Article

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Carbon footprint of heavy machinery in paving construction processes

Huella de carbono de maquinaria pesada en procesos constructivos de pavimentación

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Abstract

Climate change is a current phenomenon and represents one of the most important environmental, social and economic threats to the planet and is defined as a significant and lasting change in local and global weather patterns caused by natural or human-caused global warming. The construction of works related to earthworks such as paving of streets, parking lots, roads, highways, dams, canals, among others, generate pollution because they use heavy machinery which is a major consumer of non-renewable fossil fuels that are transformed into emissions of Carbon Dioxide (CO_2). The present work, takes as a case study the paving of a subdivision in the City of Obregon Sonora (Mexico) to determine the carbon footprint in Kg of CO_2eq/m^2 generated in the machinery, using the methodology of the carbon footprint from the quantities of work of the construction process, the selection and hourly performance of the appropriate equipment, the determination of the volumes of fuel used and the emission factor in Kg-CO_2eq for the fuel used. The results obtained were 165,742.02 Kg-CO_2eq in a surface of 128,049.59 m^2 of paving, equivalent to 1.29 Kg-CO_2eq/m^2.

CO_2, Global warming, Construction

Resumen

El cambio climático es un fenómeno de la actualidad y representa una de las amenazas ambientales, sociales y económicas más importantes para el planeta y se define como el cambio significativo y duradero de patrones locales y globales del clima, ocasionado por razones naturales o causadas por los seres humanos que generan el calentamiento global. La construcción de obras relacionadas con el movimiento de tierras como, pavimentaciones de calles, estacionamientos, caminos, carreteras, presas, canales, entre otros, generan contaminación porque utilizan maquinaria pesada la cual es gran consumidora de combustible fósil no renovable que se trasforma en emisiones de Dióxido de Carbono (CO_2). El presente trabajo toma como estudio de caso la pavimentación de un fraccionamiento en la Ciudad de Obregón, Sonora (México) para determinar la huella de Carbono en Kg de CO_2 eq/m^2 generada en la maquinaria, empleando la metodología de la huella de carbono a partir de las cantidades de obra del proceso constructivo, la selección y rendimiento horario del equipo adecuado, la determinación de los volúmenes de combustible empleado y el factor de emisión en Kg-CO_2eq por el combustible usado. Los Resultados obtenidos fueron de 165,742.02 Kg-CO_2eq en una superficie de 128,049.59 m^2 de pavimentación equivalen a 1.29 Kg-CO_2eq/m^2.

CO_2, Calentamiento global, Construcción

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Introduction

Human beings have always maintained a close relationship with nature from which they have obtained food, fuel and various materials for their survival, this includes raw materials for the manufacture of clothing, housing or other types of infrastructure, among many other products (Semarnat, 2012).

Not too long ago, the ability of human beings to alter the environment was limited and slender. But in the last hundred years this ability to alter the environment has increased significantly, to the extent of endangering the entire planet (Cidead, 2018).

Currently, one of the most alarming environmental problems in the world is surely the issue of pollution, since environmental pollution today pervades and affects the entire planet. Encinas (2011) defines pollution as the presence of unwanted substances or forms of energy in the air, water or soil in such concentrations that the comfort, health and well-being of people, animals and/or vegetation can be affected, as much as the use and enjoyment of what has been polluted.

The high levels of pollution date back to the industrial era, in which man began to change his lifestyle and environment, needing large amounts of natural resources that enabled him to achieve the technological and industrial development that he currently has. This development has resulted in excessive population growth, waste generation and creation of emissions in air, water and soil associated with increased production and consumption of resources, indirectly producing what is known as climate change (UNAM, 2016).

Espíndola & Valderrama (2018), define climate change as the significant and lasting change of local and global patterns of weather, caused by natural reasons (variations in the energy that we receive from the sun, volcanic eruptions, ocean circulation, biological processes) or caused by human activity (gas emissions, land-use change, deforestation). These changes finally produce what is called global warming, evidenced by the increase in the temperature of the earth's atmosphere which has been observed since the end of the 19th century.

