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CO_2 emissions of an asphalt pavement in kg of CO_2 per m^2

Emisiones de CO_2 de un pavimento asfáltico en kg de CO_2 por m^2

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Abstract

Climate change is one of the world's major problems and concerns the entire human population as its effects are global in scope. Climate change is driven by the greenhouse effect, which is generated by greenhouse gases (GHG). The construction industry is important in the development of a country, both economically and culturally, since it is through it that the infrastructure needs required for a nation's economic and social activities are met. Urban environments are composed of various structures that favor economic, social and any other activities of interest within the existing population; such urban environment is mainly connected by a system that is constituted by asphalt pavements of flexible or rigid type. This project analyzes the environmental impacts generated during the construction process of an asphalt pavement corresponding to the Real de Sevilla III subdivision, located in Obregon City, Sonora, Mexico, applying the Simapro 9.0 Software, obtaining a result of 12.618 Kg CO_2 eq/m2 and 1,140, 863.493 Kg-CO_2/fractionation generated by its main materials and activities and equipment consumptions.

Carbon footprint, CO2, Pavement

Resumen

El cambio climático es uno de los principales problemas a nivel mundial, concierne a toda la población humana ya que sus efectos son de alcance global. El cambio climático es impulsado por el efecto invernadero, el cual es generado por los gases del mismo nombre (GEI). La industria de la construcción es importante en el desarrollo de un país, en los ámbitos económico y cultural, ya que, a través de ella se satisfacen las necesidades de infraestructura que requieren las actividades económicas y sociales de una nación. Los entornos urbanos se componente de diversas estructuras que favorecen las actividades económicas, sociales y de cualquier otro interés dentro de la población existente, tal entorno urbano está conectado principalmente por un sistema que está constituido por pavimentos asfálticos de tipo flexible o rígido. En el presente proyecto se analiza los impactos ambientales generados durante el proceso de construcción de un pavimento asfáltico correspondiente al fraccionamiento Real de Sevilla III, ubicado en ciudad Obregón Sonora, México, aplicando el Software Simapro 9.0, obteniendo un resultado de 12.618 en kg de CO_2 eq/m2 y de 1, 140,863.493 kg de CO_2 eq. /fraccionamiento generado por sus principales materiales y actividades y consumos de los equipos.

Huella de carbono, CO_2, Pavimento

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Introduction

Human beings develop their lives in a physical space surrounded by other organisms and the physical and socio-economic environment in which biotic and abiotic factors interact with each other generating a place of their own and this space is called environment (Marino, 2009).

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

Until not so long ago, the capacity of humans to alter the environment was limited and punctual. But in the last hundred years, this capacity to alter the environment has increased significantly, to the point of endangering the entire planet (Cidead, 2018). The environment has to some extent withstood human activities with a degree of adequacy, producing desired goods and products, which have caused emissions or discharges to air, water and land (Encinas, 2011).

Air emissions have led to air pollution, which continues to wreak havoc on human health and is estimated to affect 90% of the world's population and is responsible for the premature death of seven million people each year, including 600,000 children (UN, 2019).

Atmospheric emissions, discharges or non-visible waste generated by industries are undoubtedly the most damaging of the waste produced by human activities. Their invisibility, together with the spatial and/or temporal distances at which they can manifest themselves, is one of their worst effects, as it leads to a disregard that is absolutely unacceptable when viewed from the perspective of sustainability requirements (Ripoll & Del Cerro, 2007).

The United Nations (UN) (2019), has pointed out that this type of air pollution is a "silent killer" and highlights that it does not receive due attention "as these deaths are not as tragic as those caused by disasters or epidemics". He also points out that air pollutants are mainly caused by the burning of fossil fuels for electricity production, transport, heating, industrial activity and poor waste management.

These emissions have led to what in recent decades has come to be known as climate change, which according to the Intergovernmental Panel on Climate Change (IPCC) (2014), is the change in the state of the climate, identifiable (through statistical evidence) in changes in the mean value or in the variability of its properties, that persists over long periods of time, usually decades or longer.

Climate change is driven by the greenhouse effect, which is generated by the greenhouse gases of the same name "greenhouse gases" (GHGs). GHGs are a natural part of the planet's climatic conditions, they provide optimal conditions for life on planet earth, ensuring an ideal temperature for natural processes to take place, without them the planet would have lower temperatures which would not allow the development and growth of living things (Florides, Christodoulides, & Messaritis, 2013).

The greenhouse gases that occur naturally in the atmosphere are: water vapour, carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4), and ozone (O3), which are responsible for absorbing and emitting certain radiation from the earth's surface, atmosphere and clouds. The problem occurs when there is an increase in the concentration of these gases, as the radiation absorbed and emitted by the atmosphere is greater, causing the temperature of the Earth's surface and the troposphere to rise (UNAM, 2018).

According to Figure 1, total anthropogenic GHG emissions have continued to increase between 1990 and 2019, with the largest absolute increases between 2000 and 2019, despite a growing number of climate change mitigation policies.

