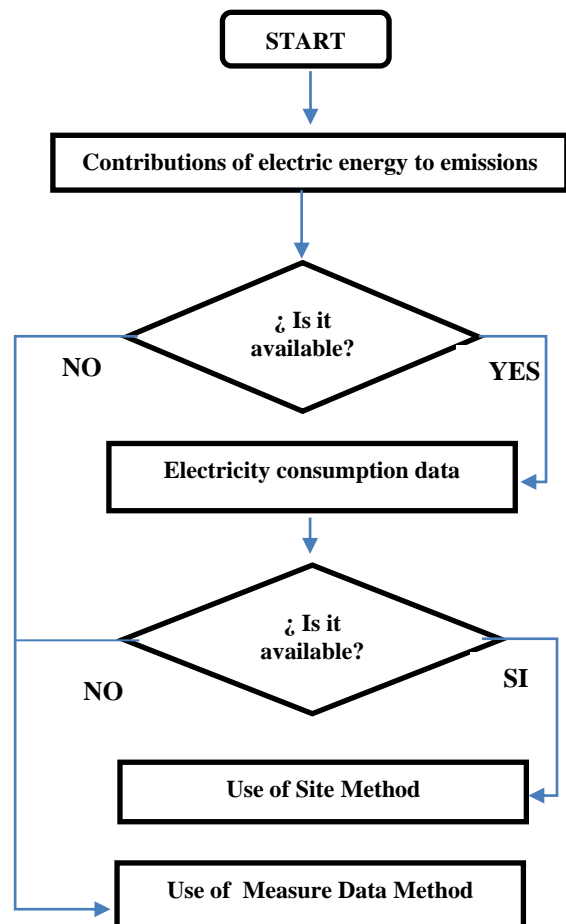


Fig. 3. Flujograma para realizar el cálculo de las emisiones del alcance II con el GHG protocolo.

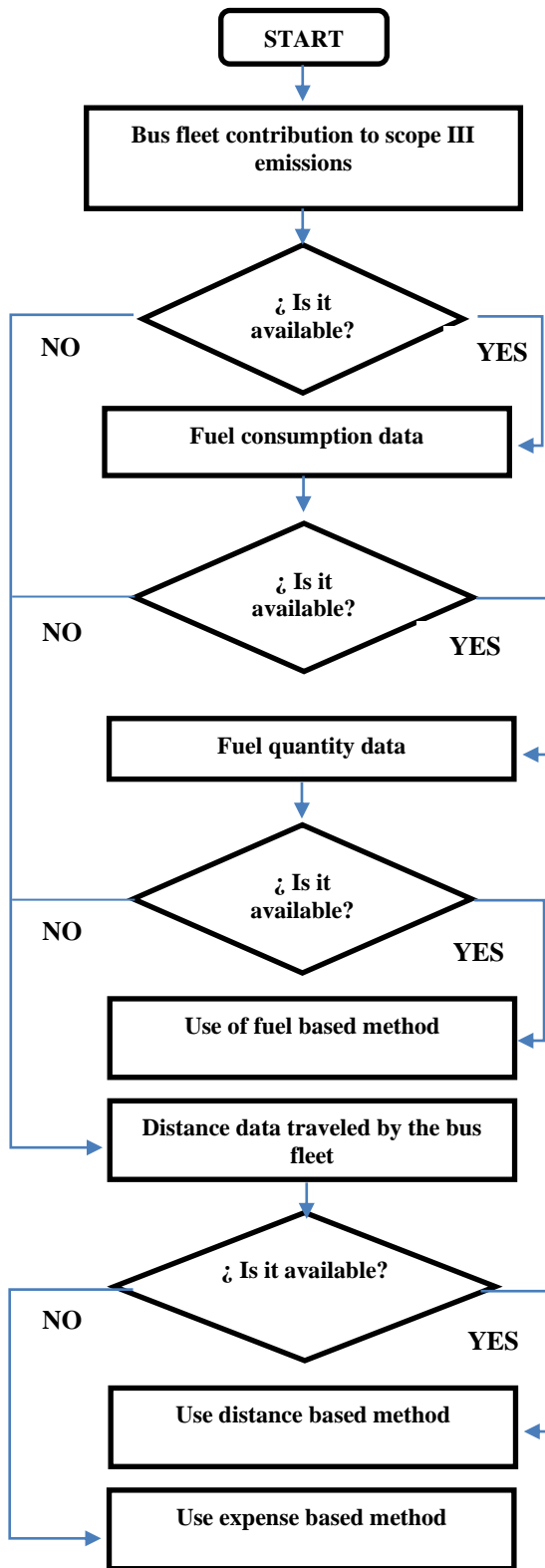


Fig. 4. Scope III emissions calculation flowchart according to the GHG protocol. Adaptation from [11].

