Greenhouse Gas emission determination of typical infrastructure in High Andean cities: Study Case Ambato city-Ecuador.

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Abstract. The building sector is one of the most important commercial activities all over the world, being one of the main producers of Greenhouse gas (GHG) emissions. In the current investigation an evaluation of the emanation of Carbon Dioxide equivalent (CO₂e) was performed to different of typical buildings in Ambato city, Ecuador. It was applied the GHG Protocol and ISO 14064-1 standards for companies and organizations. The GHG emissions calculation was based on the most representative work volumes of typical buildings of this Andean city, and its corresponding emission factor. The results show that structure type III emits more CO₂ because more structural steel, concrete and clear glass are used in its construction due to its architectural and structural design.

1. Introduction

Industrial activities in different economic sectors worldwide cause GHG emission which causes climate change, CO₂ known as carbon dioxide, is the most abundant greenhouse gas that is in the earth's atmosphere [1,2]. Global warming leads to climate change, it is predicted that there would be an increase of sea level between 18 to 59 cm, for the year 2050, if the increase of 2°C of current temperature is overrated, it will require extensive adaptation and mitigation efforts in order to reduce global warming effects, additionally there could be a shortage of water and food[3,4]. Ecuador over the years has been incorporated into some of these treaties, such as the climate summit in Paris 2015 to contribute to the reduction of pollutants[5,6]

The building sector had a 44% share worldwide as population growth is constantly present, by the year 2025 it would be ranked as the sector with the most commercial opportunity [7,8]. In Ecuador, the government increased the budget for the housing sector between 2011 and 2014, the private sector also contributed in the construction of buildings and housing, thus contributing to the GDP (Gross Domestic Product) of the country, in the processes of construction, there is a lack of control and final solid waste disposal, the amount collected between the manufacturing industry and construction outperforms other activities [9,10]. According to the census carried out by the National Institute of Statistics and Censuses of Ecuador (INEC), the owners of the households state that GHG causes contamination of water, food and the air that is breathed [11,12].

In the city of Ambato, despite the air control carried out by the Ambato city council, the building sector produces pollutants, waste, as well as CO₂ (carbon dioxide) emitted in the construction phase which go to the cities and outskirts, , causing affectations in the health of people and environmental problems [13]. The director of SOLCA (Society for Fighting Cancer), says that Ambato, being a small city, is a small space from which people cannot escape and when breathing there is an inflation of the
nostrils, causing a permanent mucus and over time breathing difficulties that are triggered in asthma or chronic bronchitis accompanied by skin diseases such as allergies [14]. When carrying out a prior study to the construction of a building, the selection of the construction material plays a key role, which is based on a technical engineering and architectural knowledge.

The generated emission factor will help to understand the global intervention that entails the use of a certain quantity of a material on site, and subsequently with this data a controlled use of the carbon footprint of the building will be allowed [15]. The stage of material selection together with a study of its behavior can have a significant impact on the reduction of greenhouse gases [16,17]. For the above, taking into account that the construction sector is one of the most carbon dioxide (CO₂) producers from the manufacture of materials to its implementation, the current research is intended to determine the carbon footprint produced in typical infrastructures of the city of Ambato in the downtown area, as a reference of the amount of pollutant that has been generated during its construction. The study will serve in the future as a reference to determine possible solutions for self-sustaining housing constructions contributing to the reduction of greenhouse gas emissions[18].

2. Methodology

2.1 Phase A
The city of Ambato has 329,856 inhabitants, where and 178,538 live in the downtown area Ambato, according to the latest data from the National Institute of Statistics and Censuses of Ecuador (INEC). Figure 1 shows the delimitation of the area from which it will be evaluated.

![Figure 1. Downtown area of Ambato city, Ecuador.](image)

For the selection of the properties to be evaluated, the type of random sampling was applied using equation 1 [19].

\[
n = \frac{N \cdot Z_{a}^{2} \cdot p \cdot q}{d^{2}}
\]

Where: N, population size; Za, confidence level; p, probability of success or expected ratio; q, probability of failure; d, accuracy or permissible error and n; sample to be evaluated.

Through technical visits to each of the selected properties, an information collection of the building construction material within the mentioned area was carried out. The East-West direction of the city of Ambato.

