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Carbon Footprints in Ecuador: Case of Riobamba city´s Bus Stations

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Abstract. Analysis of carbon footprint and its environmental impact remains one of the most critical topics in air pollution research. Likewise, the effect of the transportation sector to emissions of air pollutants and greenhouse gases is a growing concern in developing countries, but, it is more complicated in undeveloped countries because of the lousy quality of fuels, exhaust technology and non-regulations of government control agencies. In the city of Riobamba, Ecuador, the growing population associated with the massive use of public transportation have all resulted in significant air pollution and greenhouse gas emissions. In this study, emissions were obtained with the Bacharach ECA 450 analyzer and used to calculate the emission factor of carbon dioxide and nitrogen oxide in kg/TJ. It was found that value of the emission factor of CO*2* was 57690, 13 kg CO_2/TJ. All Riobamba city bus stations contribute significantly to the carbon footprint. The factors that influenced the increase in the generation of greenhouse gases were: technology, the operation of buses and characteristics of fuel (diesel).

1. Introduction

Global climate change has become a significant problem to the environment of the world [1]. To address the problem, environmental factors must be considered in some different types of decisions made by international, national and regional policies on many issues [2]-[4]. The air pollution is a severe problem that affects all people around the world [5]-[7]. The World Health Organization (WHO) estimated that it is possible to assign more than two million premature deaths annually due to the combustion of fossil fuels [8]-[10]. According to the Ministry of the Environment of Ecuador (MAE), between the years 1990 and 2016, Ecuador has experienced an increase of 78, 70% of emissions of carbon dioxide (CO_2), principally generated by public transport [11]. Carbon footprint helps in emission management and evaluation of mitigation measures as a quantitative expression of GHG emissions [12]-[14]. Having quantified the emissions, the most important sources of emissions can be identified, and areas of emission reductions and increasing efficiencies can be prioritized [15], [16]. Globally, one of the most important pollutants in the air is transportation sector, dates shown that this area contributes about 25% of carbon dioxide (CO_2) emissions, with the road transport sector responsible for 80% [17]-[19]. Emissions of gases as traditional air pollutants make the road transport sector a suitable choice for investigating and propose procedures to reduce the air pollution and establish a climate change mitigation procedure [20]. Emissions to the atmosphere are determined by the quantity of fossil fuel consumed by the vehicle, vehicle technology, fuel quality and transportation land-use planning [21], [22].This research aimed to establish the carbon footprint at the Riobamba city bus stations under considerations of the ISO 14064.

2. Materials and Methods

2.1. Identification of Measurement Places and Emission Factors

Riobamba has different areas where buses have places for taking passengers. The areas considered for the investigation were: Santa Faz, San Miguel de Tapi, El Prado, La Dolorosa and Dávalos Market. GHG emissions were quantified and documented by ISO 14064 part 1. In the same way, considering sources of emissions, different scopes were determined. A) Direct GHG emissions (Scope I) were evaluated, this scope considers all cars that belonged to the bus station and transfer areas. B) indirect emissions of GHG (Scope II) consider all consumption of electricity that was generated in the building of the bus station and transfer areas. C) Other indirect GHG emissions (Scope III) take an account buses classified in exhaust technology such as Euro I, Euro II and Euro III which provide their services to the bus stations and areas of transfer of the organization.

2.2. Technology to Quantify GHG Emissions

A Bacharach ECA 450 analyzer, designed for analysis of combustion efficiency, was used to determine and quantify the exhaust gas composition in selected buses in Riobamba bus station, the measurements were developed according to the process described by Boruta, Imiołek [23] and ISO 14064-1. The analyzer measures the percentage contents of oxygen (O_2) and fuel gases (hydrocarbons [HC], the so-called unburned fraction) in the tested gas and the levels of carbon monoxide (CO), nitric oxide and nitrogen dioxide (NO and NO_2) and sulphur dioxide (SO_2) molecules per one million gas molecules and, on this basis, computes for the defined fuels (e.g. NG or LGP) the value of the air excess factor, the percentage carbon dioxide (CO_2) content and the number of nitrogen oxide (NO_x) molecules per one million gas molecules and the amounts of NO, NO_2, NO_x, CO and SO_2 molecules per one million O_2 molecules.

