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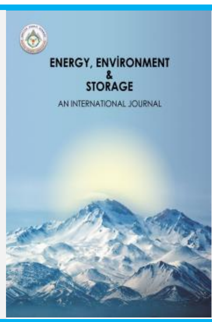

Carbon Footprint and Energy Relationship: Fossil Fuel Vehicles and Electric Vehicles in Turkey

Gürlek F.[1], Özrahat E.[2]*, Ünalan S.[3]

[1] *Erciyes University, Graduate School of Natural and Applied Science, Kayseri, Turkey*

fatihgurlek050@gmail.com

[2]*Kayseri University, Bunyan Vocational School, Bünyan, Kayseri, Turkey*

evrimozrahat@kayseri.edu.tr, ORCID: 0000-0002-6912-9633

[3]*Erciyes University, Faculty of Engineering, Department of Mechanical Engineering, Kayseri, Turkey*

s-unalan@erciyes.edu.tr ORCID: 0000-0002-5605-2614

ABSTRACT. As technology advances today, energy demand is also increasing, with approximately 85% of this demand being met by fossil fuels. The use of fossil fuels leads to the release of greenhouse gases, which are known to be one of the main causes of global warming. Although electrical energy is the most common and easily accessible form of energy, it is not found in nature and must be produced from other energy sources. Renewable energy sources, on the other hand, are not yet sufficient in terms of both cost and meeting energy demand. Therefore, additional taxation is being planned on countries and businesses that use fossil fuels with high greenhouse gas emissions. In this context, the carbon footprint becomes an important parameter for measuring polluting effects. However, calculating the carbon footprint is quite complex, which makes it challenging to ensure fair taxation in energy production and consumption. Thus, it would be fairer to base additional taxation on the amount of greenhouse gases produced per capita in a country. According to calculations, the global average per capita emission of fossil fuel-based greenhouse gases is around 5300 kg. Saudi Arabia and the UAE, as major oil producers, are responsible for producing 15 times this average, while Kuwait is responsible for 23 times the average. The largest energy consumers, such as the United States and Russia, emit three times the average, while Germany, Japan, and China contribute approximately twice the amount. For Turkey, this value is around 1.5 times the global average. Recently, electric vehicles (EVs), which have been promoted as a more environmentally friendly option, have been compared to conventional vehicles under the conditions in Turkey. Since each country has different sources of electricity generation, the goal of EVs producing fewer greenhouse gases is influenced by these factors. The results of calculations specific to Turkey show that while EVs are more environmentally friendly compared to gasoline and diesel vehicles, the situation is more complex and debatable for LPG-powered vehicles.

Keywords: Carbon Footprint, Emission, Electricity, CO_2 , Greenhouse Gas

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1. INTRODUCTION

The growing global population and increasing use of technological products are leading to higher energy consumption. The most consumed forms of energy in social and industrial life are electrical and thermal energy. Especially in the case of electrical energy, there is no area left untouched by it. From personal use to massive factories, a future without electricity is almost unimaginable. The energy sector no longer just influences social and technological life but also plays a role in shaping the political landscape of countries. On the other hand, the biggest drawback of both electrical and thermal energy is that they do not exist naturally on Earth. These types of energy must be produced from existing energy sources on Earth, such as fossil fuels, biofuels, nuclear fuels, wind energy, solar energy, hydropower, and geothermal energy. Today, there is a technological race to convert all available fuels and energy sources into electrical energy. Currently, approximately 85% of the world's primary energy consumption is met by fossil resources. [1]. Fossil fuels, such as oil, coal, lignite, and natural gas, are primarily composed of chemical compounds made up of hydrogen (H) and carbon (C) atoms. To produce electrical or thermal energy from these fuels, they must be burned in the presence of atmospheric air. In the high-temperature combustion chamber, the elements in the fuel and air form various gas compounds, which are then released back into the atmosphere through chimneys or exhaust systems. These harmful gases, known to be detrimental to plant and animal life, are collectively referred to as greenhouse gases. Over time, these gases, such as water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3), and hydrofluorocarbons (HFCs), accumulate in the atmosphere, trapping radiation from the Earth's surface and gradually increasing atmospheric temperatures.