2.2 Phase B
From the verified structures, they were classified into standard structures and the volume of work executed in their construction was calculated.
In construction, the building activities are understood as constructive activities differentiated by the elements necessary to execute them. The quantity of work, on the other hand, is the quantification of building activities executed in a construction [20].

2.3 Phase C

For the calculation of the carbon footprint of each construction activity, the methodology of inventory of CO₂e (Carbon Dioxide equivalent) emissions for companies and organizations is followed, using the GHG Protocol and ISO 14064-1 standards [21]. Once the building activities, the standard buildings have been identified, the calculation of emissions is carried out using the following equation:

\[
Total\ Carbon\ footprint = \sum (Building\ Activity \ast Emission\ factor)
\]

(2)

The building activity corresponds to the amount of work performed for each item established, the emission factor is the amount of Kg (kilograms) of CO₂e emitted for each specific building activity, the sum of these products will result in the amount of CO₂e produced at the time of the building with the emission factors investigated for each item.

In order to determine the carbon footprint per capita for each standard structure type, the total carbon footprint is divided by the construction area in km² of Ambato, then the calculated value is divided by the population density, 3839, 53 inhab/km², data obtained from INEC. [22]

\[
Carbon\ footprint\ per\ capita = \frac{Total\ Carbon\ footprint}{Total\ Construction\ Area \ast Population\ Density}
\]

(3)

3. Results and Discussion

3.1 Phase A

A total of 1830 built properties were identified, and their construction materials were determined. Table 1 shows the number of buildings evidenced according to the number of storeys.[23]

| Number of storeys | Weighting | Count | Percentage |
|-------------------|-----------|-------|------------|
| 1 storey          | 0         | 236   | 12.9%      |
| 2 storey          | 1         | 529   | 28.9%      |
| 3 storey          | 5         | 442   | 24.2%      |
| 4 storey          | 10        | 291   | 15.9%      |
| 5 storey or more  | 1         | 332   | 18.1%      |
| TOTAL             |           | 1830  | 100        |

From the identified properties, a standard building classification was established, as can be seen in table 2. Type I: one and two storey structures, because they have the same structural system and most were built in colonial years. Type II: three and four storey buildings due to their reinforced concrete structural system, residential and commercial occupation, and Type III: corresponds to the remaining buildings that are more than five floors, they present a structural system of reinforced concrete and metal structure, represent new buildings intended for commercial use.
Table 2. Type structures.

| Detail: number of storeys | Classification: structures type | Total de properties | Percentage |
|---------------------------|---------------------------------|---------------------|------------|
| 1-2                       | Type I                          | 765                 | 41.80%     |
| 3-4                       | Type II                         | 733                 | 40.06%     |
| 5 or more                 | Type III                        | 332                 | 18.14%     |
| TOTAL                     |                                 | 1830                | 100%       |

In figure 2, the typical infrastructure is shown, structures Type I (a), Type II (b) and Type III (c).

![Figure 2](image)

**Figure 2.** Structure types evidenced in the city of Ambato downtown area.

3.2 Phase B

By means of bibliographical information, the emission factors of the executed building activities are obtained, the work activity is taken into account from the creation of its materials, transport, and construction utilization, including the emissions that are produced on site for each activity, table 3 shows the factors used in the investigation to calculate the carbon footprint produced by each building activity.

Table 3(a) Emission factors Kg of CO₂e per Kg of each building activity executed in building process.

| Material                                      | Emission factor KgCO₂e per Kg |
|-----------------------------------------------|-------------------------------|
| Steel                                         | 2.301                         |
| Aluminum window profiles                      | 11.195                        |
| Prefabricated tile                            | 0.189                         |
| Concrete blocks                               | 0.068                         |
| Columns of concrete                           | 0.28                          |
| Roof tile                                     | 0.909                         |
| Structural and laminated steel                | 2.8                           |
| Chromed, enameled, galvanized steel           | 3.78887                       |
| Aluminum (anodized and lacquered)            | 31.45454                      |
| Arid                                          | 0.03                          |
| Asphalt bitumen                               | 6.497                         |
| Gypsum board - wall or ceiling coating        | 0.47415                       |
| Cement                                        | 0.41122                       |
| Ceramic material                              | 0.17516                       |
| Copper and annealed copper                    | 14.82539                      |
| Concrete and prefabricated                    | 0.45617                       |
| Prefabricated and supplied concrete           | 0.21851                       |
| Prefabricated mortar                          | 0.22268                       |
Table 3(b) Emission factors Kg of CO$_2$e per Kg of each building activity executed in building process.