The consequences of climate change are affecting natural processes that are essential for life. In the case of ecosystems, such as wetlands, they are at risk of disappearing, in addition to the increase in temperature and the decrease in precipitation that is affecting most living beings.

Climate change is driven by the greenhouse effect, which is generated by the gases of the same name "greenhouse gases" (GHG). Greenhouse gases are a natural part of the climatic conditions of the planet; they favor the optimal conditions of life on planet earth, allowing an ideal temperature for the realization of natural processes, without these the planet would have lower temperatures which would not allow the development and growth of living beings (Florides, Christodoulides, & Messaritis, 2013).

The greenhouse gases that occur naturally in the atmosphere are: water vapor, carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3), these are responsible for absorbing and emitting certain radiation from the earth's surface, the atmosphere and the clouds. The problem begins when there is an increase in the concentration of these gases, given that the radiation absorbed and emitted by the atmosphere is higher thus, causing rising temperatures on Earth's surface and in the troposphere.

Among the main greenhouse gases, the most concerning one is CO_2 due to its responsibility in climate change and according to OECC (2013), the concentration of CO_2 in the atmosphere has increased due to human activity, mainly due to the use of fuels fossil fuels and deforestation, with a smaller contribution from cement production.

CO_2 emissions from fossil fuel combustion and industrial processes contributed around 78% of the total increase in GHG emissions from 1970 to 2010, with a similar percentage contribution for the increase experienced during the period from 2000 to 2010, caused by economic and demographic growth; these continued to be the most important drivers of increases in CO_2 emissions from the burning of fossil fuels (IPCC, 2014).

The environmental impact that industries have on the environment and natural resources has been significant, not only as a result of the growth in production but also because said growth was concentrated in areas with high environmental impact (Semarnat, 2010).

Development

The construction industry, as is known, is one of the most important industries worldwide and also one of the most polluting; it can be estimated that 40% of pollution is generated by activities linked directly or indirectly to the construction of civil works, to the large amount of resources invested in obtaining raw materials, as well as their transportation and subsequent manufacturing, up to 2 tons of raw materials are required for each square meter of a building (García , Quito, & Perdomo, 2020).

According to a report presented by the United Nations Organization (UN), the construction industry additionally consumes 40% of all energy, the extraction of up to 30% of raw materials in the environment, 25% of solid waste generated come from activities linked to construction, and finally it consumes up to 25% of water and occupies an approximate 12% of the land (Rodríguez, García, & Ubaque, 2016).

The construction industry is very important in the development of a country since it contributes to producing basic welfare elements in a society by building bridges, highways, ports, railways, dams, electricity generating plants, industries, as well as houses, schools, hospitals; allowing the development of urban areas and the growth of cities (INEGI, 2009).

Urban spaces can be defined as areas accessible to all inhabitants and users at any time, they are made up of various structures that foster economic, social, cultural activities and any other interest within the existing population, such an environment is mainly connected by a system constituted mainly by asphalt pavements of a flexible type (asphalt layer) and/or rigid (hydraulic concrete); which, thanks to urban expansion, has become a growing social demand as an indicator of a better quality of life, generating with this a greater amount of resources for its construction, which in turn causes a greater impact on the environment (Cruz, Gallego, & Gonzalez, 2009).

Urban pavements are constituted from a pavement generally made up of several successive layers supported by the esplanade or embankment, which consists of a firm support surface with sufficient resistance to withstand the efforts of the upper layers of the pavement during its execution and operation. The thickness of each of the three elements that make up outdoor urban pavements (esplanade, pavement and surface coating) is determined according to the function for which the pavement is intended, the load and frequency of use and other desirable characteristics. (Francalacci, 2010).