It is known that before the industrial era, about 200 years ago, the concentration of greenhouse gases in the atmosphere was between 200-280 ppm (parts per million), whereas today, this concentration has risen to 400-420 ppm. When this concentration reaches 450 ppm, it is predicted that global temperatures will be 2°C higher than pre-industrial levels, potentially triggering catastrophic climate scenarios. Carbon dioxide (CO_2) is the most produced greenhouse gas, accounting for 82% of all greenhouse gases. Since the Industrial Revolution, the amount of CO_2 in the atmosphere has increased by 31%. Therefore, other greenhouse gases are calculated based on their carbon equivalents. To prevent climate catastrophe, the international system promotes the use of solar, wind, and hydropower—energy sources that produce no greenhouse gases—instead of fossil fuels. It also supports the use of electric vehicles over gasoline, diesel, and LPG-powered cars. Additionally, to reduce the appeal of cheap fossil fuel energy, the international community is imposing additional taxes on countries. One of the parameters for applying these taxes will be the carbon footprint. This term, which expresses the amount of greenhouse gases emitted per unit of energy produced (kg/kJ, kg/kWh, kg/kcal), has become a significant topic of discussion today. Three international conferences have been held at different times to reduce greenhouse gas emissions into the atmosphere, prevent climate change caused by these gases, and establish methods for determining the carbon footprint. The Montreal Protocol was adopted in 1987, following the Vienna Convention in 1985, which aimed to reduce substances that deplete the ozone layer. It came into effect in 1989. The Intergovernmental Panel on Climate Change (IPCC), established through collaboration between the World Meteorological Organization and UNEP, laid the foundation for international discussions on climate change, which later resulted in key conventions and protocols. Greenhouse gas emission calculation methods are divided into various levels, referred to as "Tiers." The difference between these levels is related to the technological details involved. The Tier 1 approach is a basic method with general information limitations, while the Tier 3 approach is more complex and requires specialized knowledge compared to Tier 1. It is possible to differentiate between Tier 1, Tier 2, and Tier 3 approaches, although the more complex Tier 2 and Tier 3 approaches are built on a similar foundation to Tier 1 [2].

The United Nations Framework Convention on Climate Change (UNFCCC) was adopted by 195 countries in June 1992, with the goal of reducing carbon dioxide and other greenhouse gas emissions to 1990 levels by the year 2000. The Kyoto Protocol, signed in 1997, came into force in 2005. For the protocol to become effective, the countries that ratified it needed to account for 55% of global emissions in 1990. This threshold was only reached after eight years, when Russia joined. The Paris Agreement, signed during the 21st Conference of the Parties in 2015, marked a significant turning point in the fight against climate change.

The main goal of the Paris Agreement is to keep the global temperature rise well below 2°C above pre-industrial levels, and if possible, limit the increase to 1.5°C. The European Green Deal is a comprehensive strategy set by the European Union, aiming to reduce carbon emissions by 55% by 2030 and make Europe a carbon-neutral continent by 2050. Its key objectives include eliminating pollution, promoting sustainable industry and production, preserving biodiversity, supporting sustainable transportation, clean energy, and eco-friendly construction.

Despite the outcomes of various international meetings, no clear methodology for calculating greenhouse gas emissions has been established. The Tier-1 approach is relatively simple and can be easily applied based solely on the physical properties of the fuel. However, it does not account for the carbon footprint associated with the production process of the fuel before use, nor the impact after consumption. This is because the processes involved from raw material extraction to the disposal of the product after a certain usage period are highly complex. For example, the carbon footprint of the electricity used in these processes varies significantly across countries.

In one study, the average CO_2 equivalent emissions per kilowatt-hour ($kgCO_2/kWh$) of electricity in the 27 EU countries was calculated as 0.2883 $kgCO_2/kWh$. However, this value was 0,0456 $kgCO_2/kWh$ for Sweden and 1,0595 $kgCO_2/kWh$ for Poland, highlighting the variation in carbon footprints depending on the energy mix of each country [3]. According to data shared by Turkey's Ministry of Energy and Natural Resources, 0.439 kg of CO_2 equivalent greenhouse gas emissions are released for every 1 kWh of electricity produced in Turkey [4]. These values indicate that the same products produced in different countries will result in varying greenhouse gas emissions. A study conducted in different U.S. states shows that in two states, the use of electric vehicles (EVs) causes more pollution than conventional vehicles. In about 15 states, EVs and conventional vehicles have almost the same potential for greenhouse gas emissions. This suggests that it is not easy to claim that EVs are environmentally friendly across all states within a single country, as their impact varies based on the local energy mix [5]. A detailed analysis has been conducted on the greenhouse gas emissions of electric light trucks that will be launched in China in 2025. This analysis includes factors such as electric carbon intensity, vehicle technical performance, temperature-capacity balancing coefficient, battery degradation coefficient, energy consumption per unit load, and battery system energy density. The results, covering 31 provinces of China, reveal that the situation is particularly critical for northern provinces with colder temperatures. The findings indicate that with long-term use of the battery and mechanical components, this problem is likely to worsen, highlighting the impact of colder climates on the efficiency and environmental performance of electric vehicles [6]. When adding the complexity of differences in energy production sources and the long lifecycle of a product—from raw material extraction to disposal—reaching a consensus on carbon footprint analyses becomes extremely difficult. The variability in energy mixes, production processes, and disposal methods across different regions makes it challenging to establish a uniform standard for accurately calculating and comparing carbon footprints. This complexity underscores the need for more localized and detailed methodologies to assess the environmental impact of products throughout their entire lifecycle.