| Material                          | Emission factor KgCO$_2$e per Kg |
|----------------------------------|----------------------------------|
| Neoprene                         | 17.65333                         |
| Temple - painting                | 14.72049                         |
| PVC                              | 10.35576                         |
| Terrazzo- marble floor           | 0.21619                          |
| Other (glass, metals, porcelain, lime, etc.) | 0.31949 |

3.3 Phase C

In tables 4, 5 and 6 the carbon footprint calculated in the structure Type I, Type II and Type III respectively is obtained, the construction system for the first type contains a wooden structural system and tile roof, for the second and third type a structural system of reinforced concrete is used, for all cases concrete masonry, floor finishes, tile coverings, ceramics, PVC for hydrosanitary installations, simple and cyclopean concrete in foundations is used.

Table 4(a). Carbon Footprint in Structure Type I.

| BUILDING ACTIVITY          | Unit | Quantity | Weight per unit of construction | Unity | Emission factor Kg eCO$_2$/Kg | Carbon footprint (Kg) | Weighting |
|-----------------------------|------|----------|---------------------------------|-------|------------------------------|-----------------------|-----------|
| Cyclopean concrete          | m$^3$ | 12.37    | 2410 kg/m$^3$                   |       | 0.21851                      | 6514.79               | 18.10%    |
| H.S. f’c= 180 Kg/cm$^2$;   | m$^3$ | 1.55     | 2410 kg/m$^3$                   |       | 0.21851                      | 814.35                | 2.26%     |
| Slab/floor masonry; mortar  | m$^2$ | 159.96   | 31.5 kg/m$^2$                   |       | 0.22268                      | 1122.00               | 3.12%     |
| Concrete f’c 180 in subfloor| m$^3$ | 8.00     | 2410 kg/m$^3$                   |       | 0.21851                      | 4211.70               | 11.70%    |
| Concrete masonry            | m$^2$ | 343.28   | 192 kg/m$^2$                    |       | 0.068                        | 4481.88               | 12.45%    |
| Vertical plaster mortar fine| m$^2$ | 636.44   | 31.5 kg/m$^2$                   |       | 0.22268                      | 4464.29               | 12.40%    |
| mortar mortar fine mortar 1:3 sponge | m$^2$ | 4.56     | 31.5 kg/m$^2$                   |       | 0.22268                      | 31.99                 | 0.09%     |
| Horizontal plaster mortar    | m    | 32.88    | 2,904 kg/ml                    |       | 10,35576                     | 988.80                | 2.75%     |
| Sun/Col. PVC pipe 110 mm     | m    | 32.88    | 2,904 kg/ml                    |       | 10,35576                     | 988.80                | 2.75%     |
| Excavation                   | u    | 2        | 21.5 kg                        |       | 0.31949                      | 13.74                 | 0.04%     |
| White toilet low tank; inc.  | u    | 3        | 15.3 kg                        |       | 0.31949                      | 14.66                 | 0.04%     |
| Supply tube, wax ring        |       |          |                                 |       |                              |                       |           |
| Downpipe PVC 110 mm for rain | m    | 2.7      | 2,904 kg/ml                    |       | 10,35576                     | 81.20                 | 0.23%     |
| water                        |       |          |                                 |       |                              |                       |           |
| Aluminum windows             | ml   | 52.00    | 1.1 kg/ml                      |       | 31.45454                     | 1799.20               | 5.00%     |
Table 4(b). Carbon Footprint in Structure Type I.