A pavement is a structure composed of relatively horizontal layers of adequate and properly compacted materials, overlapped on each other, which are designed to optimally resist the efforts to which they are requested by repeated traffic loads and is made up of asphalt materials, whose composition of layers can be given by the granular sub-base, granular base, asphalt layer and different types of irrigation. Within the different types of pavements, we find the one corresponding to the present research, which is of the type of flexible pavements, which are made up of a bituminous layer which is generally supported by two non-rigid layers, the base and the sub-layer base; depending on each particular case, it is possible to dispense with one layer or another and rigid pavements which are made up of a concrete slab supported on the sub-grade or on a sub-base of the rigid pavement, of selected material . Being a very rigid material with a high degree of elasticity, the stress distribution occurs over a very wide area.

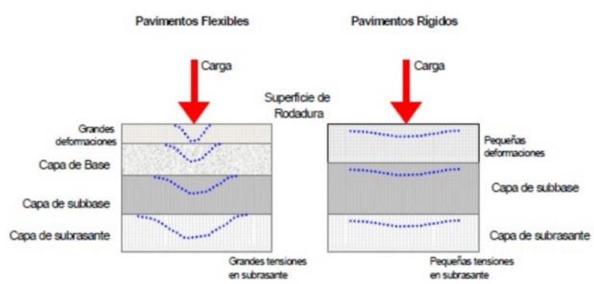

Figure 1 Diagram of the behavior of flexible and rigid pavements
Source: Pavimentos (2014)

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A major piece of equipment or heavy machinery is a machine characterized by more or less restricted mobility and a great capacity for carrying out complicated work. It is a piece of equipment or self-propelled vehicle regularly used in industrial works, such as construction, mining and quarrying, concrete handling, recycling, concrete, paving and asphalting, demolition, agriculture, public and military works. Due to their physical and technical characteristics, they do not travel on public roads such as federal or state highways or municipal streets.

According to Newman (2021), heavy machinery is classified according to its function and the specialization of its work in: universal heavy machinery or specialized heavy machinery. Universal heavy machinery can serve two or more industries, here we find loaders and backhoes, excavators, bulldozers, elevators, cranes, motor graders and tractors, on the other hand, specialized heavy machinery is one that meets the needs of a single industry such as heavy machinery for aggregates and recycling, for asphalt and concrete, for forestry work and wood treatment, for agriculture and infrastructure maintenance.

There are various types of heavy machinery and they vary depending on their power and specialty. Within the heavy machinery we find the Bulldozer, Loader Shovel, Excavator Shovel or Front Excavator, Backhoe, Scrapers, Motor Graders, Compactors, among other machines.

Figure 2 Excavator, Motor Grader, Loader and Dump Truck
Source: Pavimentos, (2014)

Land work is thus called the work necessary to build a structure that increases the height of the land, filling and compacting the soil, in this way we seek to improve the flow of rain or other specific needs of the project. (GruviMex, 2020).

All construction projects include this key phase and it is important during the planning phase to take into account the earthwork processes from a logistic and economic perspective, since highly trained personnel are required in the area and have the appropriate equipment to carry out these activities. The aims of the earthwork activities are: Leveling the ground or place of the project, as well as to improve the land so that it can support a construction, everything will depend on the type of project to be carried out, as is the case for urbanizations in order for houses to have full support and safety (CTR. Construccion, 2019).

Throughout the world and at all periods of its existence, man has always had the need and the competence to make dirt roads, highways, and traffic lanes, which would be impossible today without the use of machinery that man has designed, manufactured and used to build it. According to Quezada (2014), the heavy machinery of great power serves as support in the execution of road works, mainly in the preparation of the land, excavation or construction of terraces, these activities are: cleaning, cutting, transfer of material, compaction, among others.

The classification of equipment in paving works is according to the activity they carry out and these can be: excavation and earthmoving equipment composed mainly of shovels and excavators, which were developed from a mechanical machine that multiplied the movement and effectiveness of the work of a man carrying out excavation work with a shovel in hand, among these we find the Tractor, Bulldozer, Front Loader, Mechanical Shovel, Dredger, Backhoe and Trencher (Vise, 2021).

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Figure 3 Dredger and Bulldozer
Source: OLBAP, (2020)

Other equipment corresponds to the horizontal transfer of materials, in this category we can find the equipment intended for the hauling of material within a work, such as Trucks, Wagons, Gondolas, Off-road Trucks, Conveyor Belts, Trains, among others.