Product-based studies have also been conducted to determine carbon footprints. The use of electric vehicles (EVs) is encouraged for a cleaner environment, with the battery being a crucial component of EVs. During the production phase of batteries manufactured for EVs, approximately 60 to 100 kg of CO_2 equivalent greenhouse gas emissions are generated per kWh. This highlights the significant environmental impact associated with battery production, which is an important factor to consider when assessing the overall sustainability of electric vehicles [7]. According to a study conducted in China, which is the largest producer of batteries, the range of greenhouse gas emissions associated with battery production is between 114.3 kg CO_2/kWh and 137.0 kg CO_2/kWh. This indicates that the environmental impact of battery manufacturing is even higher than previously mentioned values, underscoring the importance of addressing emissions in the battery production process to enhance the overall sustainability of electric vehicles [8]. In this context, when considering the hundreds of other components used in the production of an electric vehicle (EV), each sourced from different countries, it becomes very challenging to draw definitive conclusions about the greenhouse gas emissions and carbon footprint of an EV. As can be seen, discussions and confusion regarding how to accurately calculate the carbon footprint are ongoing, and it is unlikely that these debates will be resolved in the near future. Thus, implementing taxation based on unreliable carbon footprint values would not be appropriate. Establishing a control mechanism for accurate carbon footprint assessment through government or international systems appears to be a daunting task. Relying on the declarations of governments and companies may not be trustworthy. Therefore, it has been proposed that a more logical and equitable approach would be to impose additional taxes based on the amount of greenhouse gases produced per capita, starting from the very beginning of the energy production process, acknowledging that the polluted atmosphere should be considered a shared resource for all people. By making high greenhouse gas-emitting energy production more expensive from the outset, the preference for costlier energy sources among firms and individuals can be discouraged. This approach aims to prevent the exploitation of inexpensive energy production that generates high greenhouse gas emissions while providing significant economic benefits. Through additional taxes within the country and increased customs duties on imported goods, governments can protect their citizens. In this regard, the per capita greenhouse gas emissions are seen as a fair reference or criterion for determining these additional taxes.

This study will evaluate the efforts made to determine the carbon footprint and focus on the relationship between energy and carbon footprint. In addition to carbon footprint analyses for both the world and Turkey, the study will also examine per capita greenhouse gas production values. A comparison will be made regarding the performance of electric vehicles (EVs) in Turkey in terms of their lower greenhouse gas emissions, highlighting the potential benefits of promoting EV usage for pollution reduction.

2. FOSSIL FUELS, ENERGY, AND CARBON FOOTPRINT ANALYSIS

2.1 Analysis of Greenhouse Gases from Fossil Fuels

As previously stated, 85% of the world's primary energy consumption is derived from fossil fuels, which leads to significant greenhouse gas emissions. Understanding the distribution of these emissions at both global and national levels is crucial for fair taxation. It would be unrealistic to claim that all countries play an equal role in greenhouse gas emissions. If we consider the polluted atmosphere as a common asset of humanity, it would be more logical to impose responsibilities based on per capita pollution levels. To begin the analysis on a global scale, it is essential to understand the fossil fuel consumption values worldwide. Below are the analyses for oil, coal, and natural gas.

Crude oil extracted from the ground is used in energy consumption as gasoline, diesel, and LPG after undergoing refinery processing. Therefore, the carbon footprint calculations for petroleum can be conducted using the Tier-1 approach based on the products derived from oil, specifically gasoline, diesel, and LPG. To carry out these calculations, it is essential to know the proportions of the products generated from crude oil. This information allows for the calculation of annual or daily gasoline, diesel, and gas quantities based on the amounts of oil produced or consumed by countries. In 2022, global oil production reached 93.8 million barrels per day (v/d), while consumption was recorded at approximately 94.4 million barrels per day. Natural gas production was 4.04 trillion cubic meters, with consumption at 3.94 trillion cubic meters, global coal production was reported at 7.9 billion tons. Additionally, global lignite production reached 638.5 million tons in 2020 [9]. Consumption also occurred at similar levels.

The distribution of products derived from petroleum varies regionally and according to the quality of the oil. For a simple analysis, it suffices to reference the United States, one of the largest fossil energy-consuming countries. According to refinery data in the U.S., the refining and processing of crude oil results in a volumetric average yield of approximately 43% gasoline, 18% fuel oil and diesel, 11% LPG (liquefied petroleum gas, propane, or a propane-butane mixture), 9% jet fuel, 5% asphalt, and 14% other products. One barrel of oil is equivalent to 159.5 liters and 42 gallons in everyday measurements. One gallon corresponds to 3.78541 liters. Using this data and the Tier-1 approach, greenhouse gas emissions from petroleum can be calculated simply. The necessary physical properties and coefficients for the calculations are provided in Table-1. For simplicity, jet fuel has been classified under gasoline in these calculations.

Table.1 Physical Properties of Fuels Tier-1 Coefficients

Fuel	Density [kg/m^3]	Conversion Factor [TJ/t] (IPCC, 2006)	Emission Factor [kg/TJ] (IPCC, 2006)
Gasoline	747	0.0443	69300
Diesel	830	0.0430	74100
LPG	550	0.0473	63100
Natural Gas	0.687	0.0442	64200

Based on this data, the quantities of gasoline, diesel, and LPG produced from crude oil extracted globally in a year can be approximately calculated as follows:

$$m_{\text{gasoline}} = 93.8x10^6x365x0.52x42x3.78541x10^{-15}x747 = 2.114 \ \ billion \ \ tons$$

$$m_{diesel} = 93.8x10^6x365x0.18x42x3.78541x10^{-15}x830 = 0.813 \ \ billion \ \ tons$$

$$m_{LPG} = 93.8x10^6x365x0.11x42x3.78541x10^{-15}x550 = 0.329 \ \ billion \ \ tons$$

