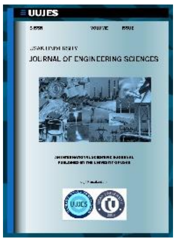

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Research article

CARBON FOOTPRINT DETECTION OF ASPHALT PAVEMENTS

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Abstract

One of the biggest causes of global warming is carbon dioxide emissions. Carbon dioxide emissions arise as a result of people's daily activities. Determining the causes and amounts of these emissions is extremely important for the world we live in. Within the scope of this study, the carbon emission value that occurs during the construction of a 1 km asphalt road was calculated. The data used in the calculations were obtained from 18 months of observations. The data obtained was calculated by the Tier 1 method recommended by The Intergovernmental Panel on Climate Change (IPCC).
As a result of the calculations, 210 tons of CO_2 emissions were determined during the construction of the 1 km asphalt pavement road. This figure is approximately 32 times higher than the amount of CO_2 that a person releases into the nature in a year as a result of her/his vital activities.

Keywords: *Sustainability; carbon; environment; society; economy; emission; highway.*

1. Introduction

The carbon footprint can be defined as the carbon dioxide equivalent of the gases that emerge as a result of the vital activities of an individual. Even in people's daily life, they emit some carbon gas to the nature even to do their very simple daily work. For example, greenhouse gases are released into the atmosphere in many processes such as the gas that is opened while cooking, the fuel used during transportation, the use of electricity for lighting. As the greenhouse gases (CO_2, CH_4, N_2O…) resulting from human activities accumulate in the atmosphere, the world we live in is getting warmer. Global warming as a result of these activities brings many problems such as drought, natural disasters, loss of biodiversity and climate change.

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Greenhouse gases have a direct effect on the emergence of global warming. CO_2, which is in the greenhouse gases, affects global warming to a great extent and emerges at a very high level due to the activities in the transportation sector. According to IPCC; It has been announced that 56% of anthropogenic greenhouse gas emissions in 2004 belong to carbon dioxide resulting from the use of fossil fuels. Approximately 25% of the world's energy consumption belongs to the transportation sector, and approximately 61.5% of the oil used every year is in the transportation sector [1].

With the continuous growth in road traffic and booming development of infrastructure business activities, vehicles inevitably produce a large amount of greenhouse gas in the driving process. Facing the background of the global urban low-carbon environment and the development of the life cycle management concept, the carbon emissions generated by vehicles during the operation period of asphalt pavement cannot be ignored. [2]

Road construction is crucial to accelerating the process of poverty alleviation in urban and rural economies. With the implementation of modernization and urbanization, the global road mileage has extended overwhelmingly in recent decades, and over 25 million kilometers of new roads have been estimated to be paved in the following 30 years. Among current road structure design, asphalt pavement is the primary form of surface structural layer and widely used in the expressway and urban road network [3].

87% of the total energy production in the world is provided by fossil fuels [1]. Since the use of fossil fuels in the transportation sector is increasing rapidly, carbon emissions are also increasing. In addition to increases in fuel consumption, increases in the number of vehicles and accelerating road deterioration are causing various types of socio-economic damages, such as traffic congestion, accidents, and time delays. They also negatively affect the environment and health due to the generation of greenhouses gases during frequent road maintenance and rehabilitation (M&R) activities. M&R work for road facilities is done repeatedly to preserve the usability of roads at its serviceable condition, which generates carbon dioxide emissions. Carbon emissions are one of the essential factors that need to be considered in the selection of alternative pavement M&R strategies. Highway agencies are faced with two goals: reducing the life-cycle cost (LCC) of construction and maintenance costs, and reducing carbon emissions for sustainable pavement construction and maintenance to cope with climate change [4].

According to TUIK data [5], as presented in Fig. 1 the amount of emissions from transportation in the total greenhouse gas in 2019 is 16%. The largest share in emissions from transportation belongs to road transportation with 93%.

