Techno-Science

Scientific Journal of Mehmet Akif Ersoy University

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Original Research Article

hosted by Turkish JournalPark ACADEMIC

DETERMINING THE CARBON FOOTPRINT OF TRANSPORTATION; THE CASE OF AFYONKARAHİSAR, TÜRKİYE

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ARTICLE INFO

Article History

Received : 30/10/2022
Revised : 13/11/2022
Accepted : 05/11/2022
Available online : 31/12/2022

Keywords

Global Warming, Transport, IPCC, Carbon footprint

ABSTRACT

The increase in greenhouse gases released into the atmosphere is shown as the most important cause of climate change. Climate change will pose a great threat to the environment and human health in the future. In this study, the carbon footprint of the greenhouse gas emissions resulting from the consumption of fossil fuels, which have a significant effect on global warming, between the years 2017-2021 in Afyonkarahisar, Türkiye was calculated. The Tier 1 approach recommended by the Intergovernmental Panel on Climate Change (IPCC) was used in the calculation. Greenhouse gas emissions were obtained by calculating the emissions from CO2, CH4, and N2O gases separately and adding them after they were converted to CO2 equivalent. It has been determined that the highest carbon emission is caused by diesel fuel consumption, followed by LPG and benzine vehicles, respectively. The amount of carbon footprint, which was 1239.85 Gg in 2017, decreased to 1117.60 Gg in 2021. The last emission was realized in 2019 with 956.51 Gg. The amount of greenhouse gas emissions per capita was realized at the highest in 2017 at 173.2□10-5 Gg and at least in 2019 at 31.1□10-5 Gg.

1. INTRODUCTION

Global climate change can be defined as the situation that arises due to the increase in the concentration and density of greenhouse gases in the atmosphere as a result of the use of agricultural, industrial, and fossil fuels. Global warming manifests itself in the form of imbalances and deviations in precipitation, and increases in meteorological events such as desertification, drought, tornado, and storm. [1-3]. Climate change affects the world negatively. It causes environmental problems such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), which cause climate change. Increasing CO2 causes climate change. The energy sector in Türkiye caused the largest greenhouse gas emissions in 1990 (134 Mt) and 2020 (361 Mt) [4].

Approximately one-third of the world's CO2 production comes from transportation. Emissions to the atmosphere from motor vehicles that consume fossil fuels in transportation cause the greenhouse effect and thus global climate change. More than 95% of the energy consumed for vehicles on a global scale originates from motor vehicles. Globally, roads 70%, airways 12%, seaways 11%, and railroad 2% are the sources of emissions. In 2020, 81 Mt of CO2 was emitted from transportation, and 95% of this emission is due to road transportation and approximately 3% to domestic air transportation [5-6]. For this reason, countries take some precautions against global warming. In this context, contracts and protocols have been signed to reduce greenhouse gas emissions and certain commitments have been requested from countries. Depending on the signed contracts and protocols, some standards have been introduced to regulate the calculation and trade of greenhouse gas emissions. It was stated that carbon footprint calculations should be made and a greenhouse gas inventory should be created by introducing emission quotas to the countries in the agreements and protocols. Determining targets and approaches, global warming, climate change, problems and solutions, carbon footprint calculations, and evaluations have been the main research area for researchers [7-8]. Human activities (transportation, heating, electricity consumption, etc.) cause serious damage to the environment in terms of the amount of greenhouse gas produced, measured in carbon footprint units of CO2. The carbon footprint consists of two main parts, the primary and secondary carbon footprint, and can be calculated individually or institutionally. The primary footprint is direct CO2 emissions from the combustion of fossil fuels, including

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To cite this article: KUMAŞ, K., YILDIRIM, R., AKYÜZ, A. Ö. (2022). Determining the Carbon Footprint of Transportation; The Case of Afyonkarahisar, Türkiye, Techno-Science, vol. 5, no. 2- p. 39-44

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domestic energy consumption and transportation. The secondary footprint represents the amount of CO2 released from the manufacture of all products originating from the life cycle. The secondary carbon footprint includes the primary footprint. The IPCC guide was organized to achieve the greenhouse gas emission targets of the countries, to develop and publish their national inventories, and to enable them to use comparative methodologies in their greenhouse gas emission inventories.