Based on these values, the greenhouse gas emissions released into the atmosphere will be calculated as follows using Tier-1 coefficients:

$$Gasoline, \quad m_{CO_2} = 0.0443x2.114x69300 = 6489.96 \ \ billion \ \ kg$$

$$Diesel, \quad m_{CO_2} = 0.0430x0.813x74100 = 2590.46 \ \ billion \ \ kg$$

$$LPG, \quad m_{CO_2} = 0.04730x0.329x63100 = 981.94 \ \ billion \ \ kg$$

$$Petroleum, \quad m_{CO_2} = 6489.96 + 2590.46 + 981.94 = 10062.36 \ \ billion \ \ kg$$

Assuming a world population of 8 billion, it will be observed that the amount of greenhouse gases released into the atmosphere per capita from oil production is approximately 1257.8 kg or 1.257 tons over the course of a year. Similar calculations can be made for the greenhouse gas emissions released from the natural gas produced in the world as follows:

$$Natural \ \ gas, \quad m_{CO_2} = 0.0442x4.04x10^9x0.687x64200 = 7875.81 \ \ milyar \ \ kg$$

According to this result, 984.26 kg of greenhouse gases are emitted per person per year from natural gas.

Calculations for coal and lignite (brown coal) extracted from underground will be somewhat more challenging. There are not significant differences in the chemical and physical properties of oil extracted from different geographies. For example, a typical bituminous coal may have a final analysis of 84.4% carbon, 5.4% hydrogen, 6.7% oxygen, 1.7% nitrogen, and 1.8% sulfur on a dry, ash-free weight basis. [10]. In lignite, the carbon content can drop to around 25%. On average, the carbon content in lignite can be estimated at about 35%. As the carbon content in lignite decreases, the amount of ash produced increases. The hydrogen (H) present in coal converts to water during combustion and is released into the atmosphere as vapor. As the temperature of the water vapor drops, it condenses and falls to the ground. Therefore, in greenhouse gas analyses, the presence of hydrogen in coal can be disregarded, focusing solely on the carbon content. Assuming that all carbon is combusted, the resulting greenhouse gas emissions can be calculated as follows.

$$m_{CO_2} = \frac{44}{12}xCoal \ \ QuantityxCarbon \ \ Percentage$$

$$Coal, \quad m_{CO_2} = \frac{44}{12}x7.9x0,84 = 24332 \ \ billion \ \ kg$$

$$Lignite, \quad m_{CO_2} = \frac{44}{12}x638.5x0.35 = 819.41 \ \ million \ \ ton$$

These calculations indicate that approximately 3041.35 kg of greenhouse gases are produced per person annually from coal and lignite. Therefore, the total annual greenhouse gas emissions per person from fossil fuels worldwide can be summarized as follows;

$$Per \ \ person, \quad m_{CO_2} = 1257.8 + 984.26 + 3041.35 = 5283.41 \ \ \text{kg/yr}$$

This average value can be validated with real-world data. We can assume that a family uses approximately 100 liters or 75 kg of gasoline in a month, consumes 500 kWh of electricity per month, and utilizes 3,000 m³ of natural gas equivalent to 0.1 TJ in a year. In this case, the family's contribution to greenhouse gas emissions can be simply calculated on an annual basis as follows.

$$Family, \quad m_{CO_2} = 12x0.075 \ \ tx0.0443\frac{\text{TJ}}{\text{t}}x69300\frac{\text{Kg}}{\text{TJ}} + 0.1 \ \ TJx64200\frac{\text{Kg}}{\text{TJ}} + 12.500 \ \ kWhx0.439 \ \ \frac{kgCO_2}{kWh} = 2763 + 6420 + 2634 = 11818 \ \ kg$$

Assuming the family consists of 3 or 4 people, it can be stated that approximately 3000 kg of greenhouse gases are produced per person from social activities. Given that the world average is around 5300 kg, the difference of 2300 kg would reflect the contributions from society, industry, and other activities of the state. As a result, considering the annual amount of greenhouse gases produced from fossil resources globally at 5300 kg per person is largely accurate. Both consumer and producer countries should be held responsible for the pollution of the atmosphere with greenhouse gases from fossil fuels. The prosperity level provided by the export of fossil resources must come at the cost of greenhouse gas emissions. Therefore, an analysis of the contributions to greenhouse gas production from the production potentials of certain OPEC countries and Turkey, which are the largest fossil fuel producers, has been conducted. The tables below show the quantities produced, populations, and calculated greenhouse gas amounts.