| BUILDING ACTIVITY                                      | Unit | Quantity | Weight per unit of construction | Unity | Emission factor Kg eCO₂/Kg | Carbon footprint (Kg) | Weighting |
|--------------------------------------------------------|------|----------|----------------------------------|-------|----------------------------|----------------------|------------|
| Provision and installation of clear glass e = 6mm      | m²   | 17,52    | 43.8                             | kg/m²| 1.263                      | 969.20               | 2.69%      |
| Wooden doors                                           |      | 1.89     | 700                              | kg/m³| -0.29                      | -384.53              | -1.07%     |
| Pasting for interiors and exteriors                     | m²   | 609.20   | 31.5                             | kg/m²| 0.22268                    | 4273.21              | 11.87%     |
| Tile flooring                                          | m²   | 122.90   | 50                               | kg/m²| 0.189                      | 1161.43              | 3.23%      |
| Wall covering / countertops with ceramic                | m²   | 2.18     | 17.84                            | kg/m²| 0.17516                    | 6.82                 | 0.02%      |
| Inner tap drinking water. PVC tube 1/2"; inc. Stopcock | m    | 24.65    | 0.218                            | kg/ml | 10.35576                   | 55.65                | 0.15%      |
| Cover with eternit                                      | m³   | 165.572  | 12.1                             | kg/m³| 0.909                      | 1821.11              | 5.06%      |
| Plasterboard cover on roof                             | m³   | 165.572  | 12.1                             | kg/m³| 0.47415                    | 949.92               | 2.64%      |
| Wooden pillars                                          | m³   | 1.458    | 750                              | kg/m³| -1.57                      | 1716.80              | -4.77%     |
| Wooden beams                                           | m³   | 1.1448   | 750                              | kg/m³| -1.57                      | 1348.00              | -3.74%     |
| Concrete foundation                                     | m³   | 10.68    | 2410                             | kg/m³| 0.21851                    | 5622.50              | 15.62%     |
| TOTAL Kg                                               |      |          |                                   |       |                            | 40212.5              | 100        |
| TOTAL T                                                |      |          |                                   |       |                            | 40.21                |            |

Table 5(a). Carbon footprint in the Type II structure.

| BUILDING ACTIVITY                                      | Unit | Quantity | Weight per unit of construction | Unity | Emission factor Kg eCO₂/Kg | Carbon footprint (Kg) | Weighting |
|--------------------------------------------------------|------|----------|----------------------------------|-------|----------------------------|----------------------|------------|
| H.S. f’c = 180 Kg / cm²;                               | m³   | 1.38     | 2410                             | kg/m³| 0.21851                    | 725.04               | 0.48%      |
| Cyclopean concrete                                     | m³   | 11.01    | 2410                             | kg/m³| 0.21851                    | 5800.28              | 3.82%      |
| Slab / floor masonry; mortar 1:3                       | m²   | 424.27   | 31.5                             | kg/m²| 0.22268                    | 2976.02              | 1.96%      |
| Concrete f’c 180 in subfloor                            | m³   | 8.28     | 2410                             | kg/m³| 0.21851                    | 4359.04              | 2.87%      |
| Block masonry                                          | m³   | 444.09   | 192                              | kg/m²| 0.06800                    | 5797.97              | 3.82%      |
| Vertical plaster mortar fine mortar 1:3 sponge         | m²   | 920.74   | 31.5                             | kg/m²| 0.22268                    | 6458.44              | 4.26%      |
Table 5(b). Carbon footprint in the Type II structure.

| BUILDING ACTIVITY | Unit | Quantity | Weight per unit of construction | Unity | Emission factor Kg eCO₂/Kg | Carbon footprint (Kg) | Weighting |
|--------------------|------|----------|---------------------------------|-------|---------------------------|----------------------|------------|
| Horizontal plaster mortar fine mortar 1: 3 sponge | m²   | 322.44   | 31.5 kg/m²                      |       | 0.22268                   | 2261.72              | 1.49%      |
| Sum / Col. PVC pipe 110 mm drain; Incl. Excavation | ml   | 35.7     | 2,904 kg/ml                     |       | 10.35576                  | 1073.61              | 0.71%      |
| White toilet low tank; Inc. Supply tube, wax ring | u    | 6        | 21.5 kg                         |       | 0.31949                   | 41.21                | 0.03%      |
| White sink 1 well; Inc. Wrench, supply tube | u    | 6        | 15.3 kg                         |       | 0.31949                   | 29.33                | 0.02%      |
| Downpipe PVC 76 mm drain; Incl. Excavation | ml   | 46.06    | 5,835 kg/ml                     |       | 10.35576                  | 2783.22              | 1.84%      |
| Aluminum windows | m²   | 236.40   | 1,1 kg/ml                       |       | 31.45454                  | 8179.44              | 5.39%      |
| Provision and installation of clear glass e = 6mm | m²   | 98.95    | 247,375 kg/m²                   |       | 1,26300                   | 30915.41             | 20.38%     |
| Wooden doors | m²   | 43.26    | 700 kg/m³                       |       | -0.29000                  | -8781.78             | -5.79%     |
| Pasting for interiors and exteriors | m²   | 920.74   | 31.5 kg/m²                      |       | 0.22268                   | 6458.44              | 4.26%      |
| Floor covering with porcelain | m²   | 356.52   | 50 kg/m²                        |       | 0.18900                   | 3369.10              | 2.22%      |
| Ceramic barriers | m²   | 11.57    | 50 kg/m²                        |       | 0.17516                   | 101.34               | 0.07%      |
| Wall covering / countertops with ceramic | m²   | 10.14    | 17.84 kg/m²                     |       | 0.17516                   | 31.69                | 0.02%      |
| Inner tap drinking water, PVC tube 1"; Inc. Stopcock | ml   | 58.21    | 0.36 kg/ml                      |       | 10.35576                  | 219.42               | 0.14%      |
Table 5(c). Carbon footprint in the Type II structure.