With the approaches proposed in the IPCC, the carbon footprint is calculated in terms of unit carbon dioxide equivalent of the total amount of greenhouse gas emissions [9-11]. The transportation sector is one of the key components of economic growth and is growing rapidly to meet the increasing demand for transportation in both developed and developing countries. This situation poses a problem in many countries in terms of increasing energy consumption and carbon footprint [12-14]. There are many studies in the literature on transport-based greenhouse gas emissions. Sreng et al. (2017) calculated the greenhouse gas emissions of Sakarya University Esentepe Campus in 2015. The greenhouse gas emission amount of the campus has been calculated as 12 330 73 tCO2 [15]. Binboğa and Ünal (2018) calculated the carbon footprint of Manisa Celal Bayar University according to 2016 data. Using the IPCC Tier 1 approach in the calculation, the amount of carbon footprint was determined as 8,953,906 tCO2e [16]. Kumaş et al (2019) calculated the carbon footprint of Burdur Mehmet Akif Ersoy University Bucak Health School. The amount of carbon footprint has been calculated as 217.503 kgCO2e/year [10]. Argun et al. (2019) determined the amount of carbon footprint by using Tier 2 method for the year 2015 in the Selçuklu district of Konya province. It has been determined that the carbon footprint amount that is not included in the industrial emissions is 0.94 million tCO2 [11]. Kumaş et al., (2019) examined the carbon footprint value depending on the type and number of aircraft on flights from Muğla airport. In the calculation made using the Tier calculation method, the amount of carbon footprint was determined as 93 410 75 tCO2 per year [17]. Bıyık and Civelekoğlu (2020) determined the greenhouse gas emissions from transportation in Isparta between 2010-2016 using Tier 1 and Tier 2 methods. It has been reported that there is an increase of 34% in emissions with Tier 1 and 43% in calculation with Tier 2 [7]. Haksevenler et al. (2020) determined the amount of carbon footprint by using different emission sources such as residences and businesses in the Ümraniye district of Istanbul province in 2017. The total amount of carbon footprint is calculated as 2 027 549 tons/year CO2e [18]. Yayili Kılıç et al. (2021) calculated the transportation-related carbon footprint for Çanakkale, covering the years 2015-2018. The amount of carbon footprint was determined as 701.435 GgCO2 for 2015 and 752.536 GgCO2 for 2018 in the Tier 1 approach [8]. Emissions from the transport sector are mainly related to fuels. CO2 in greenhouse gases can be calculated more precisely as it is directly linked to the combustion of fuel. It is necessary to know various factors such as combustion conditions and technology, emission standards, and fuel characteristics. At this stage, concepts of "Tier" come to the fore [19]. In this study, the carbon footprint of road transportation in Afyonkarahisar province between 2017 and 2021 was calculated using the Tier 1 method recommended by the IPCC.

2. MATERIALS AND METHODS

There are many vehicles to be used in the fields of transportation and transportation on highways in Türkiye. To calculate the carbon emissions generated during the use of these vehicles, conversion factors taken from the IPCC guideline and still used in emission calculations were used. In this study, the effect of fossil fuel consumption originating from road transportation on carbon emissions in Afyonkarahisar, Türkiye was investigated. The Tier-1 methodology was used from the published methods. The use of fuel types other than road transport has been neglected. Estimated emissions from road transport are based on two independent data sets, fuel sales and vehicle kilometers [20]. Emissions can be estimated based on the fuel consumed by the vehicles or the distance they have traveled. CO2 emissions are determined by the amount, type, and carbon ratio of fuels [21]. Greenhouse gas emissions are obtained by calculating the emissions from CO2, CH4, and N2O gases separately and adding them after they are converted to CO2 equivalent. Equation 1-4 was used in Tier 1 calculation method [22]. In the study, the consumption amounts of fuel types in Afyonkarahisar were calculated using the data obtained from the Energy Market Regulatory Authority (EMRA) for the years 2017-2021 [23,24]. Accordingly, the consumption amounts of the fuels used in road freight and passenger transportation in the mentioned years are given in Table 2 [25]. When the change in fuel consumption amounts according to years is examined, it is seen that while there is an increase in benzine and LPG fuel types, there is a decrease in diesel fuel. It was the largest consumption amount in LPG and benzine type in 2021 and diesel fuel type in 2017.