Table.2 Fossil Fuel Exporting Countries' CO_2 Greenhouse Gas Production [Billion Kg]

Country	Petroleum	Coal	Lignite	Natural Gas
World	10062.36	24332	819.41	7875.81
Russia	1941.47	1225.46	0.01	1403.61
India	112.08	2340.08	0.05	116.42
Australia	35.60	226.99	0.05	233.93
USA	2366.84	1493.34	0.06	2144.40
Canada	1025.61	254.02	0	487.35
Saudi Arabia	2371.75	0	0	311.91
Chinese	829.54	18204.89	509.53	0.27
Iraq	908.73	0	47,33	0
United Arab Emirates	595.76	0	144.79	0
Iranian	750.36	4.23	576.36	0
Kuwait	531.66	0	47.33	0
Brazil	595.76	29.64	144.79	0
Türkiye	14.91	10.1	1.57	0.09

Country	Population [Billion]	Total Emission [Billion Kg]	Emission per capita [kg]
World	8000	43089.58	5386
Russia	0.144	4570.5576	31739
India	1.42	2568.637	1808
Australia	0.026	496.57733	19099
USA	0.334	6004.6493	17977
Canada	0.039	1766.9945	45307
Saudi Arabia	0.037	2683.6695	72531
Chinese	1,409	19544.233	13870
Iraq	0.043	956.06272	22234
United Arab Emirates	0.01	740.55915	74055
Iranian	0,089	1330,9536	14954
Kuwait	0.005	578.99853	115799
Brazil	0.205	770.19915	3757
Türkiye	0.089	26.670595	299

As seen in the table above, the amount of greenhouse gases produced from fossil fuels globally is around 5.400 kg per person per year. For Australia, which has a low population and lacks significant political weight on the world stage, this value rises to 19.099 kg. For OPEC countries, which rely solely on underground oil and have a total population of approximately 442 million, the value is around 9.750 kg. Saudi Arabia and the UAE produce greenhouse gases at levels 15 times higher than the average, while Kuwait's production is 23 times the average. Even indirectly, these countries contribute significantly to greenhouse gas production, well above the average. In contrast, countries that govern the world today, such as the USA and Russia, show values that are far above the average. India, which is rich in coal but lacks oil, has shown below-average trends. Despite its high population, China has had an impact that is more than double the average. For Turkey, which is particularly poor in oil and natural gas, the per capita value is quite low.

The main responsible countries for greenhouse gas emissions are the developed countries that consume the most fossil energy. The results calculated for the G7 countries, Turkey, and the total world regarding the highest thermal and electrical energy production are presented in the table below.

Table-3. Greenhouse Gas CO2 Production of Fossil Fuel Importing Countries [Billion Kg]

Country	Petroleum	Coal	Lignite	Natural Gas
World	10437.4	23339.2	820.0	7695.7
Russia	558.1	692.7	91.0	751.9
Germany	373.2	526.5	133.0	136.7
India	927.6	2918.9	45.0	126.9
Chinese	2982.0	11780.4	173.0	781.3
USA	3548.0	1681.2	54.0	175.8
England	232.6	21.1	0.0	223.2
France	188.2	12,7	0,0	111.5
Japan	621.2	296.0	17.0	245.5
Türkiye	135.7	372.0	88.0	117.2

Country	Population [Billion]	Total Emission [Billion Kg]	Emission per capita [kg]
World	8000	42292.3	5286
Russia	0.144	2093.7	14539
Germany	0.84	1169.4	1392
India	1.4	4018.4	2870
Chinese	1.43	15716.7	10990
USA	0.334	5459.0	16344
England	0.069	476.9	6911
France	0.068	312.5	4595
Japan	0.124	1179.7	9513
Türkiye	0.089	712.9	8009

It should be considered normal for the world average calculated based on consumption to fall below production values. In addition to the use of all produced fossil fuels, their storage is also a factor. According to the results in the table above, the per capita greenhouse gas emissions of the countries that consume the most energy are well above the world average. The countries in the table are the leading nations that influence world politics, with only two countries falling below the average. India, being a developing country with a very large population, has fallen significantly below the world average. France, on the other hand, has a lower average because it obtains about 70% of its electricity from nuclear power plants, resulting in less fossil fuel consumption.

China has demonstrated its status as a superpower by producing more than twice the average greenhouse gas emissions. Considering China's very high coal consumption, this result should be seen as normal. The superpowers of the world, namely the USA and Russia, have produced three times the average amount of greenhouse gases. Germany and Japan, as major world economies, have also contributed approximately twice the average amount of greenhouse gases. Despite making significant investments in renewable energy, Germany still ranks among the top three due to its high coal usage and a relatively small population for its economy. Japan, using less coal but having a larger population, has ranked below Germany.

Turkey, as a developing country, has performed slightly above the average. This poor performance is influenced by the high usage of lignite and coal, as well as its ongoing efforts in achieving efficient energy use. Consequently, it would be fair for countries that contribute to greenhouse gas production, from both production and consumption perspectives, to pay a higher cost in terms of carbon taxation. It would not be equitable for end users with a higher carbon footprint to bear the brunt of increased taxes.

2.2 Greenhouse Gas Analysis of Electric Vehicles for Turkey

One of the proposed solutions for environmental sensitivity today is Electric Vehicles (EVs). Traditional vehicles that use internal combustion gasoline and diesel engines have a significant negative impact on urban air quality due to the greenhouse gases emitted from their exhaust systems. Therefore, efforts are being made to mitigate this effect with EVs. However, these EVs are still powered by the city grid, and the use of fossil fuels for electricity generation indirectly contributes to greenhouse gas emissions for these vehicles.