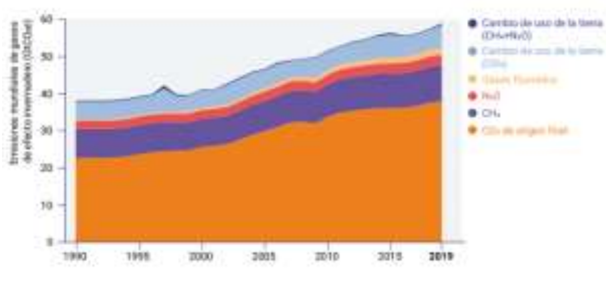

Figure 1 Total annual anthropogenic GHG emissions by gas, 1990-2019
Source: UN, 2020

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Among the main GHGs, carbon dioxide (CO_2) is of most concern because of its responsibility for climate change and according to OECC (2014), the concentration of CO_2 in the atmosphere has increased due to human activity, primarily fossil fuel use and deforestation, with a minor contribution from cement production. It is also noted that current concentrations of CO_2, CH_4 and N_2O substantially exceed the range of concentrations recorded in ice cores over the past 800,000 years. The rate of increase in atmospheric concentrations of CO_2, CH_4 and N2O in the past 20th century is unprecedented in the last 22,000 years, as they have increased since 1750, exceeding pre-industrial levels by 40%, 150% and 20%, respectively, and finally the pH of ocean water has decreased by 0.1 since the beginning of the industrial era, which corresponds to a 26% increase in hydrogen ion concentration (see Figure 2).

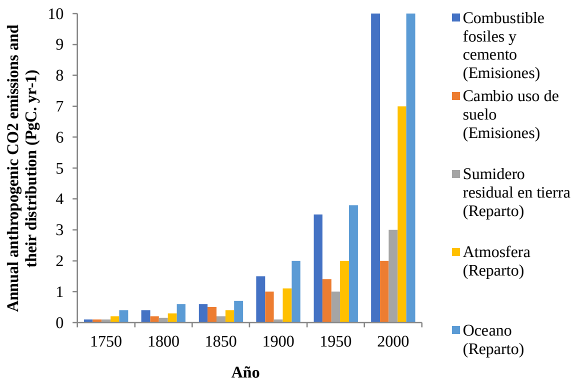

Figure 2 Annual anthropogenic CO_2 emissions and their distribution (PgC.year)
Source: OECC, 2014

According to Semarnat (2015), the effects produced by the emission and accumulation of GHGs include extreme changes in environmental temperature, precipitation, winds, an increase in the frequency of extreme weather events such as increased flooding in some regions with decreased rainfall and increased droughts in others, melting of the polar ice caps and continental glaciers. In addition, with the result of severe flooding and rising global sea levels, the migration of flora and fauna from one latitude to another, an increase in diseases, especially infectious and contagious diseases, and finally variations in the cycle and intensity of hurricanes, among many others, most of which have negative effects.

(Soto, González, & Fernández, 2013), state that the increase in carbon concentrations in the atmosphere acidifies the oceans, which affects marine biodiversity. Terrestrial biodiversity is influenced by climate variability, such as extreme weather events (e.g. droughts or floods) that influence the sustainable productivity of soils; hence, adequate nutrition.

The World Health Organisation (WHO) has estimated the number of deaths attributable to climate change at 160,000 per year; however, in 2003 the effects of the heat wave exceeded forecasts, with 70,000 more deaths than expected occurring in Europe that summer (Sunyer, 2010).

In the second half of the 21st century, heat waves are predicted to become more frequent and extreme in parts of Europe and North America. As this pattern becomes more pronounced, extreme heat waves will affect the Mediterranean area, southern and western United States (Soto, et al, 2013).

The environmental impact that industries have on the environment and natural resources has been considerable, not only as a result of the growth in production but also because this growth has been concentrated in sectors with high environmental impact. Among the industrial sectors that most affect the environment are basic petrochemicals, chemicals and metallurgy, which together may account for more than half of the pollution generated by the industrial sector. In terms of hazardous waste, the chemical, metallurgical and automotive industries are the industrial sectors with the highest generation, followed by the electricity and food industries (Semarnat, 2010).

The construction sector uses inputs from other industries such as steel, iron, cement, sand, lime, wood, among others. Construction has numerous negative effects on the environment, among the most notable are: pollution, excessive use of materials with the consequent loss of natural resources, degradation of landscape quality and alteration of natural drainage (Acosta B., 2019).

The soil is altered due to the waste that comes from the dumping of construction waste and debris with numerous negative effects on the environment, among which are pollution, degradation of landscape quality and alteration of natural drainage, this generates the impacts of acidification, eutrophication and eco-toxicity which causes modification generated to the ecosystem (Acosta D., 2002).

In addition, earth movement generates alterations to geomorphology, the loss of vegetation cover causes faster erosion processes and sometimes, when explosives are used for excavations in the construction industry, slope instability can be generated (Arenas, 2010). Disturbances in the air are associated with dust, noise, CO_2 emissions from the use of fossil fuels, minerals, excavation works, cutting of slopes and operation of machines and tools.

(Medineckiene, Kazimieras, & Turskis, 2010), highlight that the use of minerals as construction material generates fine dust particles during its degradation process, according to the dispersion, the most dangerous of them are hard particles of class 5º, which are not stopped by the upper respiratory tract of humans, causing problems in the mucous membrane of the nose, trachea, bronchial tubes, which cause inflammatory reactions and eventually chronic disturbances and then people get respiratory tract diseases, such as bronchitis, tracheitis and pneumonia (diffuse sclerosis of the lungs).