$$Energy\ Consumption\ [TJ] = Fuel\ Consumption\ [t] \times 0.001 \times Conversion\ Factor\ [TJ/kt] \quad (1)$$

$$Carbon\ Content\ [Gg\ C] = Carbon\ Emission\ Factor\ [tC\ TJ] \times Energy\ Consumption\ [TJ] \times 0.001 \quad (2)$$

$$Carbon\ Emission\ [Gg\ C] = Carbon\ Content\ [Gg\ C] \times Oxidation\ Rate \quad (3)$$

$$Greenhouse\ Gas\ Emission\ [Gg\ CO2e] = Carbon\ Emission\ [Gg\ C] \times Molecular\ Weight\ Ratio \quad (4)$$

Table 1. Fuel consumption in Afyonkarahisar between 2015-2020 [23,24]

Year	Benzine (t)	Diesel Fuel (t)
2017	18553	317446
2018	18779	236793
2019	19891	223550
2020	20450	292982
2021	26188	269903

Table 2. Emission factors and coefficients for fuel types [25]

Fuel type	Conversion Factor (TJ/Gg)	Carbon Emission Factor (kg/TJ)			Oxidation Rate	Global Warming Coefficient			Molecular Weight Ratio
		CO_2	CH_4	N_2O	CO_2	CO_2	CH_4	N_2O	
Benzine	44.3	18.9	33	3.2	0.99				
Diesel Fuel	43.0	20.2	3.9	3.9	0.99	1	21	310	44/12
LPG	47.3	17.2	62	0.2	0.995				

3. RESULTS AND DISCUSSION

Emissions from the transport sector are directly related to the combustion of fuels. Especially since CO2 is a gas directly associated with the combustion of fuel, it can be calculated much more precisely. The CO2 that comes out as a result of combustion is also an indicator of how efficiently the fuel used is burned [8].
CO2 emissions can be calculated using fuel sales or consumption values. In this study, the amounts of CO2, CH4, and N2O released as a result of benzine, diesel fuel, and LPG fuels consumed from road transportation in Afyonkarahisar province between 2017-2021 were calculated by IPCC Tier 1 method.

The population growth between 2017-2021 led to an increase in private and public vehicles, thus it was observed that the amount of fuel consumed throughout the province increased. The CO2 value was calculated with the help of the global warming potential coefficients, and the amounts of CH4 and N2O gases were determined in terms of CO2e. The CO2e amounts of CH4 and N2O by year are given in Table 3. According to Table 3, the amount of CO2 emissions caused by N2O is higher than the number of emissions created by CH4 for each year. The amount of CO2 emissions from CH4 has approximately the same amount in 2017 and 2020. Although the amount of CO2 emissions from CH4 decreased from 2017 until 2020, it increased in 2020 and beyond. While there was a decrease in the amount of CO2 emissions originating from N2O between 2017-2019 compared to 2017, there was an increase in 2020 and a decrease in 2021.