| BUILDING ACTIVITY                        | Unit | Quantity | Weight per unit of construction | Unity | Emission factor Kg eCO$_2$/Kg | Carbon footprint (Kg) | Weighting |
|------------------------------------------|------|----------|----------------------------------|-------|---------------------------------|-----------------------|-----------|
| Solid slab HS f'c 210 Kg / cm$^2$, e = 20cm | m$^3$ | 68.34    | 2410.00                          | kg/m$^3$ | 0.21851                      | 35990.98             | 23.73%    |
| Mooring chains on foundations            | m$^3$ | 6.08     | 2410.00                          | kg/m$^3$ | 0.21851                      | 3201.78              | 2.11%     |
| HS in Columns                            | m$^3$ | 13.26    | 2410.00                          | kg/m$^3$ | 0.21851                      | 6983.27              | 4.60%     |
| HS f'c = 210 Kg / cm$^2$ in Beams        | m$^3$ | 23.31    | 2410.00                          | kg/m$^3$ | 0.21851                      | 12274.73             | 8.09%     |
| HS f'c = 210 Kg / cm$^2$ on plinths      | m$^3$ | 20.80    | 2410.00                          | kg/m$^3$ | 0.21851                      | 10953.47             | 7.22%     |
| HS f'c = 210 Kg / cm$^2$ in stands       | m$^3$ | 5.78     | 2410.00                          | kg/m$^3$ | 0.21851                      | 3043.78              | 2.01%     |
| Internal supply drinking water, PVC tube 1 / 2" | ml | 9.24 | 0.218 | kg/ml | 10.35576 | 20.86 | 0.01% |
| Structural steel                         | kg   | 2782.29  | 2782.292                         | kg     | 2.30100                       | 6402.05              | 4.22%     |
| TOTAL Kg                                 |      | 151669.85|                                  |        |                                 | 151669.85            | 100.00%   |
| TOTAL T                                  |      | 151.67   |                                  |        |                                 |                       |           |

Table 6(a). Carbon footprint in the Type III structure.

| BUILDING ACTIVITY                        | Unit | Quantity | Weight per unit of construction | Unity | Emission factor Kg eCO$_2$/Kg | Carbon footprint (Kg) | Weighting |
|------------------------------------------|------|----------|----------------------------------|-------|---------------------------------|-----------------------|-----------|
| H.S. f'c = 180 Kg / cm$^2$        | m$^3$ | 7.78     | 2410                             | kg/m$^3$ | 0.21851                      | 4094.91              | 1.10%     |
| Cyclopean concrete                      | m$^3$ | 8.76     | 2410                             | kg/m$^3$ | 0.21851                      | 4615.20              | 1.24%     |
| Slab / floor masonry; mortar 1: 3      | m$^2$ | 831.02   | 31.5                             | kg/m$^2$ | 0.22268                      | 5829.10              | 1.56%     |
| Concrete f'c 180 in subfloor           | m$^3$ | 4.56     | 2410                             | kg/m$^3$ | 0.21851                      | 2401.34              | 0.64%     |
| Block masonry                          | m$^2$ | 1040.58  | 192                              | kg/m$^2$ | 0.068                        | 13585.79             | 3.64%     |
| Vertical plaster mortar fine mortar 1: 3 sponge | m$^2$ | 2081.16  | 31.5                              | kg/m$^2$ | 0.22268                      | 14598.10             | 3.92%     |
| Horizontal plaster mortar fine mortar 1: 3 sponge | m$^2$ | 828.42  | 31.5                              | kg/m$^2$ | 0.22268                      | 5810.89              | 1.56%     |
Table 6(b). Carbon footprint in the Type III structure.