The commercial and residential construction sector generates 39% of the CO_2 emitted into the atmosphere, as well as 30% of the solid waste and 20% of the water pollution. It is therefore concluded that half of the CO_2 emitted into the atmosphere is related to the construction of buildings and construction sites of all types throughout all phases: construction, use and subsequent demolition (Growing Buildings, 2017).

Lu, Shen, Yao, & Wu (2005), argue that construction is the main source of environmental pollution compared to other industries, on the other hand, Bravo (2011) points out that the construction sector generates 36% of CO_2 emissions, in the European Economic Community and that it is the industry that consumes the most energy, generates the most waste and uses 60% of the materials that are extracted on the continent.

It has been reported that very few private developers and contractors make efforts to consider the environment and take into account the recycling of construction materials and give more importance to completion time (Poon, Yu, & Ng, 2001).

The construction sector is very important in the development of a country as it contributes to generate basic welfare elements in a society by building bridges, roads, ports, railways, dams, power plants, industries, as well as housing, schools, hospitals; allowing the development of urban areas and the growth of cities (INEGI, 2009).

In the coming decades, much of Mexico's population growth will be urban. This means that the country will grow from 384 cities to 961 in 2030, where 83.2% of the national population will be concentrated and where the poor population will most likely predominate (UN-Habitat, 2017).

In the state of Sonora in 1990, 79% of the population lived in localities of 2 500 and more inhabitants. In 2020, that percentage was 87.13%, for a population of 3 million 304 thousand 011 inhabitants (see Figure 3), according to data published by INEGI (2020).

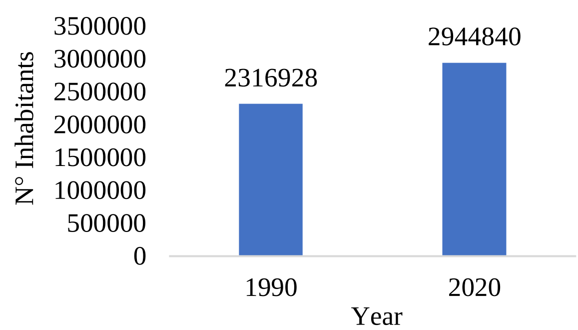

Figure 3 Urban population growth in Sonora
Source: INEGI, 2020

The state of Sonora has been characterised by demographic concentration, a product of migratory flows that have opted to seek alternatives for better jobs and income. First secondary activities and now tertiary activities have been the main attractions of these demographic movements, which have been lodged in certain points of the territory known as population centres. The advantages of location, as well as the density and speciality of non-primary activities, have led to different urbanisation phenomena in the territory.

This urbanisation process has also been characterised by intense land use measured by population density (Sidur, 2016). All this will increase the distances, times and costs of urban journeys, and will require increased investment to achieve greater connectivity between workplaces and housing or service centres.

Urban spaces can be defined as areas accessible to all inhabitants and users at any time, they are composed of various structures that favour economic, social, cultural and any other activities of interest within the existing population, such an environment is mainly connected by a system consisting mainly of asphalt pavements of flexible type (asphalt binder) 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, thus generating a greater amount of resources for its construction, which in turn causes a greater impact on the environment (Cruz, Gallego, & González, 2009).

Urban pavements are made up of a pavement generally made up of several successive layers supported on the esplanade or embankment, which consists of a firm support surface with sufficient strength to withstand the stresses of the upper layers of the pavement during its construction and operation. The thickness of each of the three elements that make up external urban pavements (road surface, pavement and surface course) is determined according to the function for which the pavement is intended, the load and frequency of use that the pavement is intended to receive, and other particular desirable characteristics (Francalacci, 2010). Normally, urban pavements of the flexible hot mix asphalt type are made up of 4 layers consisting of the graded or embankment, the pavement, which in turn is made up of a sub-base, a base and the overlay represented, in this case, by an asphalt layer (see Figure 4).

Figure 4 Flexible pavement structure
Source: UNAM, 2018

According to Angulo and Zavaleta (2021), one option for the design of pavement structures is soil stabilisation, defined as the improvement of the physical properties of a soil through mechanical procedures and the incorporation of natural or synthetic chemical products. Soil stabilisation for roads has technical, environmental, economic and social advantages over traditional construction.

From the environmental point of view, the use of existing materials on the ground reduces the consumption of aggregates, reducing the exploitation of aggregate pits and riverbeds, and the transport of materials to and from the construction site, with a lower consumption of fossil fuels and emission of gases into the atmosphere.

It also has associated benefits for rural communities or populations, given that it is a faster construction technique than the traditional one, which implies shorter intervention times for roads, less presence of machinery in the environment and a positive perception of the environment.

In the world, the alternative of using geosynthetics is already common in many countries, where geogrids in flexible pavements increase the bearing capacity of a given material, providing lateral confinement, reducing the load stresses produced by vehicles on the pavement structure. These geogrids provide increased strength, which certifies a 90% higher efficiency (Tolentino, 2021).

At present, the carbon emissions or emission factors generated by each material, product or existing service are known, which has allowed us to clearly know the impact generated in each activity, allowing us to quantify the CO_2 emissions generated in the construction of a road infrastructure and how this can vary depending on the materials and the construction area, so it is imperative to consider the environmental impact generated by any construction (Rico, et al, 1998).

Different methodologies and tools are known to help us for the inventory of pollutant emissions both for organisations and for products or services in particular, with differences in terms of scope, gases covered or the scale to which it is applied.