Figure 4 Off road truck
Source: Tracsa CAT, (2017)

Another important activity within the construction process of dirt roads and paving is compaction, which is the process of increasing the density of a soil through the application of mechanical forces such as the forces generated by Static Pressure, Vibration, Impact, and Manipulation. Within the compaction equipment are the following: Vibratory plate compactors and Pneumatic compactors, Smooth rollers, Pneumatic rollers, Sheepsfoot rollers.

Figure 5 Smooth rollers, Sheepsfoot rollers and Pneumatic rollers
Source: Cueva del Ingeniero Civil, (2012)

For works related to the activities of impregnation against dust, fog seal and seal, the Asphalt Distributor or oiler is used, while in the placement and distribution of the asphalt layer the Asphalt Finisher or paver or finisher that has a tractor and paver unit, compaction equipment of the static smooth roller and pneumatic roller type is also used to carry out the corresponding compaction of the asphalt layer.

Figure 6 Paver
Source: Tracsa CAT, (2017)

The fuel consumption per hour varies according to the load factor that the engine receives and the type of operation that the machine performs.

In heavy machinery, the engine load factor is directly affected by variables such as periods of idling (keep the vehicle running without moving), tool handling implemented, equipment movement, part-throttle maneuvers, downhill work, which affect the final fuel consumption (SECSA, 2021).

Fuel consumption per hour is classified as follows:

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Low consumption activities that bring the engine to a load factor of between 20 to 40%, such as excavation and movement of material to a defined place at ground level, excavation of shallow trenches in low-density materials. Average consumption occurs in activities that bring the engine to a load factor of 40 to 60%, including continuous loading of trucks, excavation of materials with low to medium density and with the bucket of service between 60 to 90% of its capacity. And the high consumption occurs in the tasks that take the engine to a load factor of 60 to 80%, among which are the continuous loading of trucks, excavation in rocky soils or blasting rock, transport displacements over 200 m long in which the ground provides difficult traction and greater impact. To make an approximate calculation of the fuel consumption per hour in liters for other vehicles, the following operation can be carried out in accordance with Fundación para la Enseñanza de la Construcción, A. C. (2014).

Formula: Gh = (C.H.) * (No. of HP) * (F.O.)

With it, the amounts of fuel used per effective hour of work are obtained.

At present, through various bibliographic sources, we are able to know the carbon emissions generated in each existing material, product or service, which has allowed us to clearly know the impact generated in each activity and quantify the CO_2 emissions generated in the construction of an infrastructure of any type and how this can vary according to the materials and the construction area, so it is imperative to consider the environmental impact generated by any construction (Rico, et al, 1998).

There are different methodologies and tools we can use to calculate the inventory of emissions of polluting agents both for organizations, and for products or services in particular with differences in terms of their scope, gases or scale to which it is applied. In order to select a methodology, you must focus mainly on the objective that is planned to be obtained to achieve the expected result.

To calculate the carbon footprint of the machinery for work to be carried out at a construction site, first we need calculate the amount of fuel used per effective hour of work (Gh), which is obtained based on the nominal power of the engine, on the operative factor of the machine or equipment, and on a coefficient determined by experience, which varies according to the fuel used. According to Fundación para la Enseñanza de la Construcción, A.C. (2014), the amount of fuel per effective hour of work can be calculated using the following expression:

Gh = (C.H.) * (No. of HP) * (F.O.)

Where:

Gh: Represents the amount of fuel used per effective hour of work (L / hr.).

C.H: Represents an average factor of fuel consumption, for each hour of operation referred at sea level. For Gasoline engines a factor of 0.24 liters per HP op./hour is used, while for Diesel engines 0.20 liters per HP op./hour is used.

O.F: It is the operation factor which is obtained by dividing the number of minutes that the operator works per hour / 60 minutes, which is usually considered less than 1. For representative purposes, this document deems 50 minutes for every hour of work; thus, giving us a 0.833 O.F.