It is also important to mention a detail regarding the production phase of electric vehicles. The production of electric vehicles results in a higher amount of greenhouse gas emissions due to their batteries. According to research conducted by a consulting firm named Ricardo, the average CO_2 emissions during the production phase of gasoline vehicles is about 5.6 tons, while this value is 8.8 tons for EVs. Half of the 8.8 tons of CO_2 emitted occurs during battery production. In other words, there is a difference of 3.2 tons of CO_2 equivalent greenhouse gas emissions between the production of the two types of vehicles [11].

In Turkey, the greenhouse gas burden of electricity produced is reported as 0.439 $kgCO_2/kWh$. This value is higher than the EU average. Therefore, while the use of EVs is a suitable choice for a cleaner environment in Sweden, the situation is debatable for Poland and Turkey. How much greenhouse gas emissions do vehicles used in Turkey produce? The answer to this question cannot be provided very accurately based on the catalog values given by companies under ideal conditions. The fuel consumption is traditionally defined as the liters of fuel consumed per 100 km of travel. A vehicle's fuel consumption can vary significantly depending on the age of the vehicle, the technology of the vehicle and engine, the driver's usage, and the weather and road conditions.

In the calculations below, the amounts of greenhouse gas emissions generated by different fuels for every 100 km have been calculated for reference. It is assumed that the consumption of gasoline, diesel, and LPG is 5 liters (= 0.005 m^3) per 100 km. According to online research, an EV (Togg V2 RWD Long Range) consumes 16.9 kWh of electricity per 100 km. However, this value is not definitive and can vary depending on the manufacturer and the condition of the vehicle. The calculations of the amounts of greenhouse gases produced by fuels used in internal combustion engines over 100 km are presented in Tables 4, 5, and 6.

$$\text{Fuel Consumption} = \text{Density} * \text{Fuel Volume}$$

$$\text{Energy Consumption} = \text{Fuel Consumption} * \text{Conversion Factor}$$

$$CO_2 \ Emission = \text{Energy Consumption} * Emission \ Factor$$

$$Carbon \ Footprint = \frac{CO_2 \ Emission}{Energy \ Consumption}$$

Table.4 The Amount of Greenhouse Gas Produced by Gasoline per 100 km and Carbon Footprint

Density	747 kg/m^3 0.747 t/m^3
Conversion Factor (IPCC, 2006)	44.30 TJ/Gg 0.0443 TJ/t
Fuel Consumption per 100 km	0,003735 t
Energy Consumption	0.00016546 TJ 45.96 kWh
CO_2 Emission Factor (IPCC, 2006)	69300 Kg/TJ
CO_2 Emission	11.47 kg
Carbon Footprint	0.249 $kgCO_2/kWh$

Table.5 The Amount of Greenhouse Gas Produced by Diesel per 100 km and Carbon Footprint

Density	830 kg/m^3 0,830 t/m^3
Conversion Factor (IPCC, 2006)	43.00 TJ/Gg 0.0430 TJ/t
Fuel Consumption per 100 km	0.00415 t

Energy Consumption	0.00017845 TJ 49.57 kWh
CO_2 Emission Factor (IPCC, 2006)	74100 Kg/TJ
CO_2 Emission	13.223 kg
Carbon Footprint	0.266 $kgCO_2/kWh$

Table.6 The Amount of Greenhouse Gas Produced by LPG per 100 km and Carbon Footprint

Density	550 kg/m^3 0.550 t/ m^3
Conversion Factor (IPCC, 2006)	47.30 TJ/Gg 0.04730 TJ/t
Fuel Consumption per 100 km	0.00275 t
Energy Consumption per 100 km	0.00013075 TJ 36.32 kWh
LPG CO_2 Emission Factor(IPCC, 2006)	63100.00 Kg/TJ
CO_2 Emission	8.21 kg
Carbon Footprint	0.226 $kgCO_2/kWh$

Table.7 Amount of Greenhouse Gas Produced and Carbon Footprint per 100 km for EV

Carbon Footprint of Electricity	0.439 $kgCO_2$/ kWh
Electricity Consumption per 100 km	16.9 kWh
CO_2 Emission	7.42 kg
Carbon Footprint	0.439 $kgCO_2$/ kWh

According to the calculations above in Table 7, electric vehicles (EVs) provide the least emissions for every 100 km distance in Turkey. Diesel vehicles have the highest emissions. If conventional vehicles consume 5 liters of fossil fuel per 100 km, they will produce an average of 8 to 13.5 kg of CO_2 emissions. For a conventional vehicle to cause emissions equivalent to an EV over its lifespan, it would need to consume less than 5 liters per 100 km. Unfortunately, under current technological conditions, especially for gasoline and diesel vehicles, this is not feasible. For gasoline, diesel, and LPG to have emissions equivalent to EVs, their consumption values would need to be 3.25 liters, 2.81 liters, and 4.5 liters, respectively.

This simple analysis indicates that EVs and LPG vehicles, which produce more greenhouse gases during manufacturing, may have an intriguing dynamic. In other words, if LPG vehicles can meet the 5 liters/100 km target, they could cause lower greenhouse gas emissions than electric vehicles. In such a case, the only advantage of EVs would be overcoming the difficulty of controlling greenhouse gases from mobile systems. Since electricity is produced in fixed centers far from cities, this would mean that EVs contribute positively to urban pollution.