2.3. Sample Size

The sample for the research was calculated with a confidence level of 95% from a population of 709 buses. Likewise, a stratified sampling with proportional affixation was carried out according to the Euro technology to have different strata in which there are homogeneity and a minimum variance.

2.4. Calculation of GEI Emission

The factors corresponding to indirect GHG emissions (Scope II) by energy were obtained using the information provided by the Energy Minister of Ecuador according to the types of fuel used in the generation of electricity. For the calculation of indirect emissions, the factor 0.5062 tCO_2/MWh was used. The average of electrical energy consumption was transformed into emissions of carbon dioxide (t CO_2-e). The emission of carbon monoxide (CO *mg/m3*) in the Scope III with Bacharach ECA 450 analyzer were used for the calculation of the Kilograms of carbon dioxide (CO_2 *Kg*). Through stoichiometric estimates based on the chemical reaction (1) presented by Lipman and Delucchi [24] the nitrogen monoxide (NO mg/m^3) concentrations were transformed into Kilograms and finally the emission factor of CO_2 and N_2O were calculated.

$$2\mathrm{NO} + \mathrm{CO} \rightarrow \mathrm{N2O} + \mathrm{CO2} \quad (1)$$

For the calculation of direct emissions and other indirect GHG, the equation (2) was applied.

$$\mathrm{Emission} = \Sigma[\mathrm{DAa} * \mathrm{EFa}] \quad (2)$$

Where:
Emission = emissions of GHG (Kg)
DAa = fuel sold (TJ)
EFa = emission factor (Kg/TJ).
a = fuel type

2.5. Calculation of the Carbon Footprint
Once quantified the GHG emissions, there were transformed from kilograms of CO_2 to a ton of CO_2. At the end equation (3) was used to convert CO_2 ton to tCO_2-e. According to ISO 14064 part 1, a value of 1 t CO_2 –e for the 100-year global warming potential was used.

$$Emissions\ (tCO_2\text{-e}) = emission * 100\text{-}year\ global\ warming\ potential \quad (3)$$

Once the unit value of the emissions of scope I, scope II and scope III in t CO_2 -e were obtained, all the emissions of the same category were added together to obtain the total emissions of GHG global.

3. Results and Discussion

3.1. Global Emissions of Greenhouse Gases (GHG)
Results of GHG emissions were quantified and classified in scope I (direct emissions) and scope II and III (indirect emissions) considering the protocol reported in the standard ISO 14064:1. The most significant contribution of GHG emissions comes from scope III emissions. There were produced by the buses which were at the bus stations and areas of transfer. Results showed that emissions at scope I and scope II were not significant. It was attributable because of in scope I there was not an own vehicle to quantify the emissions. In scope II the consumption of electricity from the bus station building or management office were not possible because there was not building for this purpose.

3.2. Emission Factors
Emission factor was obtained from the data of activity and greenhouse gases (GHG) in kilograms, in this study an amount of 57690, 13 CO_2 kg/TJ was established, is it the most significant rate of emission factor obtained. The values of Nitrogen dioxide (N_2O) emission factor shows a value of 0, 08 kg/TJ, methane (CH_4) emission factor was 3, 90 kg/TJ; both were got from the bibliography. However, according to ISO 14064-1, sources of quantification such as equipment or concentration of pollutants are not enough to quantify and could be excluded. On the other hand, CO_2 emission factor average was 57690,13 kg/TJ; it was lower than the emission factor of the diesel which is 74100 kg/TJ [10]. In the same way, CO_2 emission factor generated to take into account the conditions of the technology of buses, geography location, and fuel quality (diesel) used by vehicles to transport people. Also, a GHG average that Riobamba bus station is affected by external situations; for instance, reduced technical support by governmental agencies, defective policy to control GHG ́s emissions are reasons, too.