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So to select a methodology it is necessary to focus mainly on the objective that is planned to be obtained to achieve the expected result. Among the most widely used tools is the "Life Cycle Assessment" (LCA) which has been considered one of the most appropriate methodologies for the interactive study between products and services of the construction industry and the environment, as numerous objectives and methodological references have been used for its development (Naked, et al, 2013).

The LCA allows determining the environmental burdens associated with products, processes or activities (Condeixa, Haddad, & Boer, 2014), and is developed through the identification and quantification of energy, materials used and waste discharged into the environment (Domínguez & Júárez, 2011). Due to its simplicity, ease and efficiency, it has been used as a basis for various methodologies, tools and standards.

According to the "ISO 14040" standard, LCA is defined as a technique for determining the environmental aspects and potential impacts associated with a product (or service) through an inventory of the relevant inputs and outputs of the system, an assessment of the potential environmental impacts associated with those inputs and outputs, and an interpretation of the results of the inventory and impact phases in terms of the objectives of the study (Suárez, 2014).

LCA is a tool for a better understanding of the dimensions of the environmental profile of products, processes and services and is suitable for comparing the potential environmental impacts of two or more similar products and if necessary can be combined with economic and social considerations, and depending on the processes covered by the LCA, it can have different scopes, according to Badilla, et al. (2015).

- "Cradle to grave": Includes the extraction of raw materials and the processing of materials necessary for the manufacture of the component, the use of the product and finally its recycling and/or final management. Transport, storage, distribution and other intermediate activities between life cycle phases are also included when they are sufficiently relevant.
- "Cradle to gate": The scope of the system is limited from when raw materials are sourced to when the product is placed on the market, at the exit of the manufacturing plant.
- "From the door to the door": Only manufacturing processes are considered

There are various technologies for the determination of quantifications of greenhouse gas emissions and other environmental impacts, so-called specialised software or tools, among which we can find the software "Air.e HdC" which is focused on the calculation of Carbon Footprint of products, services, events, organisations and projects, allows the preparation of verification reports and is adjusted to the international standards ISO 14040, PAS 2050, GHG Protocol, ISO 14064, ISO 14067 and ISO 14069 (TYS Magazine, 2014).

SimaPro" is an analytical software used to measure the environmental footprint of products and services in an objective way and with a high level of transparency and allows to view complete supply networks and provides a total view of databases and unit processes, this provides full ability to analyse and modify choices and assumptions, indispensable for professional LCA investigations (SimaPro, 2017). In relation to the existence of previous works carried out by various researchers having carbon footprint and the construction industry as a topic we find the following:

Environmental impact assessment of outdoor urban pavements (Francalacci, 2010). Environmental impact of road projects. Effects of the construction and maintenance of road surfaces: II rigid pavements. (Hernández, et al, 2001). Model for quantifying the CO2 emissions produced in buildings derived from the material resources consumed in their execution (Mercader, Ramírez, & Olivares, 2013).

Assessment of the Carbon Footprint with a Life Cycle Analysis approach for 12 Building Systems (Güereca, et al, 2016). Determination of the carbon footprint in the construction of 3 types of Walls, applied to low-income housing, Mexico-Puebla (Hoyos, 2018).

In the same way, the research analysed various existing methodologies for calculating the carbon footprint or CO_2 emissions, some of which were, Methodologies for calculating the carbon footprint and its potential implications for Latin America (ECLAC, 2010). 7 methodologies for calculating greenhouse gas emissions (IHOBE, 2013). Methodological approaches for calculating the carbon footprint (Herrero, 2017).

In the present project, the carbon footprint of an asphalt pavement is calculated in kg CO_2 eq per m^2 in Ciudad Obregón Sonora, Mexico, by means of emission factors obtained from Simapro 9.0 software, with the Ecoinvent 3 libraries. Allocation at point substitution system APOS U- used in this LCA project, Method Global, ReCiPe 2016 Midpoint (E), World 2010 E, option characterisation, taking into account from the process of obtaining the raw material to the production of inputs, in the machinery the operation of the equipment is taken into account, as well as that of fuels and oils.

The object of the study was considered to be the functional unit $1m^2$ of asphalt pavement of 4 cm thickness, 15 cm thickness of the base layer, 15 cm thickness of the sub-base layer and 20 cm thickness of the underlying layer as natural soil material.

It was hypothesised that the emissions in KG-CO_2/m^2 produced by the asphalt binder pavements are within the range of 10-25 KG-CO_2/m^2, and that the emissions in KG-CO_2/m^2 produced by the asphalt binder pavements are within the range of 10-25 KG-CO_2/m^2

Methodology

Participants:

– Research professor of the Instituto Tecnológico de Sonora of the Civil Engineering Department, who created the main idea of the project, as well as the research guide and provided the tools and means for it.
– Students from the Civil Engineering educational programme of the Sonora Institute of Technology, who helped in the collection of information and preliminary tests of the SIMAPRO 9.0 software, with the aim of developing them to continue the research with other types of works or pavements.