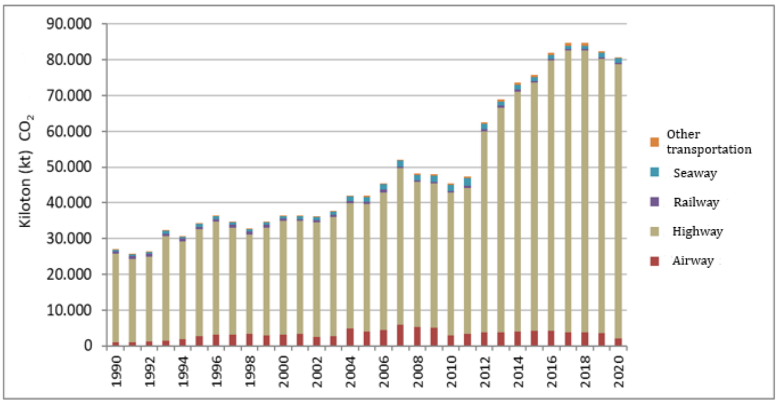

Fig. 1 Greenhouse gas emissions by transport type [5]

Road transportation is by far the most carbon-emitting mode of transportation among transportation modes. The main reason for this is situation is that it is the most preferred mode of transportation.

Asphalt coatings used in road transportation are materials with high viscosity, consisting of a mixture of aggregate and bitumen in appropriate amounts. As the construction cost is lower than other alternatives, asphalt pavements are frequently used in road construction. As asphalt pavements with a high viscosity ratio become softer when heated, they provide great convenience in road construction. Asphalt coatings, which exhibit a very flexible behavior against impacts and loads, are highly resistant to permanent deformations in this respect. Asphalt pavements contain 93-97% aggregate and 3-7% bitumen. It is produced by heating aggregate and bitumen in an asphalt plant at a temperature range of 140-160 degrees. Asphalt pavements are produced in Fig. 2 separate layers as bituminous base, binder and surface course.

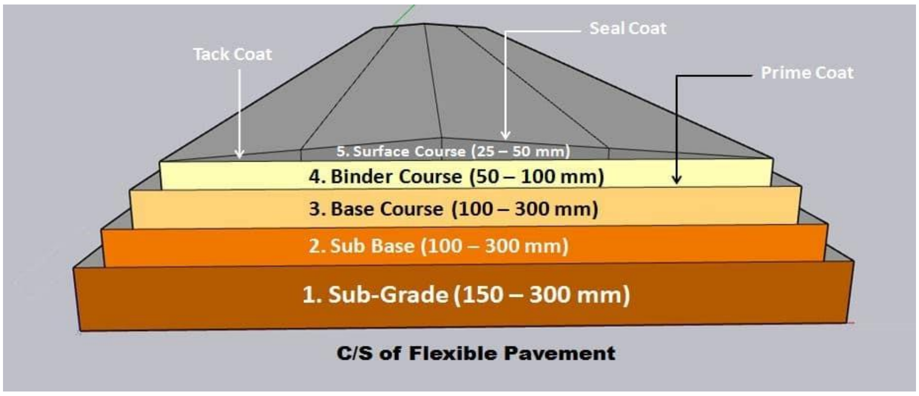

Fig 2. Asphalt Paving Layers [6]

The base course layer is manufactured to distribute the loads caused by traffic, environment and climate and to prevent the unbonded/bonded layers underneath from being exposed to excessive stress and deformation. Depending on the traffic density, the base course layer is produced in the range of 8-18 cm. It is usually applied on the plant-mix base (PMT). It can be applied in two different gradations according to the existing ground conditions [7]. The main task of the binder course, which is located between the surface course and the base course is to provide stability and durability and to reduce the formation of rutting. In order for the road pavement to be used for a longer life, the binder course should be produced in a way that prevents permanent deformation [8].

Since the surface course is the last layer of the pavement, it must be extremely resistant to traffic loads and environmental conditions without the formation of cracks and rutting. In addition, for the comfort of the drivers, it should have a low noise level, high slip resistance, a smooth profile and sufficient friction resistance. It is usually produced in 4-5 cm thickness [8]

In this study, the CO_2 emission during the construction of a 1 km asphalt pavement was made using the Tier 1 approach recommended by the IPCC. The Tier 1 approach includes the calculations made with the data obtained from the use of electricity, diesel, gasoline, natural gas at the construction site and the emission factors in the IPCC Guide. This approach uses IPCC emission factors and calculates carbon emissions from fuel combustion [9].

In Equation 1, ∑ Emission (kg) refers to the emission due to fuel consumption, ∑ Fuel (Tj) refers to fuel consumption, and Emission Factor refers to the data that varies depending on the fuel used.

$$\sum \text{Emission (kg)} = \sum \text{Fuel (Tj)} \times \text{Emission Factor} \quad (1)$$

Emission factors vary according to sectors and fuel type. These should be taken into account when taking the values from the table. In the calculations, the construction site and plant data of Oze Group located in Denizli Kaklık region were used. Asphalt plant batch type has a capacity of 300 tons/hour and produces an average of 750,000 tons of asphalt per year.