3 Results and discussion

3.1. Results of emission factors.

Table 2 shows the total emission factor by city.

Table 2. Emission factors by city

City	Emission Factor (Kg/TJ)	Emission Factor IPCC* (Kg/TJ)
Latacunga	78793,66	74100
Riobamba	57690,13	
Salcedo	89842,21	
Ambato	78131,53	
Guaranda	49172,97	

Note: *IPCC=Intergovernmental Panel on climate change

Although the city of Salcedo did not have a large number of vehicles compared with the other cities in the study, it has, however, recorded a higher emission factor value.

3.2. Results of emission factors by scope

Table 3 illustrates the CO₂ emissions in tons. (tCO₂) by cities. It is considered 851,4 Kg/m³ as the diesel density and 0,04 TJ/t as the calorific value of diesel [20].

Table 3. Emission factors by scope

City	Scope I (tCO ₂)	Scope II (tCO ₂)	Scope III (tCO ₂)
Latacunga	0,0	23,3	25.723,6
Riobamba	0,0	16,2	37.388,2
Salcedo	0,0	33,8	8.728,9
Ambato	71,7	133,4	92.159,7
Guaranda	0,0	23,1	31.967,2

Note: In the city of Ambato, the values in Scope I are shown because the bus station in question has its own vehicles. 36/5000.

For scope II the value taken was 0.5062 tCO₂/MW.h.

3.3 Results of total emissions by category

In table 4 is presented the CO₂ emissions in tCO_{2-eq} from each city.

Table 4. Results of total emissions by category

City	EURO 1 (number of busses)	EURO 2 (number of busses)	EURO 3 (number of busses)
Latacunga	33	322	99
Riobamba	99	400	210
Salcedo	10	56	37
Ambato	51	845	608
Guaranda	0	110	335

In table 5 is presented the CO₂ emissions in tCO_{2-eq} from each city mentioned in this study

Table 5. shows the CO₂ emissions in tCO₂-eq from each city.

City	EURO 1 (tCO ₂ -eq)	EURO 2 (tCO ₂ -eq)	EURO 3 (tCO ₂ -eq)
Latacunga	2.176,1	18.250,3	5.297,1
Riobamba	5.445,7	20.908,1	11.034,5
Salcedo	730,6	4.866,1	3.132,2
Ambato	3.918,9	52.622,8	35.716,9
Guaranda	0,0	8.277,7	23.689,4

Note: As The Global Warming Percentage values are considered 1, 25, 298 for CO₂, N₂O ,CH₄, respectively. [21]

3.4 Results of total GHG emissions

Table 6 illustrates the CO₂ emissions in tCO₂-eq for each city.

Table 6. Total GHG emissions

City	Total emissions tCO ₂ -eq
Latacunga	25.746,8
Riobamba	37.404,6
Salcedo	8.762,7
Ambato	92.364,9
Guaranda	31.990,3

3.5 Cost results for GHG in bus stations

In table 7, the costs for GHGs are presented from 5 cities' bus stations within the central area of Ecuador. The data required to estimate each of the scopes is requested by ISO 14064.1: 2006/ISO 14064.1:2006. They were calculated based on the information provided by the Decentralized Autonomous Governments (GADS) from each of the cities.

Table 7. Costs considering GHG externalities at bus stations within the central region of Ecuador.

City	GHG cost (€/year)
Latacunga	3.604.552,0
Riobamba	5.236.644,0
Salcedo	1.226.778,0
Ambato	12.931.086,0
Guaranda	4.478.642,0

Note: The shadow cost used is 140€/tCO₂.

4 Conclusions

From the results by scope of 5 cities having 11 bus stations, it is observed ranges between 99.99% to 99.62% of tCO₂-eq global emissions for Scope III.

Nonetheless, there are some other modern factors which might increase this emission factor; as can be seen in old cars or busses, which are not functioning according to international standards. Moreover, altitude can also be another factor that increases CO₂-eq. In the central area of Ecuador, the global GHG emissions reports was 196.269,3

(tCO₂-eq). The said value was higher in interprovincial buses from Ambato and Riobamba, accounting for 99.99%. Similarly, the previous result is compared to the amount of (tCO₂-eq) generated by electricity consume of approximately 220,480.1 Ecuadorian individual houses per year.

The GHG pollution cost is 27.477.702 € per year.