3.3. Global Emission of Greenhouse Gases
In Figure 1 present values of CO_2 emissions in function of bus technology shown a decrease. Firstly, Euro I has the maximum emissions because of it has an old technology. Secondly, Euro II technology demonstrated a considerable reduction of emissions which are attributable to changes in systems introduced in the exhaust pipe by manufacturers, to reduce a 60% of CO_2 emissions [11]. However, in Euro III there were little increase emissions despite are new technology, this may be due to the engine power system which is not according to rules for operation in Ecuador.

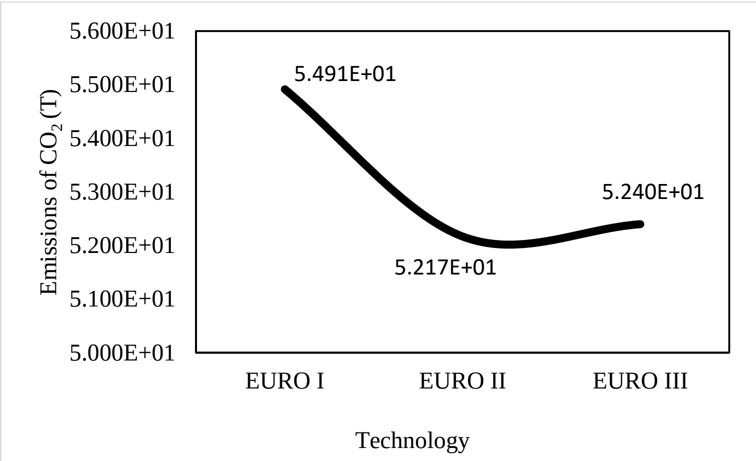

Figure 1. Average emissions of CO_2 by technology

Nitrous oxides are a part of most polluting GHG that exist in current days. As shown in Figure 2 the emissions of N_2O in tonnes increased to Euro II about Euro I, this could happen due to mechanical failure in one of the vehicles, while the Euro III technology decreased, since that this kind of vehicles had the modern and ecological technology to reduce emissions of N_2O.

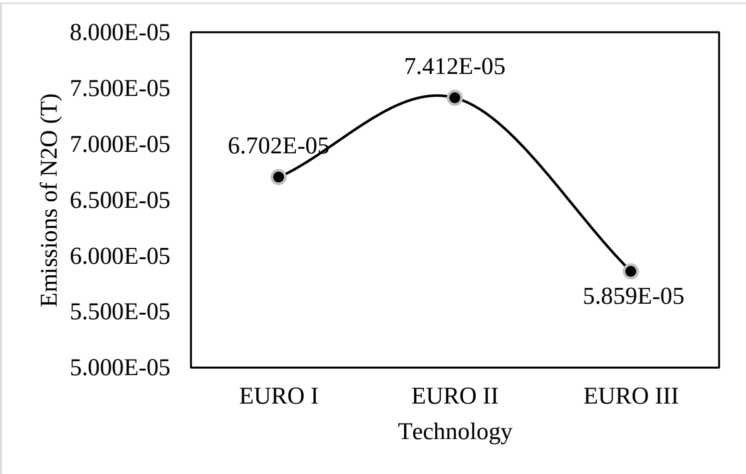

Figure 2. Average emissions of N_2O by technology

In Figure 3 was observed an increase of CH_4 according to the technology, which showed that the Euro III technology had not reduced the production of this gas, on the contrary, emissions have instead increased. This type GHG contributed with a 20% of the greenhouse effect [25]. The calculation of this emission was the theoretical emission factor obtained by the Intergovernmental Panel on climate change IPCC according to the type of fuel.