2. Materials and Method

In order to determine the carbon footprint of the asphalt pavement, it is necessary to have a great command of the project data and asphalt production stages at the construction site. Within the scope of this study, the amount of carbon dioxide released to the environment for the construction of a 1 km long road will be determined based on the data within the scope of Denizli Çardak City Crossing project.
Denizli Çardak City Transition Project ;
Road width PMT : 12 m
Road width base course : 11.57 m
Road width binder course : 11.28 m
Road width surface course : 11.00 m
The road length will be accepted as 1 km as standard.
PMT thickness : 35 cm
Base course thickness : 11 cm
Binder course thickness : 8 cm
Surface course thickness : 5 cm
According to the experiments;
PMT density : 2.25 t/m^3
Base course density : 2.411 t/m^3
Binder course density : 2.4 t/m^3
Surface course density : 2.4 t/m^3
According to the above data , 9450 tons of PMT, 3068 tons of base course , 2165 tons of binder course, 1320 tons of surface course are needed. According to these data, 15169 tons of aggregate, 1055 tons of bitumen and 529 tons of water are needed to meet the need for flexible pavement materials. In order to procure the material, first of all, a blasting must be done in the quarry. Then, the rocks that come out as a result of blasting must be brought to the crusher and crushed in order to be brought to the aggregate size. Dump trucks were used to transport the materials, and excavators were used to load them. Bitumen is transported from Kırıkkale Tüpraş Refinery. The distance between the construction site where the asphalt plant is located and Kırıkkale Tüpraş Petroleum Refinery is 545 km. A bitumen tank can carry an average of 70 tons of bitumen. The company has 4 bitumen tanks. Bitumen can be transported to the construction site by making 16 trips in total by making 4 trips for each vehicle. A total of 17440 km is traveled round-trip.
As a result of the data obtained from the crusher for 10 days, 1237 tons of material per day is crushed in the crusher and an average of 45 trips are organized from the quarry to the crusher in 1 day. A total of 15169 tons of material is needed. The crusher, which can convert 1237 tons of material per day into aggregate, can meet all material needs in approximately 12 days. The distance between the crusher stone quarry is 11 km in total, 45×11=1550 km is traveled daily. Since the trucks will work for a total of 12 days; 12×1550km = 18600km in total. The excavator works an average of 6 hours a day. It will

have worked for a total of 72 hours in 12 days. The crusher works an average of 8 hours a day. A total of 96 hours worked in 12 days. 16003 tons of material, 9450 tons of pmt, 3068 tons of bituminous foundation, 2165 tons of binder, 1320 tons of surface course, will be transported to the road construction site by dump trucks. The mechanical plant produces 500 tons of material per hour and produces 9450 tons of material in 19 hours. Asphalt plant produces 300 tons of material per hour and produces 6553 tons of material in 22 hours. During these operations, one rubber loader bucket works for a total of 41 hours to feed the bunkers. A dump truck carries an average of 25 tons of material. A total of 16003 tons of material can be transported to the laying area by making 640 trips.
The distance between the construction site settlement area and the road construction site is 15 km round trip. Since there will be 640 expeditions in total, 640×15= 9600 km is traveled. There are 1 paver, 1 wheel cylinder and 1 roller in the road construction area. The finish lays an average of 400 tons of material per hour. It lays 16003 tons of material in 40 hours. The wheel cylinder and cylinders will have worked for a total of 80 hours. Based on these data, the carbon footprint of the 1 km long flexible pavement manufacturing phase can be determined.

3. Results and Discussion

In this section, with the help of the data obtained in the material and method section, the carbon footprint that emerges during the production of 1 km asphalt pavement will be calculated using the Tier 1 method.
The greenhouse gas that emerged during the construction and material supply phase was formed as a result of the use of diesel, natural gas or grid electricity. 1 truck consumes 0.85 liters of diesel per 1 km. During the construction process, a total of 45640 km will be covered, 28200 km of which is by trucks and 17440 km of bitumen tankers. In this case, the total fuel consumed will be 45640 × 0.85 = 38794 liters. The rock drilling machine works for 8 hours to blast in the quarry.