The 2018 external costs of the bus stations are estimated to represent 30,2 % of Gross Domestic Product (GDP) of Ecuador. Surprisingly, this figure exceeds in 10.2% in similar studies that were conducted in Euskadi - Europe [22]. The externality total cost data is required to compare with the European GDP percentage.

References

1. R. Perman, Y. Ma, J. McGilvray, and M. Common, "Natural resource and environmental economics," Harlow: Pearson, (2003).
2. N. E. P. Bellido, "Cambio climático, pobreza y sostenibilidad," *EHQUIDAD. Revis. Inter. de Polí. de Biene. y Trab. So.l*, pp. 81-116,(2017).
3. R. A. Rohde and R. A. Muller, "Air pollution in China: mapping of concentrations and sources," *PloS one*, vol. **10**, p. e0135749, (2015).
4. H. C. Frey, N. M. Roupail, H. Zhai, T. L. Farias, and G. A. Gonçalves, "Comparing real-world fuel consumption for diesel- and hydrogen-fueled transit buses and implication for emissions," *Transportation Research Part D: Transport and Environment*, vol. **12**, pp. 281-291, 2007.
5. C. Wang, Z. Ye, Y. Yu, and W. Gong, "Estimation of bus emission models for different fuel types of buses under real conditions," *Science of the Total Environment*, vol. **640-641**, pp. 965-972, 2018.
6. J. A. Barbero and R. R. Tornquist, "Transporte y cambio climático: hacia un desarrollo sostenible y de bajo carbono," *Revi. Trans. y Territo.*, pp. 8-26, (2012).
7. L. Flores Fernández, "Terminales terrestres interprovinciales."
8. D. W. Pearce and R. K. Turner, *Economía de los recursos naturales y del medio ambiente* Economics of natural resources and the environment: Celeste Ediciones: Colegio de Economistas de Madrid, 1995.
9. D. Azqueta, ", McGraw Hill Profesional, Madrid, 420 p," *Biblioteca Introducción a la Economía Ambiental*, 2002.
10. G. K. F. Tso and J. Guan, "A multilevel regression approach to understand effects of environment indicators and household features on residential energy consumption," *Energy*, vol. **66**, pp. 722-731, (2014).
11. M. A. León Silva, "Cálculo de las emisiones de efecto invernadero en el terminal terrestre de Salcedo como base para futuros proyectos de Mecanismo de Desarrollo Limpio (MDL)," Universidad Técnica de Ambato. Facultad de Ciencia e Ingeniería en Alimentos. Carrera de Ingeniería Bioquímica,(2018).
12. C. E. Galarza Baldeón, "Estimación de la huella de carbono según la ISO 14064-1 alcance 1 y 2 de una

- planta productora de concreto premezclado y prefabricado," 2016.
13. S. Finnegan, S. Sharples, T. Johnston, and M. Fulton, "The carbon impact of a UK safari park – Application of the GHG protocol using measured energy data," *Energy*, vol. 153, pp. 256-264, (2018).
 14. E. G. Hertwich and R. Wood, "*The growing importance of scope 3 greenhouse gas emissions from industry*," *Environmental Research Letters*, vol. 13, 2018.
 15. Dolzhno, "Cálculo de la densidad del aire.," (2017).
 16. T. E. Lipman and M. A. Delucchi, "Emissions of nitrous oxide and methane from conventional and alternative fuel motor vehicles," *Climatic Change*, vol. **53**, pp. 477-516, (2002).
 17. R. Price, S. Thornton, and S. Nelson, "*The social cost of carbon and the shadow price of carbon: what they are, and how to use them in economic appraisal in the UK*," (2007).
 18. M. Maibach, C. Schreyer, D. Sutter, H. Van Essen, B. Boon, R. Smokers, *et al.*, "*Handbook on estimation of external costs in the transport sector*," *CE Delft*, 2008.
 19. INFRAS/IWW. (2004). *External Costs of Transport. Update Study, Zurich/Karlsruhe, UIC*.
 20. MAE. (2012). *Factor de emisión de CO2 del Sistema Nacional Interconectado del Ecuador*. Available: www.ambiente.gob.ec
 21. GHG. Global Warming Potential Values (AR5). Greenhouse Gas Protocol [Online]. Available: [http://ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20\(Feb%2016%202016\).pdf](http://ghgprotocol.org/sites/default/files/ghgp/Global-Warming-Potential-Values%20(Feb%2016%202016).pdf)
 22. D. H. Ramos, "*La estimación de costes externos del transporte: una aplicación para Euskadi*," *Ekonomiaz: Revista vasca de economía*, pp. 240-267, (2004).