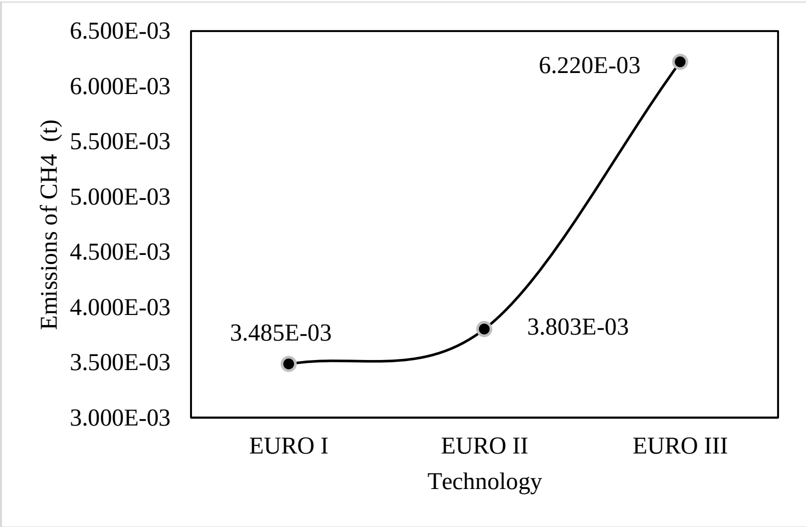

Figure 3. Average emissions of CH_4 calculated with the theoretical emission factor

Average emissions of SO_2 are shown in Figure 4. It shows a drastic decrease of this compound which varied according to the improvement of technology. Sulphur Dioxide would be lower if in Ecuador there would produce fuel with a few sulfur pollutants.

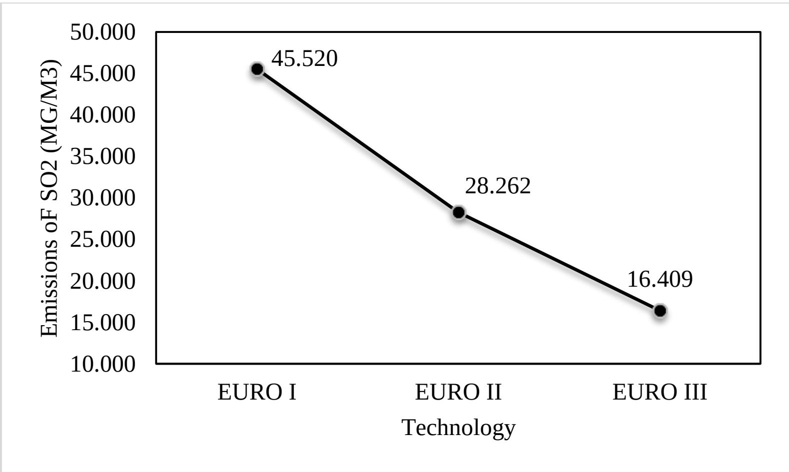

Figure 4. Average for emissions of SO_2 by technology.

3.4. Assessment of the Carbon Footprint

The emissions of scope III were those who presented the most significant contribution the global carbon footprint. Scope III was integrated by buses which operate in bus stations such as Santa Faz, San Miguel de Tapi, El Prado, La Dolorosa and Mercado Davalos, being these the primary sources of activity inside and outside of the bus station and affect all Riobamba city by a large number of network routes.