Subsequently, to obtain the CO_2 emissions per hour for each type of machinery, the Gh obtained will be multiplied by an emission factor in Kg of CO_2 eq per liter of fuel (see Table 1).

Sample	Dend. Kg/liter	Carbon cont. % Weight	PCN MJ/Kg	Carbon cont. Kg C/GJ	Emission factors		
					$KgCO_2/TJ$	$KgCO_2$/ Kg comb.	$KgCO_2$/ l comb.
D. ZMVM	0.827	85.78	42.83	20.03	73,385.49	3.143	2.599
D. ZMM 1	0.832	85.78	43.08	19.91	72,959.62	3.143	2.614
D. ZMM 2	0.817	85.84	43.34	19.81	72,572.65	3.145	2.569
D. ZMG 1	0.826	85.40	42.98	19.87	72,805.41	3.129	2.586
D. ZMG 2	0.826	85.85	43.18	19.88	72,850.05	3.146	2.597
Average	0.826	85.83	43.18	19.88	72,850.77	3.145	2.596

Table 1 Emission factors and uncertainty for diesel
Source: Instituto Nacional de Ecología y Cambio Climático (2014)

In the present study, the carbon footprint generated by the construction of an asphalt pavement is calculated by means of emission factors obtained by the use of machinery used in each construction process.

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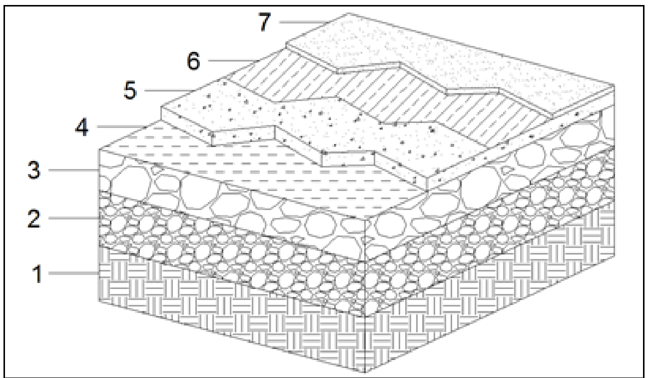
An urban suburb located in Ciudad Obregón, Sonora, Mexico, was taken as the object of this study. The pavement is made of asphalt with a 4 cm thick layer, 15 cm thick base layer, 15 cm thick base sub layer, and 20 cm thick of the underlying layer as natural ground material.



Stabilizer layer	1		20 cm
Granular Base/Sub-Base	2		15 cm
Layer	3		15 cm
Impregnation Layer	4		1.15 l/m^2
Asphalt pavement layer	5	Asphalt layer	4 cm
Tack coat	6		0.8 l/m^2
Seal coat	7		2 cm

Figure 7 Specifications of the structure of an asphalt pavement of 4 cm
Source: Own elaboration

Methodology

To carry out this project, the following participants were involved:

- Research professors from Instituto Tecnológico de Sonora from the Department of Civil Engineering.

- A student of the educational program of Civil Engineering from Instituto Tecnológico de Sonora.

Materials and equipment

- Paving blueprints of the suburb: File where the shape, dimensions, design characteristics are specified.

- Equipment: Desktop computer and LAPTOP.

- AutoCAD, Software for the design, review and modification of blueprints.

- Microsoft Word, Excel, and PPT.

Process

- The suburb on which the study is based was selected.

- The concepts of work were defined and the quantities of work in each stage of the construction process were calculated.

- The appropriate construction machinery was selected for each type of work and the specific characteristics of each one was determined (machinery performance, power and consumption coefficient).

- Using the formula: Gh = (C.H.) * (No. of HP) * (O.F.), the amounts of fuel used per effective hour of work for each stage of the process were obtained.

- The fuel emission factor was determined and the amounts of Kg-CO_2eq obtained for each hour of work performed by each machine were determined.

- The amounts of Kg-CO_2 eq. obtained by the entire work were determined and, in turn, the Kg-CO_2 emissions were determined for each m^2.