The simple and ideal analyses provided above may not be sufficient for decision-making. It is essential to determine the actual values. Achieving completely accurate values is often not possible; however, it may be feasible to get close to the truth. To obtain results that are close to reality, it is necessary to know the number of vehicles and the amount of fuel consumed in Turkey. In 2023, Turkey had sales of 5454312.3 m^3 (4074371.35 tons) of gasoline, 31344927.31 m^3 (26016289.67 tons) of diesel fuel, and 3519265 tons of autogas LPG **[**12**]**. The emission values resulting from the combustion of these sold fuels over a year have been calculated using the Tier-1 approach and are presented in Tables 8, 9, and 10.

Table.8 The Amount of Greenhouse Gas Produced from Gasoline in a Year in Turkey and Carbon Footprint

Density	747 kg/m^3 = 0.747 t/ m^3
Conversion Factor (IPCC, 2006)	44.30 TJ/Gg = 0.0443 TJ/t
Fuel Consumption in 1 Year	4074371.35 t
Energy Consumption in 1 Year	180494.65 TJ = 50137402777.77 kWh
Gasoline CO2 Emission Factor	69300.00 Kg/TJ = 69.3 t/TJ
CO_2 Emission	12508279.3 t
Carbon Footprint	0.249 $kgCO_2/kWh$

Table.9 The Amount of Greenhouse Gas Produced from Diesel in Turkey in a Year and Carbon Footprint

Density	830 kg/m^3 = 0.830 t/ m^3
Conversion Factor (IPCC, 2006)	43.00 TJ/Gg = 0.043 TJ/t
Fuel Consumption in 1 Year	26016289.67 t
Energy Consumption in 1 Year	1118700.5 TJ = 310750138888.88 kWh
Diesel CO2 Emission Factor	74100.00 Kg/TJ = 74.1 t/TJ
CO_2 Emission	82895707 t
Carbon Footprint	0.266 $kgCO_2/kWh$

Tablo.10 The Amount of Greenhouse Gas Produced from LPG in Turkey in a Year and Carbon Footprint

Density	550 kg/m^3 = 0.550 t/ m^3
Conversion Factor (IPCC, 2006)	47.30 TJ/Gg = 0.0473 TJ/t
Fuel Consumption in 1 Year	3.519.265 t
Energy Consumption in 1 Year	166.461 TJ = 46239166666.6 kWh
LPG CO2 Emission Factor	63100.00 Kg/TJ = 63.1 t/TJ
CO_2 Emission	10503689.1 t
Carbon Footprint	0.227 $kgCO_2/kWh$

The values presented in the tables above reflect Turkey's annual fuel consumption by various vehicles. According to the initial results, a significant portion of greenhouse gases originates from diesel vehicles. Diesel fuel is primarily used by heavy-duty vehicles and generators. Therefore, to achieve lower greenhouse gas emissions, it is essential to produce not only passenger cars but also heavy vehicles in electric versions.

To obtain more accurate results from the data above, it is necessary to know the number of vehicles for estimating their greenhouse gas production potential. According to 2023 data, there are 28,951,792 registered vehicles in traffic. Of these vehicles, 15,723,762 are cars and minibuses, while 5,657,777 consist of trucks, buses, and construction machinery [13]. All heavy-duty vehicles consume diesel fuel. Cars and minibuses, on the other hand, can consume all three types of fuel. One of the effective parameters in fuel consumption is vehicle mass. There is not a significant difference in mass values between cars and minibuses. Therefore, it is necessary to classify the vehicles according to their fuel types within the categories of cars and minibuses.

As of the end of 2023, the number of gasoline vehicles registered in Turkey is 4,362,975, the number of diesel vehicles is 5,425,652, and the number of vehicles using LPG is 5,094,751. The number of electric vehicles has been determined to be 80,043 [12]. According to traffic records, it can be assumed that 502,628 minibuses use diesel fuel, and they can be included among diesel cars. If a diesel vehicle at the car level is used for commercial purposes, it is normal to cover an annual distance of 30,000 km. Assuming it consumes 8 liters of diesel per 100 km, the annual consumption per vehicle would be 2400 liters of diesel. This means approximately 2 tons of diesel fuel used annually. About 5.5 million diesel cars consuming 11 million tons of diesel fuel annually implies that only a small portion of the total 26 million tons of diesel consumption is used by cars. Therefore, it would be highly inaccurate to assume that almost all of the diesel released into the market in Turkey is used by cars and minibuses. It is essential to remember that diesel fuel is also used by generators alongside cars and heavy-duty vehicles. Considering the number of vehicles and the fuel consumed, matching gasoline and LPG with cars would be logical. Table 11 shows the amount of greenhouse gases released into the atmosphere in Turkey for gasoline and LPG vehicles over one year.