| BUILDING ACTIVITY                                      | Unit | Quantity | Weight per unit of construction | Unity | Emission factor Kg eCO₂/Kg | Carbon footprint (Kg) | Weighting |
|--------------------------------------------------------|------|----------|---------------------------------|-------|---------------------------|----------------------|------------|
| Sum / Col. PVC pipe 110 mm drain; Incl. Excavation     | ml   | 23.5     | 2.904                           | kg/ml | 10,35576                  | 706.72               | 0.19%      |
| White toilet low tank; Inc. Supply tube, wax ring      | u    | 12       | 21.5                            | kg    | 0.31949                   | 82.43                | 0.02%      |
| White sink 1 well; Inc. Wrench, supply tube             | u    | 12       | 15.3                            | kg    | 0.31949                   | 58.66                | 0.02%      |
| Downpipe PVC 160 mm drain; Incl. Excavation            | ml   | 158.59   | 5.835                           | kg/ml | 10,35576                  | 9582.94              | 2.57%      |
| Aluminum windows                                       | ml   | 322.80   | 1.1                             | kg/ml | 31.45454                  | 11168.88             | 3.00%      |
| Provision and installation of clear glass e = 6mm      | m²   | 115.13   | 287.825                         | kg/m² | 1.263                     | 41852.40             | 11.23%     |
| Wooden doors                                           | m²   | 111.14   | 700                             | kg/m³ | -0.29                     | -22561.42            | -6.05%     |
| Pasting for interiors and exteriors                    | m²   | 2081.16  | 31.5                            | kg/m² | 0.22268                   | 14598.10             | 3.92%      |
| Floor covering with porcelain                          | m²   | 831.02   | 50                              | kg/m³ | 0.189                     | 7853.10              | 2.11%      |
| Ceramic barriers                                       | m²   | 50.69    | 50                              | kg/m³ | 0.17516                   | 443.92               | 0.12%      |
| Wall covering with ceramic                             | m²   | 191.75   | 17.84                           | kg/m² | 0.17516                   | 599.19               | 0.16%      |
| Inner tap drinking water, PVC tube 1"; Inc. Stopcock   | ml   | 174.72   | 0.36                            | kg/ml | 10,35576                  | 658.61               | 0.18%      |
| Solid slab HS f'c 210 Kg / cm², e = 20cm               | m³   | 135.15   | 2410.00                         | kg/m³ | 0.21851                   | 71170.83             | 19.09%     |
| Mooring chains on foundations                          | m³   | 13.97    | 2410.00                         | kg/m³ | 0.21851                   | 7354.10              | 1.97%      |
| HS f'c = 210 Kg / cm² in Columns                       | m³   | 129.03   | 2410.00                         | kg/m³ | 0.21851                   | 67947.75            | 18.23%     |
| HS f'c = 210 Kg / cm² in Beams                         | m³   | 71.14    | 2410.00                         | kg/m³ | 0.21851                   | 37465.11             | 10.05%     |
| HS f'c = 210 Kg / cm² on plinths                       | m³   | 34.86    | 2410.00                         | kg/m³ | 0.21851                   | 18360.21             | 4.93%      |
Table 6(c). Carbon footprint in the Type III structure.

| BUILDING ACTIVITY | Unit | Quantity | Weight per unit of construction | Unity | Emission factor Kg eCO₂/Kg | Carbon footprint (Kg) | Weighting |
|-------------------|------|----------|---------------------------------|-------|---------------------------|----------------------|------------|
| HS f’c = 210 Kg / cm² in stands | m²   | 6.47     | 2410.00 | kg/m² | 0.21851 | 3406.37 | 0.91%     |
| Internal supply drinking water, PVC tube 1 / 2” | ml   | 13.73 | 0.218 | kg/ml | 10,35576 | 31.00 | 0.01%     |
| Structural steel | kg   | 22182,34 | 22182,34 | kg | 2.301 | 51041,55 | 13.69%    |
| TOTAL Kg         |      |          | 372755,7 |     |               |                     | 100.00%    |
| TOTAL T          |      |          | 372,76 |       |               |                     |            |

For structure Type I, the greatest amount of carbon footprint are the Cyclopean concrete 18.10%, concrete foundation 15.62%, concrete masonry 12.45%, vertical plaster 12.40%. For the structures type II and III the items with the greatest amount of carbon footprint are steel with a percentage of 4.22% and 13.69%, the solid slab with 23.73% and 19.09%, the clear glass with 20.38% and 11.23%, the concrete columns with 4.60% and 18.23%, and the concrete beams with 8.09% and 10.05% respectively.