Materials and equipment:

– Paving plans of the subdivision: File where the shape, dimensions and design characteristics are specified.
– Equipment: Desktop computer and LAP TOP.
– AutoCAD, Software for the design, revision and modification of plans.
– OPUS 2010 software, for the determination of fuel consumption of the equipment.
– Microsof, Word, Excel and PPT.
– Earth Google, for the location of the subdivision and the distances to the places of origin of the materials.
– The SIMAPRO 9.0 software was used to determine the CO_2 emissions (carbon footprint) in Kg-CO_2 eq, which is based on the Life Cycle Analysis (LCA) methodology and has as its regulatory framework the international standards of application such as:
  – UNE-EN ISO 14040.
  – UNE-EN ISO 14044.

Several tables were designed in Excel and formulated for the capture of project data to determine the quantities of work for each layer of the structure, to quantify the number of working hours and the number of litres of fuel (diesel) consumed at each stage of the construction process.

Design of tables to calculate the quantities of work per functional unit m2 of pavement indicating each layer of the structure, which included base materials, sub-base, sub-surface and asphalt binder, as well as the watering and impregnation, also the tables of volumetric weights that allowed to convert the units of weight to mass and to be able to use it in mass units as allowed by the software Simapro 9.0.

Procedure:

1. Once the object of study has been selected, and all its characteristics are known:

– Location
– Plans and projects
– The content of the projects relating to the layout, road area, characteristics of the pavement structure (thickness of the different layers of asphalt binder, base, sub-base and underlayer).
– Location of procurement points for the various materials required in the different stages or layers of construction in relation to the location of the subdivision.

2. In relation to the construction site and construction processes:

– Defined the various activities required for each layer of the pavement structure and the appropriate equipment.
– Calculated the volumes or quantities of work at each stage of the construction process relating to the various layers that make up the pavement structure.
– Calculated the consumption in litres of fuel per HP of equipment power per hour of work, considering the operating factors.
– Designed tables to calculate the quantities of work per functional unit m2 of pavement indicating each layer of the structure, which included base, sub-base, sub-surface and asphalt binder materials and the binding and impregnation watering.
– The volumetric weight tables were established to convert the weight units to mass and to be able to use them in mass units as allowed by the SIMAPRO 9.0 software used.

3. Procedures for data collection:

– The information on CO_2 emissions were those established in the software available for the SIMAPRO 9.0 project.

Results

In this work there are two types of results, preliminary and necessary for the development of the study and the final results relating to the carbon footprint.

Figure 5 shows how the inputs to the construction process behaved, the process itself in its development and its outputs, in which the materials, energy consumption of the construction work and the transport of materials to the site stand out, and a square metre of pavement with a defined structure was also established as a functional unit.

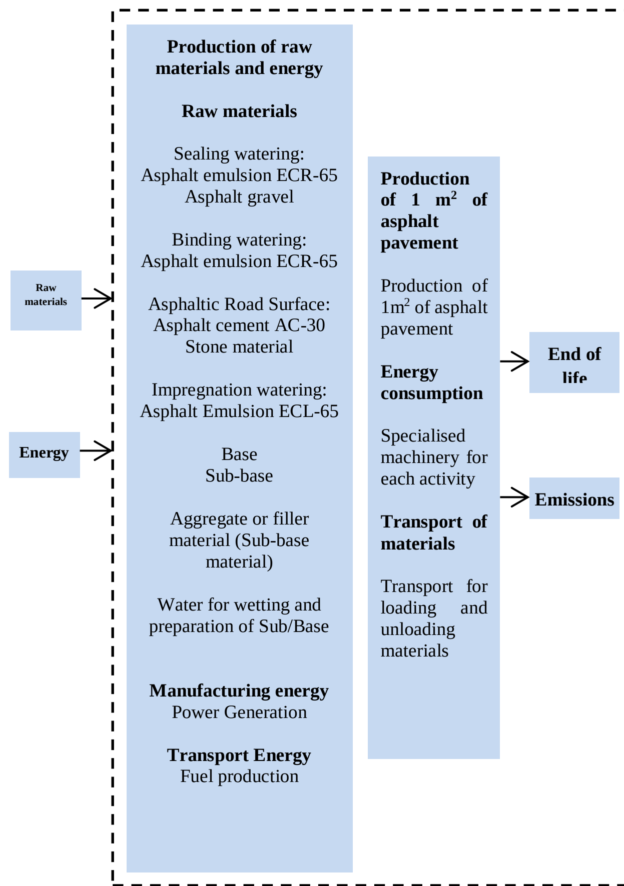

Figure 5 Schematic of the product-system
Source: Own Elaboration

Figure 6 shows the pavement structure where the thickness of the asphalt layer is 4 cm thick.

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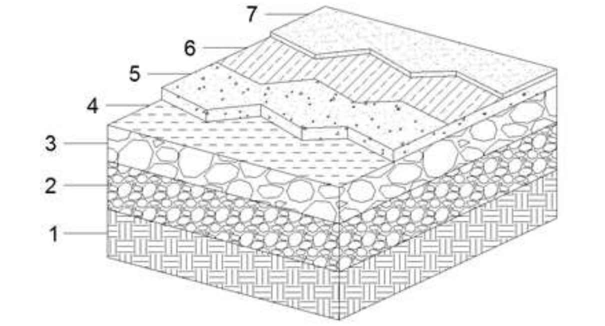

Stabilising layer	1	Sub-Base	20 cm
Granular Base/Sub-Base Course	2	Sub-Base	15 cm
Impregnation layer	3	Base	15 cm
Asphalt pavement layer	4	Emulsion	1.15 l/m^2
Bond Coat	5	Asphalt Carpet	4 cm
Seal coat	6	Emulsion	0.8 l/m^2
Stabilising layer	7	Surface treatment	2 cm

Figure 6 4 cm asphalt pavement structure specifications
Source: Own Elaboration

In table 1, the materials can be seen, where the subgrade stands out with 488,580 kg, the base and subbase with 312,475 kg, and the lowest values are for the cementitious material and asphalt emulsion with 1,574 and 1,229 kg respectively.