Result

The Puente Real suburb was selected for this study, it is located north of Ciudad Obregón Sonora; the blueprints and data of the pavement structure were used to obtain the construction concepts.

Table 2 shows the different volumes of work that were determined and that were necessary for the study, highlighting the paved area of 128,049.59 m^2 and the volumes of 26,204.97 m^3 of sub-grade and the volume of sub-base from 20,875.29.

Name of the street	Area (m^2)	Asphalt Layer (m)	(m^3)	Base (m)	(m^3)	Sub-Base (m)	(m3)	Sub-grade (m)	(m^3)
Río Volga	2009.25	0.04	80.37	0.15	301.39	0.15	301.39	0.2	401.85
Azer	876.34	0.04	35.05	0.15	131.45	0.15	131.45	0.2	175.27
Rio Esteras	1321.53	0.04	52.86	0.15	198.23	0.15	198.23	0.2	264.31
Caudal	487.1	0.04	19.48	0.15	73.07	0.15	73.07	0.2	97.42
Hacho	283.16	0.04	11.33	0.15	42.47	0.15	42.47	0.2	56.63
Sagasta	2914.98	0.04	116.6	0.15	437.25	0.15	437.25	0.2	583
Oviedo	2975.27	0.04	119.01	0.15	446.29	0.15	446.29	0.2	595.05
Río Puelo	971.24	0.04	38.85	0.15	145.69	0.15	145.69	0.2	194.25
Río Garona	2058.74	0.04	82.35	0.15	308.81	0.15	308.81	0.2	411.75
Rio Carrión	846.87	0.04	33.87	0.15	127.03	0.15	127.03	0.2	169.37
Rio Ortiga	1294.52	0.04	51.78	0.15	194.18	0.15	194.18	0.2	258.9
TOTAL	128049.59		5485.31		19653.73		20875.29		26204.97

Note: They are representative values.

Table 2 Amounts of suburb work
Source: Own elaboration

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In Table 3, the hours of work required in each of the stages of the construction process for the paving of the suburb were determined, giving a total of 2,250.29 hours of work, it is also noted that the process that requires the most hours of work is in the improvement of the sub-grade with a total of 1,168.21 hours, in turn, the one that takes the least time is the placement of gravel with tipper truck with 13.45 hours.

Concept	Area	Carrying volume (m3)	Vol. (m3)	Rend. (m^3/hr)	Work Hours
Asphalt Layer		5485.3	6928.8	227.84	30.41
Total					24.08
Comp Base At 95%		19653.72	25549.84		
Extend		19653.72	25549.84	268.00	95.34
Moist		19653.72	25549.84	200.00	127.75
Mix		19653.72	25549.84	268.00	95.34
Extend		19653.72	25549.84	268.00	95.34
Compact		19653.72	25549.84	59.90	426.54
Total					840.30
Sub-Base Compc. at 95%		20875.28	28566.17		
Extend		20875.28	28566.17	227.84	125.38
Moist		20875.28	28566.17	200.00	142.83
Mix		20875.28	28566.17	268.00	106.59
Extend		20875.28	28566.17	268.00	106.59
Compact		20875.28	28566.17	63.59	449.22
Total					930.61
Impregnation irrigation	128049.59			15000	8.54
Seal irrigation	128049.59			15000	8.54
Total					17.08
Sub-Grade Improvement		26204.97	35859.43		
Extend		26204.97	35859.43	227.84	157.39
Moist		26204.97	35859.43	200.00	179.30
Mix		26204.97	35859.43	268.00	133.80
Extend		26204.97	35859.43	268.00	133.80
Compact		26204.97	35859.43	63.59	563.92
Total					1168.21
Seal placement with Tipper Truck	128049.59	0.003	403.36	9.33	43.23
Gravel placement with Tipper Truck	128049.59	0.003	403.36	30.00	13.45
Total					2250.29

Table 3 Hours of machinery work for each stage of the construction process in the Real de Sevilla III suburb
Source: Own elaboration

Table 4 shows the amounts of diesel required in each of the stages of the construction process for the paving of the Suburb, and in turn, the KG-CO_2 eq emissions obtained for the total work; a total of 46,903.19 liters of diesel were needed throughout the construction process, with the improvement of the subgrade being the largest contributor with a total of 24,281.16 liters and the placement of gravel with a Tipper Truck being the smallest contributor with a total of 390.58 liters.