Table 3. Amount of CO2e by years resulting from CH4 and N2O

	2017	2018	2019	2020	2021
CH_4	5.01	4.94	4.99	5.00	5.21
N_2O	17.48	13.30	12.67	16.29	15.35

The CO2 emission and the CO2e amount of CH4 and N2O gases are given in Figure 1. According to Fig. 1, the excess CO2 emissions emitted by diesel-fueled vehicles for each year are considerably higher than other fuel types. Diesel-fueled vehicles are followed by LPG and benzine vehicles, respectively. It has been observed that CO2 emissions from benzine vehicles have increased at certain rates over the years. The highest increase was realized at 41.15% between 2017-2021. CO2 emissions for LPG-fueled vehicles increased by 8.41% between 2017 and 2019, decreased by 7.21% in 2020 compared to 2019, but increased by 3.37% in 2021 compared to 2020. The evolution of the total emission amount over the years is analyzed, the highest amount of emission occurred (1239.85 Gg CO2) in 2017, and the least emission occurred in 2019 (956.51 Gg CO2). The annual total amount of CO2 emissions tended to decrease between 2017-2019, it increased again in 2020.

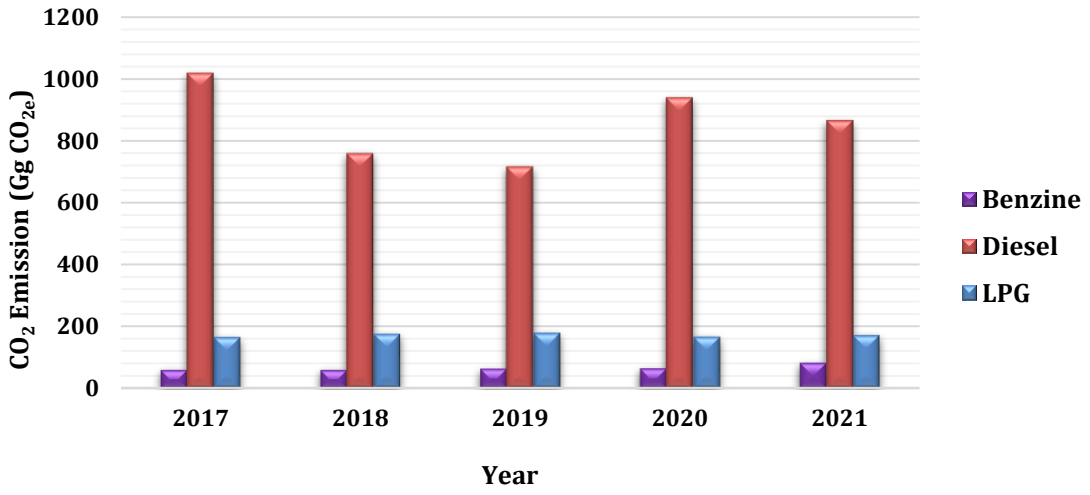

Fig 1. Change of greenhouse gas emissions by years (CO2e) by fuel type

The evolution of the amount of greenhouse gas emissions per capita originating from road transport in Afyonkarahisar province and the population number are given in Table 4. The amount of greenhouse gas emissions per capita was highest in 2017 with 173.2×10-5 Gg CO2, and at least in 2019 with 131.1×10-5 Gg CO2. The greenhouse gas emissions per capita from road transport decreased by 13.3% in total from 2017 to 2021, and there was an increase of approximately 3.39% in the population in the same period.

Table 4. The evolution of the amount of greenhouse gases related to the population over the years

Year	Population	Total Greenhouse Gas Amount (Gg CO_2)	GHG Amount Per Capita (Gg CO_2)
2017	715693	1239.85	173.2×10^{-5}
2018	725568	992.10	136.7×10^{-5}
2019	729483	956.51	131.1×10^{-5}
2020	736912	1168.23	158.6×10^{-5}
2021	744179	1117.60	150.2×10^{-5}

The proportional change in population, total greenhouse gas, and per capita greenhouse gas emissions between years are given in Fig. 2. The change in the total and per capita amount of greenhouse gas occurred the most between 2017, 2018 and 2019, 2020. It is seen that there is a decrease of approximately 20% between 2017-2018 and an increase of approximately 22% in 2019. The years when the change in the total and per capita greenhouse gas amount was the lowest was between 2018-2019 with an average decrease of 3.7%.