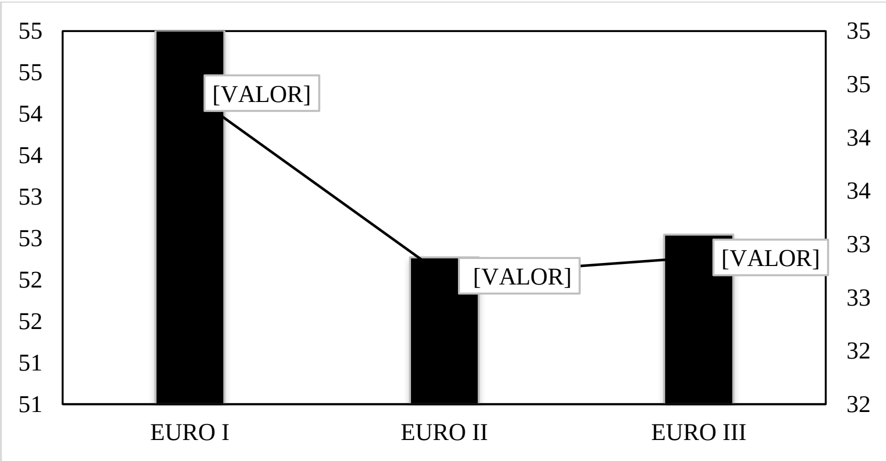

Figure 5. Average and percentage of the calculation of the carbon footprint obtained by the sum of the emissions of CO_2, N_2O, CH_4.

Figure 5 is shown the results of the Global carbon footprint. The carbon footprint emissions were decreasing as the technology improved. In EURO II there was a small decrease in comparison to EURO III. This decline was due to some EURO II buses have proper maintenance and regulation of the injection pump, while some EURO III vehicles were newly purchased and had not passed the review by National Transit Agency (NTA), by which their Jet pump could have been unregulated.

The most significant emissions contribute to the Global carbon footprint was given by buses with Euro II technology. Euro I represented 15% of total emissions, this was lower than other technologies despite that generated the highest emissions, this was due to that the 709 entire buses in Riobamba bus station, only 99 belong to Euro I technology. Table 1 displays the carbon footprint by scopes. The scope I and II did not exceed the emissions of the carbon footprint reported by the organization that controls the operation of the buses in this city (Interurbana S.A). However, the scope III corresponding to the vehicle fleet has the most significant quantity of emissions; this is attributable to the more considerable amount of buses which has Euro III technology and operate in Riobamba bus stations.

Table 1. Carbon footprint in tCO_2–e-relationship between the terminals of Riobamba and Interurbana S.A

Categorization	**Riobamba bus station**	**Interurbana S.A.**
Scope I	0,00	84, 07
Scope II	0,55	125, 29
Scope III	37388,23	18264, 40

4. Conclusion

The results in scope III shown emissions which contribute 99.99% in the global carbon footprint of the total GHG generated in the terminals. Similar effects of GHG were found in the construction sector in China, according to the study 72,1 % GHG were emitted [1]. According to ISO 14064, some GHG emission sources can be excluded because total emissions are not significantly, Scope I is an example. In the same way, some emission sources cannot be measured because instruments or supplies do not exist. Therefore, Scope II could be excluded. CO_2 emission factor value did not exceed to that reported by IPCC; it was due to fuel, not only quality but also geographic situation could change it, according to a new investigation transport of fuel can increase the GHG[26]. Likewise, some modern factors can increase this emission factor; for instance, vehicles or buses which are old, or it not are working according to international rules, altitude can be some other factor that together increase CO_2-e. Therefore, carbon fingerprinting is a powerful procedure that has been developed as a tool in the environmental assessment to fuel pollutants (fuel contaminants), and find the influence in GHG production [27]. It established that the carbon footprint of bus stations: Santa Faz, San Miguel de Tapi, El Prado, La Dolorosa and Mercado Dávalos, reported 37388.23 t CO_2–e value. This value was higher than the reported carbon footprint by Interurbana S.A. bus station in 2012, which was of 18264.40 tCO_2–e for the transportation sector (Scope 3). Finally, It investigation show us that the carbon footprint at bus station Riobamba city´s 37388. 23 tCO_2-e, where the 99.99 % concern to bus station terminals, it is similar to GHG´s emission generated by the electric energy consumption of 42000 single Ecuadorian homes per year.

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