The building activities based on cement and concrete such as masonry, plaster and slab, have a significant emission because for the extraction of raw materials from mines such as limestone, sand and gravel machinery and transportation based on diesel or gasoline are used, in the plant conveyor belts based on electrical energy to enter the material are used, forklifts and silos are used to place the additive and cement, for the formation and compaction of blocks engines and pumps based on electricity are used, after the curing and stripping of the concrete blocks, they are transported to the site by fuel-based machinery, in the place of destination, emissions are produced by machinery and construction labor.

Table 7. Carbon footprint per capita and per area of the total number of buildings.

| Structure Type | Ton CO₂e | Ton CO₂e/ km² | Ton CO₂e/ habitant |
|---------------|-----------|----------------|--------------------|
| TYPE I        | 27540.62  | 4.41E+04       | 11.49              |
| TYPE II       | 11174.00  | 1.78E+05       | 46.39              |
| TYPE III      | 123754.91 | 1.98E+05       | 51.64              |
| TOTAL         | 262469.53 | 4.21E+05       | 109.53             |

Table 7 shows the emissions for each group of type structures and the total CO₂ emission present in the Ambato city center per capita; the results of type III structure data produces the highest CO₂ emissions due to the volume of material necessary for its building. It is important to mention that the central area of Ambato as its buildings are old. Therefore it is clear that the emissions are high.

4. Conclusions

The type of structural system, area and building material influences directly on the amount of CO₂e released to the atmosphere. Ambato being a small city, shows a greater concentration of this gas causing environmental and health effects.

The carbon footprint produced by the type I structure represents 40212.5 kg of CO₂e, its value is relatively low due to the structural system and smaller construction area, since it uses less natural, artificial and labor resources for the materials extraction and construction. The carbon footprint...
produced by the type II and type III structures equals 151669.85 kg of CO$_2$e and 372755.76 kg CO$_2$e respectively.

The building that produced the highest emissions of CO$_2$ was the type III structure with 372755.7 Kg of CO$_2$e. This can be entitled to the great amount of natural, artificial, energetic and human resources for the elaboration of its materials and construction.

Steel and concrete have significant emissions (13.69%) and (47.37%) respectively, given that during its extraction, transportation (by land or sea) and production fuel-based machinery is utilized. Even more, the heating process uses rolling mills and ovens based on diesel, for the evacuation and cooling of the material lubrication pumps, centrifugal pumps and fans that work with electrical energy are used. Besides, the carried out work by workforce also contributes with emissions mainly coming from ground transportation.

Clear glass produces a relatively large amount of CO$_2$ (11.23%) because in the extraction of the sand and the conversion process fuel-based machinery, extra energy and resources are used.

All these statements demonstrate that in all stages from the obtention of materials to the actual use of them in constructions it is required large amounts of energy which are mainly obtained from fossil fuels and its derivates that when burnt emit CO$_2$ the main component of GHG, affecting the environment and contributing with the global warming.

That is why in Paris and New York for instance, over the last few years a reduction in the CO$_2$ emissions per unit area coming from the construction industry is evidenced. The reason behind these facts are the approach to new technologies, techniques and materials these cities are implementing, such as retrofitting their infrastructure applying the design of green buildings, promoting new construction alternatives with recycled materials, reusing water and energy, and green environments inside and outside the construction.

In order to reduce the CO$_2$ concentrations in Ambato, it is recommended to retrofit the facets of the structures, replace the construction material with sustainable alternatives such as the combination of aluminum and wood that can contribute to the reduction of up to 86% in the life-cycle of the product.

There is also a new LEED technology in renovations and constructions that guarantees sustainability, energy and water savings. The technology consists of a certification to the designer and builder which guarantees that the construction has water and energy saving systems, correct selection of construction materials and interior environmental quality. These model could be implemented in Ambato’s new construction projects taking into account that currently the city has 1.85 million square feet of construction market that is constantly growing. The implementation of these techniques and technologies can lead not only to the reduction in the CO$_2$ emisions, but it might become an example to follow for other cities in Ecuador and in the region, therefore contributing to the global warming problem.

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