It can also be seen that a total of 165,742.02 Kg of CO_2 eq is generated throughout the construction process, with the improvement of the Subgrade being the one that contributes the most with a total of 63,033.90 Kg of CO_2 eq and the one that contributes the least is the placement of gravel with a Tipper Truck with a total of 1,013.95 Kg of CO_2 eq.

Concept	Hours of work	Pot.	l/hr	Oper. Factor	Diesel consumption (L)	Emission Factor	Total Kg CO2 eq
Asphalt Layer	30.41	125	0.2	0.83	631.02		
Total	24.08				631.02	2.596	1638.14
Comp Base At 95%							
Extend	95.34	125	0.20	0.83	1978.21		
Moist	127.75	205	0.20	0.83	4347.31		
Mix	95.34	125	0.20	0.83	1978.21		
Extend	95.34	125	0.20	0.83	1978.21		
Compact	426.54	100	0.20	0.83	7080.59		
Total	840.30				17362.51	2.596	45073.08
Sub-Base compc. at 95%							
Extend	125.38	125	0.20	0.83	2601.60		
Moist	142.83	205	0.20	0.83	4860.53		
Mix	106.59	125	0.20	0.83	2211.75		
Extend	106.59	125	0.20	0.83	2211.75		
Compact	449.22	100	0.20	0.83	7457.12		
Total	930.61				19342.75	2.596	50213.77
Impregnation irrigation.	8.54	205	0.20	0.83	290.62		
Seal irrigation	8.54	205	0.20	0.83	290.62		
Total	17.08				581.23	2.596	1508.88
Sub-Grade Improvement							
Extend	157.39	125	0.20	0.83	3265.81		
Moist	179.30	205	0.20	0.83	6101.48		
Mix	133.80	125	0.20	0.83	2776.43		
Extend	133.80	125	0.20	0.83	2776.43		
Compact	563.92	100	0.20	0.83	9361.01		
Total	1168.21				24281.16	2.596	63033.90
Placement of seal with Tipper Truck	43.23	175	0.20	0.83	1255.89	2.596	3260.30
Placement of gravel with Tipper Truck	13.45	100	0.20	0.83	390.58	2.596	1013.95
Total	2250.29				46903.19		165742.02

Table 4 Fuel consumption for each stage of the construction process in the Real de Sevilla III Suburb
Source: Own elaboration

Table 5 shows the KG-CO_2 eq emissions generated by each m^2 of asphalt pavement due to the use of earthmoving machinery and equipment, giving a total of 1.29 Kg of CO_2 eq for each m^2 of pavement.

Impact category	Emissions in kg-CO_2/Suburb	Paved area	Emissions in kg-CO_2 per m^2
Unit	kg of CO2eq	m^2	kg of CO2eq/m2
4 cm Layer	165 742.02	128 049.59	1.29

Table 5 Emissions Analysis in Kg- CO_2 eq /m^2 generated in the Suburb
Source: Own elaboration

Conclusions

Based on our results, it was possible to observe that the large emission factors do not impact as much as one would think, but rather that the main factor that increases the total emissions is the volume and quantity of material, given that the elements with the greatest quantity of weight and/or pieces are those with a higher number of emissions.

It is recommended to use, during the execution of the works, vehicles or machinery of recent models, in order to avoid atmospheric emissions that exceed the allowed limits.

We also recommend the use of the cleanest technologies and the use of fuels that are friendly to the environment, as well as ensuring their efficient use.

With the right handling, maintenance and care of the machinery, we intend to minimize the adverse effects on the environment and reduce the negative effects that these can cause on human health, in order to favor the life of future generations.

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