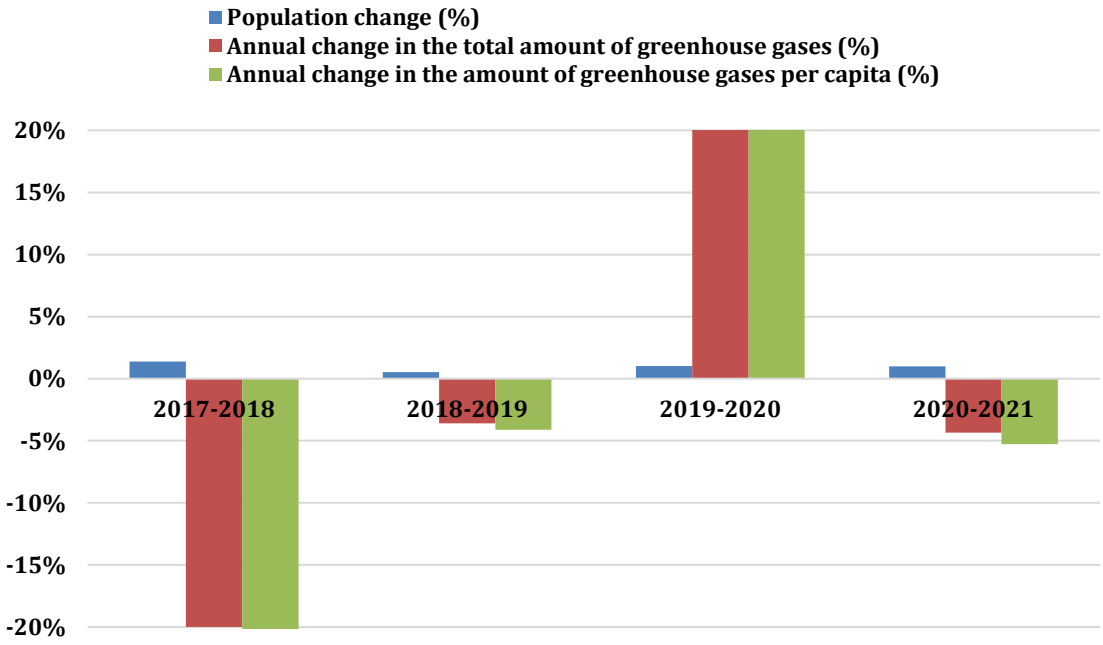

Fig 2. Population number and greenhouse gas emission comparison (CO2e)

4. CONCLUSIONS

Measures to minimize the factors that cause human-induced greenhouse gas emissions due to climate change and its effects on global warming are one of the priority issues of all countries. Greenhouse gas emissions are caused by many different sources and one of these sources is the transportation sector. The intensive use of fuels such as benzine, diesel fuel, and LPG continues to increase emissions. In this study, the carbon footprint of road transportation in Afyonkarahisar, Türkiye between 2017-2021 was calculated using the Tier 1 method recommended by the IPCC. It is seen that the largest consumption share among fuels is in diesel fuel compared to other fuels. As a result of the calculations, it was determined that the highest carbon emission between 2017-2021 was caused by diesel fuel consumption. Diesel-fueled vehicles are followed by LPG and benzine vehicles, respectively. Although the amount of CO2 emissions from CH4 decreased in the period from 2017 to 2020, it increased in 2020 and beyond. While the amount of CO2 emissions from N2O decreased between 2017 and 2019 compared to 2017, it increased in 2020 compared to 2019 and decreased again in 2021. While the highest amount of emissions occurred with 1239.85 Gg CO2 in total emission amount in 2017, the lowest emission amount was 956.51 Gg CO2 in 2019.

In the period between 2017-2021, greenhouse gas emissions per capita decreased by 13.3%, and there was an increase of 3.39% in the population in the same period. The highest decrease and increase in total and per capita greenhouse gas amount occurred between 2017-2018 and 2019-2020, respectively. While the maximum decrease was approximately 20%, the maximum increase was 22%. The years in which the change in the total and per capita greenhouse gas amount was the least occurred between 2018 and 2019 with an average of 3.7% decrease.

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