Material	Ud.	Cant. (m^3)	Specific gravity (kg/m^3)	Conversion (kg)
Sub-Base	m^3	0.2874	1700.00	488.580
Sub-Base	m^3	0.2155	1450.00	312.475
Base	m^3	0.2155	1450.00	312.475
Stone material	m^3	0.0553	1500.00	82.950
Asphalt gravel	m^3	0.0276	1500.00	41.400
Asphalt cement AC-30	m^3	0.0015	1035.27	1.574
Asphalt emulsion ECR-65	m^3	0.0024	1001.59	2.424
Asphalt emulsion ECL-65	m^3	0.0012	1015.88	1.229
Water	m^3	0.1260	1000.00	126.000

Table 1 Volumes and weights of materials at fractionation Real de Sevilla III 4 cm
Source: Own Elaboration

In the analysis of the emissions generated by the transport of inputs, the most unfavourable distances from the place where the inputs were obtained to the location of the fractionation were calculated, considering adequate transport for the transfer of each input, asphalt cement travels 1854.60 km, water, 9.00 km and stone material 35.70 km (see Table 2).

Material	Net distance to the activity site in km
Base	15.5
Sub-Base	15.5
Asphalt cement AC-30	1854.6
Stone material	35.7
Asphalt emulsion ECR-60 for the seal course	1854.6
Asphalt gravel	25.3
Asphalt emulsion ECL-65 for impregnation irrigation	1838
Asphalt emulsion ECR-60 for the binder irrigation	1838
Water	9

Table 2 Travel distances of materials to the Real de Sevilla III subdivisión
Source: Own Elaboration

Table 3 shows the quantities of diesel required in each of the stages of the construction process by the unit corresponding to each stage, where it is found that the sub-base works and the improvement of the compacted base require 0.4948 l/m^3, while 0.0721 l/m^3 are required for the asphalt layer.

Concept	Area	Vol. hauling (m3)	Vol. (m3)	Rend. (m^3/hr)	Working hours	Pot.	l/hr	Factor de oper.	Diesel consumption (L)	Consumo diesel (L/m3)
Asphalt road surface		4469.10	5645.18	227.84	19.62	125	0.20	0.83	407.02	
Totals					19.62				407.02	0.0721
Base compc. Al 95%		16119.9	20955.9							
Extend		16119.90		268.00	60.15	125	0.20	0.83	1248.09	
Moisten		16119.90		200.00	80.60	205	0.20	0.83	2742.80	
Mix		16119.90		268.00	60.15	125	0.20	0.83	1248.09	
Extend		16119.90		268.00	60.15	125	0.20	0.83	1248.09	
Compact		16119.90		59.90	269.10	100	0.20	0.83	4466.99	
Totals					530.15				10954.06	0.5227
Sub-Base compc. al 95%		16972.30	23225.25							
Extend		16972.30		227.84	74.49	125	0.20	0.83	1545.75	
Moisten		16972.30		200.00	84.86	205	0.20	0.83	2887.84	
Mix		16972.30		268.00	63.33	125	0.20	0.83	1314.09	
Extend		16972.30		268.00	63.33	125	0.20	0.83	1314.09	
Compact		16972.30		63.59	266.90	100	0.20	0.83	4430.57	
Totals					552.91				11492.34	0.4948
Impregnation irrigation	107466.24			15000	7.16	205	0.20	0.83	243.81	
Seal irrigation	107466.24			15000	7.16	205	0.20	0.83	243.81	
Totals					14.32				487.62	0.0045
Sub-grid improvement		21493.20	29411.75							
Extender		21493.20		227.84	94.34	125	0.20	0.83	1957.49	
Moisten		21493.20		200.00	107.47	205	0.20	0.83	3657.07	
Mix		21493.20		268.00	80.20	125	0.20	0.83	1664.12	
Extend		21493.20		268.00	80.20	125	0.20	0.83	1664.12	
Compact		21493.20		63.59	338.00	100	0.20	0.83	5610.74	
Totals					700.21				14553.54	0.4948
Dompe seal installation	107466.24		0.00	15000	7.16	175	0.20	0.83	208.13	
Laying of gravel with dompe	107466.24		29411.75	125.00	17.19	100	0.20	0.83	285.43	
Totals					24.35				493.56	0.0046
Totals					1841.57				38388.11	

Table 3 Machinery working hours and fuel consumption for each stage of the construction process in the Real de Sevilla III subdivision
Source: Own Elaboration

Table 4 shows the quantities of calorific value for the functional unit of one m^2 of the Real de Sevilla III subdivision, highlighting the volume of Sub-Base with a value of 17.790 MJ and the compacted base with 18.790 MJ, the lowest value is the impregnation irrigation with 0.165 MJ.

Phase	MJ
Asphalt road surface	2.590
Compacted Base	18.790
Sub-base volume	17.790
Irrigation impregnation with oiling machine	0.163
Improvement of sub-base layer	17.790
Compaction of gravel with smooth compactor	0.165

Table 4 Real bridging fractionation calorific value in mj/m^3/phase
Source: Own Elaboration

Once the information necessary to use the Simapro software was gathered, the requested information was entered and the program was run.