Table 1 The amount of diesel used by the construction site vehicles

VEHICLE	AMOUNT OF FUEL USED (L)
TRUCK	23970
BITUMEN TANKER	14824
ROCK	176
ASPHALT PAVE MACHINE	360
EXCAVATOR	1800
LOADER	820
WABİL-CYLİNDER	960
TOTAL	42910

This construction machine, which burns 22 liters of diesel per hour, consumes 176 liters of diesel during its working time. Working to feed the bunkers, the loader consumes an average of 20 liters of diesel per hour. It burns 820 liters of diesel during 41 hours, which is the total working time. Asphalt pave machine spend 9 liters of diesel per hour. It burns 360 liters of diesel for a total working time of 40 hours. Wheel cylinders and cylinders spend 12 liters of diesel per hour. They spend 960 liters of diesel for a total of 80 hours of operation. According to the calculated average values, asphalt plant causes 680 kWh/hour, mechanical plant 200 kWh/hour, and crusher 500 kWh/hour electricity consumption. The amount of diesel consumed by the vehicles used in the construction of the 1 km long road at the construction site is shown in Table 1. Based on this table, the carbon dioxide emissions that occur according to the amount of diesel use are summarized in Table 2.

...Table 2 CO_2 Emissions from diesel use

A	Fuel Consumption (Ton)		33.46
B	Conversion Factor (TJ/kt)		43.33
C	Energy Consumption (TJ)	$C=A\times B\times 10^{-3}$	1.45
D	Carbon Emission Factor (TC/TJ)		20.2
E	Carbon Content (Gg C)	$E=C\times D\times 10^{-3}$	0.029
F	Percentage Of Oxidized Carbon		0.99
G	Actual Carbon Emissions (Gg C)	$G=E\times F$	0.029
H	Actual Carbon Dioxide Emissions (Gg CO_2)	$H=G\times 44/12$	0.11

At the construction site, a total of 66760 kWh of electricity was consumed, 14960 kWh due to the 22-hour operation of the asphalt plant, 3800 kWh due to the 19-hour operation of the mechanical plant, and 48000 kWh due to the 96-hour operation of the crusher. According to the information obtained from the website of the Ministry of Environment and Urbanization; greenhouse gas conversion coefficient of final electrical energy = 0.555 kg.CO_2/kWh. According to this; CO_2 Emission = 66760 kWh × 0.555 kg CO_2/kwh × 10^{-3} = 37.05 tons of CO_2. When this value is converted to gigagram. The result is 37.5 tons of CO_2 × 10^{-3}=0.04 Gg of CO_2. 5 m^3 of natural gas is used to produce 1 ton of asphalt. In our total asphalt production of 6553 tons, 32765 m^3 natural gas is used. Since Liquefied Natural Gas (Lng) gas density is 0.66 kg/m^3; 32765 × 0.66/ 1000 = 21.62 tons Lng. If this number is multiplied by 0.048 Terajoule (tj)/ Gigagram (Gg); Energy consumption = 1.04 TJ. In order to find the emission content, it is necessary to multiply the energy consumption by the emission factor 56,100 Ton carbon amount per unit TJ energy (TC/TJ). Emission Content= 1.04TJ×56.1TC/TJ= 58.34 tons of CO_2 When this value is converted to gigagram; the result is 58.34 tons of CO_2 × 10^{-3}=0.06 Gg of CO_2. During the preparation of PMT in the mechanical plant, 5.6% of water is used. Since the emission rate depending on the amount of water corresponding to this rate is a very small number, water use was not taken into account in the calculations.

4. Conclusion and Recommendations

With the continuous growth in road traffic and booming development of infrastructure business activities, vehicles inevitably produce a large amount of greenhouse gas in the driving process. Facing the background of the global urban low-carbon environment and the development of the life cycle management concept, the carbon emissions generated by vehicles during the operation period of asphalt pavement cannot be ignored.

Within the scope of this study, the carbon footprint resulting from the construction of a 1 km road within the scope of Denizli Çardak City Crossing project was calculated. Tier 1 method was used in the calculation. 0.11 Gg CO_2 from diesel use, 0.04 Gg CO_2 from electricity use. A total of 0.21 Gg of CO_2 emissions, 0.06 Gg of CO_2, originating from the use of natural gas.

From this point of view, the fact that the number of only 1 km road construction work is so much more than the carbon dioxide emission arising from the vital activities of a person for a year proves the extent of the damage to the environment when all other roads in our country and in the world are considered together.

In order to reduce the greenhouse gases released from road construction works, engine technologies should be developed, the use of electric vehicles should be expanded, less emissive sources such as electricity should be preferred more, systems that can produce their own electricity during and after the road construction phase should be developed.

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