The following results were obtained:

Figure 7, indicates in what percentages with which the different stages of the construction process contribute to the environmental impacts such as the case of the Sub-base with 33.30% and 32.04% of the base and in a sub-stage the burnt diesel fuel contributes 46.91%.

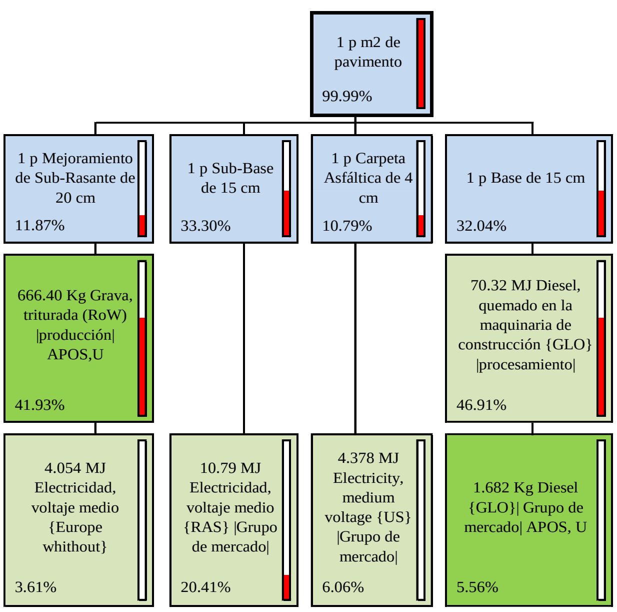

Figure 7 Contributions of the stages of the construction process and of the most representative materials involved Real de Sevilla III 4 cm Simapro 9.0
Source: Own Elaboration

Table 5 shows the environmental impact categories, where it can be seen that global warming has a value of 12,618 kg CO_2 eq, of which the sub-base contributes 4,202 and the base 4,043 kg CO_2 eq, the values for ionising radiation are 2,403 kg CO_2, which is also a significant value.

Impact category	Unit	Total	Subgrade 20 cm	Subbase of 15 cm	Asphalt road surface of 4 cm	Base of 15 cm	Irrigation
Global warming	Kg CO_2 eq	12.618	1.498	4.202	1.361	4.043	1.514
Stratospheric ozone depletion	Kg CFC11 eq	1.33E-05	1.30E-06	3.20E-06	2.20E-06	3.00E-06	3.70E-06
Ionising radiation	KBq Co-60 eq	2.403	0.127	0.344	0.522	0.331	1.079
Terrestrial acidification	Kg SO2 eq	0.073	8.85E-03	0.021	0.010	0.020	0.014
Freshwater eutrophication	Kg P eq	3.26E-04	1.80E-06	1.42E-04	2.81E-05	1.42E-04	1.18E-05
Marine eutrophication	Kg N eq	3.50E-05	1.90E-06	8.40E-06	6.00E-06	8.20E-06	1.05E-05
Terrestrial ecotoxicity	Kg 1,4-DCB	10.412	1.248	3.242	1.275	3.110	1.537
Freshwater ecotoxicity	Kg 1,4-DCB	0.010	5.80E-04	1.62E-03	2.08E-03	1.56E-03	4.15E-03
Marine ecotoxicity	Kg 1,4-DCB	132.079	8.159	19.645	28.361	18.779	57.136
Human carcinogenic toxicity	Kg 1,4-DCB	2.045	7.29E-03	0.876	0.244	0.876	0.042
Land use	m^2a crop eq	0.215	5.86E-04	0.087	0.034	0.087	5.84E-03
Scarcity of mineral resources	Kg Cu eq	4.82E-03	2.32E-05	2.00E-03	7.08E-04	1.99E-03	9.87E-05
Scarcity of fossil resources	Kg oil eq	9.651	0.519	1.299	2.132	1.244	4.457
Water consumption	m^3	0.313	2.39E-03	0.113	0.065	0.113	0.020

Table 5 Emissions results and others by impact category 4 cm pavement of the Real de Sevilla III 9.0 subdivision
Source: Own Elaboration

Figure 8 shows the results of the different environmental impacts and shows the 5 stages of the construction process in the category of global warming, the stages that contribute most are the sub-base and the base, in the same situation as occurs with ozone formation, on the other hand, in the category of freshwater ecotoxicity and marine ecotoxicity, the stage that contributes most is the irrigation stage.

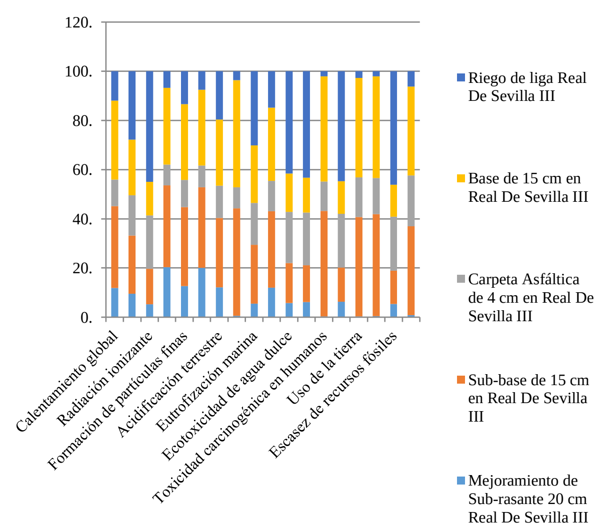

Figure 8 Graph of the categories of environmental impacts in the different stages of the construction process in the Real de Sevilla III 4 cm Simapro 9.0 subdivision
Source: Own Elaboration

Figure 9 shows that CO_2 emissions related to global warming are the most representative of the construction process and are in the order of 13 kg of CO_2, it is also observable that the stages that contribute the most are the base and sub-base, another of the categories that stands out is ionising radiation in KBqCO-60eq, which is in the order of 1.5 kg, where it can be seen that the stage that contributes most is the stage of irrigation of the asphalt emulsion.

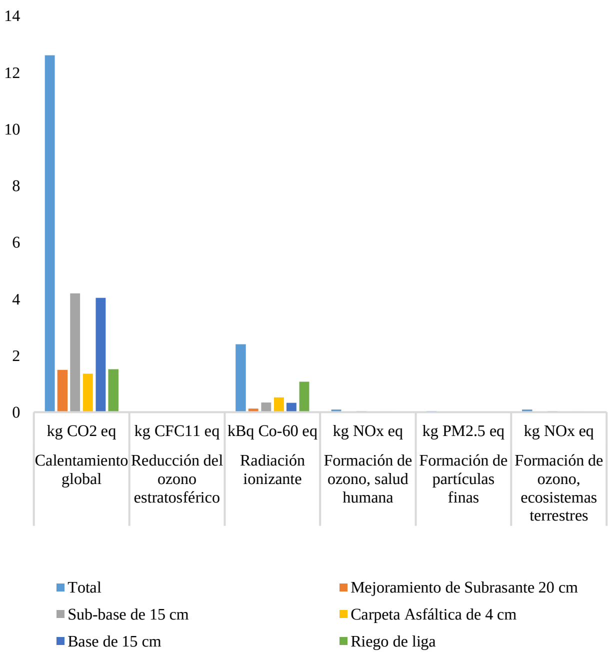

Figure 9 Categories of environmental impacts associated with greenhouse gas emissions from the 4 cm pavement of the Real de Sevilla III subdivision Simapro 9.0
Source: Own Elaboration

Table 6 shows the final results where the emissions in kg CO_2 eq/m^2 are 12.618 while the totals correspond to a total area of 90,418.33 m^2 of asphalt paving construction which produces a total of 1,140,863.493 kg CO_2 eq.

Impact category	Global Warming	Paved area	Emissions in kg-CO_2/fracking
Unit	kg de CO_2 eq/ m^2	m^2	kg de CO_2 eq
Layer of 4 cm	12.618	90, 418.33	1, 140, 863.69
Total		90,418.33	1, 140,863.69

Table 6 Analysis Emissions in Kg- CO_2 eq./m^2 generated in the Real de Sevilla III subdivisión
Source: Own Elaboration

Conclusions

The tables and figures above were used to determine the final conclusions of this work.

1. Emissions in kg of CO_2 eq/m_2 are 12.618 while the totals correspond to a total area of 90,418.33 m^2 of asphalt pavement construction.
2. Hypothesis raised for the study states textually the following: "Hi: In the construction of a flexible pavement in a subdivision in Ciudad Obregón Sonora, between 10 and 25 kgCO_2/m^2 are emitted", so it can be concluded that the hypothesis is accepted since the value found is 12.618 Kg-CO_2/m^2, and it is within the proposed values.
3. Of the stages of the construction process, the contributions of emissions in kg of C O_2 eq/m^2, the highest contribution is the sub-base layer with 33.30%, while the lowest is the asphalt layer with 10.79%.
4. The highest Global Warming value corresponds to the sub-base with a value of 4,202 kg C O_2 eq/m^2, while the lowest value is for the asphalt layer with 1,361 kg CO_2 eq.
5. The total emissions of the subdivision are 1,140,863.493 kg CO_2 eq.
6. If these values are to be reduced, lime stabilisation techniques for base and sub-base materials can be used, which can reduce the need for base and sub-base materials and eliminate the need to carry them.

Recommendations

1. Taking into account that the durability of the flexible pavement and according to Wright and Dixon, the climate and environment where a flexible pavement will be built, influences its useful life and it is very likely that two of the most influential factors are temperature and humidity, since under these conditions the flexible pavement has an average useful life of 12.5 years and taking into account that it has a higher maintenance cost and with a greater environmental impact when performing maintenance, it is recommended not to build with asphalt binder.

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2. As the greatest contamination is generated in the movement of earth, it is advisable to explore the possibility of using the technique of soil stabilisation with lime, especially in the case of expansive clays, which are very common in our environment.

3. According to the development of our study, which indicates that a rigid pavement "are those that are fundamentally constituted by a hydraulic concrete slab, supported on the subgrade or on a layer, of selected material, which is called sub-base" this indicates that we can suppress one of the layers that most pollute the base in both results are contributing with values close to 30% of the total emissions of KG-CO_2 eq.

4. In rigid pavements, use ecological cement, which generates less Kg-CO_2/tonne emissions in its production process.

5. Carry out a greater number of studies changing the pavement variables, such as concrete, clay stabilisation, cobblestones, paving stones, soil cement.

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