Tablo.11 Emission Amount Per Gasoline and LPG Vehicle

Gasoline CO_2 Emission Amount [t]	12,508,279.3
Number of Gasoline Vehicles	4,362,975
Emission Amount per Gasoline Vehicle [kg]	2866,91
LPG CO_2 Emission Amount [t]	10,503,689.10
Number of LPG Vehicles	5.094.751
Emission Amount Per LPG Vehicle [kg]	2061.66

According to the given vehicle numbers, the previously calculated CO_2 emission of 12,508,279.3 tons of gasoline would result in an average of 2,866.9 kg per vehicle. Taking as a reference the CO_2 emission of 11.47 kg generated by consuming 5 liters of gasoline per 100 km, this indicates an annual usage of 24,994.76 km (= 2866,9 / 11.47 * 100). This number, suggesting approximately 25,000 km of annual usage, is considered high for a vehicle that is not used for commercial purposes. Vehicles used for commercial activities can cover much greater distances in a year and generally use diesel fuel. The typical annual distance covered is around 15,000 km. Considering that gasoline commercial vehicles are not frequently used and diesel vehicles are generally preferred, the following scenario arises: the vehicle may have consumed more than 5 liters of gasoline per 100 km, indicating higher fuel consumption per kilometer. Thus, for a normal annual distance of 15,000 km, the consumption per 100 km would be around 8.3 liters (= 24,994.76 / 15,000 * 5). Based on this result, it is very reasonable to claim that using electric vehicles (EVs) instead of gasoline vehicles will contribute to a lower carbon footprint in Turkey.

This value indicates that the CO_2 greenhouse gas emission previously calculated for gasoline at a consumption of 5 liters per 100 km (11.47 kg) would now be 19 kg (= 8.3 / 5 * 11.47). However, it should not be forgotten that more greenhouse gases are produced during the manufacturing of EVs. In this case, there would be approximately 11.5 kg of additional greenhouse gas emissions for every 100 km between EVs and conventional vehicles. According to reference 14, there is an excess greenhouse gas emission of 3.2 tons in the production of electric vehicles. Therefore, EVs could result in less greenhouse gas production compared to gasoline vehicles after approximately 28,000 km (= 3200 / 11.5 * 100) of usage. This distance corresponds to about 2 years of usage. In other words, after two years of use, an electric vehicle would cause lower greenhouse gas emissions.

When we conduct the same analysis for LPG, the previously calculated greenhouse gas emission of 10,503,689.10 tons would equate to approximately 2,061.66 kg per vehicle. Taking as a reference the CO_2 emission of 8.25 kg generated by consuming 5 liters of LPG per 100 km, this indicates an annual usage of 24,990 km (= 2061.66 / 8.25 * 100). LPG is widely used in Turkey because it is cheaper in vehicles. It is especially a preferred option in older and heavily used vehicles. Therefore, an annual usage of 20,000 km for LPG vehicles should be considered normal.

In this scenario, the fuel consumption would be around 6.25 liters per 100 km (= 24,990 / 20,000 * 5). This value corresponds to a CO_2 emission value of 10.3 kg per 100 km for LPG vehicles. As a result, LPG vehicles would produce approximately 3 kg more greenhouse gas emissions per 100 km than electric vehicles (EVs). According to reference 28, considering the 3.2 tons of excess greenhouse gas emissions in vehicle production, after approximately 106,600 km (= 3200 / 3 * 100) of usage, LPG and EVs would contribute equally to pollution. This distance corresponds to about 5-6 years of usage.

In today's electric vehicles, Li-ion batteries with capacities generally ranging from 10 to 90 kWh are preferred, and it is expected that future generations of electric vehicles will predominantly utilize these types of batteries [14]. Although the lifespan of these batteries can vary depending on usage conditions, we can generally assume a lifespan of 5 to 10 years. These values indicate a value that would be higher than the previously mentioned 3,200 kg in Reference 14. Considering that China is the largest battery producer, it would be difficult to make optimistic statements about electric vehicles (EVs). If we take a good-faith approach and assume that a lithium-ion battery produces 40-90 kg of CO_2 per kWh, a 90 kWh battery would mean producing between 3,600 and 8,100 kg of CO_2. If we consider 8,100 kg as a reference, the point at which a gasoline vehicle would match an EV in terms of emissions would extend to 5 years. For LPG, this point would exceed 10 years. Assuming a battery lifespan of 10 years, this would imply that over a 30-year usage period, three battery replacements would occur. Each battery would result in only 5 years less greenhouse gas emissions when compared to gasoline vehicles. For LPG vehicles, claiming that EVs are cleaner would be challenging. To achieve lower greenhouse gas emissions, the battery's lifespan would need to be well above 10 years. In conclusion, the analyses indicate that recommending the use of electric vehicles for a cleaner environment is appropriate for gasoline and diesel vehicles in Turkey, while the situation is more contentious for LPG vehicles.

3. DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

With the developing technology of today, there has been a high demand for energy. This energy is largely supplied by fossil fuels. Approximately 85% of the primary energy consumption used today comes from fossil sources. The combustion of fossil fuels releases significant amounts of greenhouse gas compounds, namely water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ozone (O_3), and hydrofluorocarbons (HFC), into the atmosphere. These compounds create a greenhouse effect in our atmosphere and contribute to global warming. Generally, electricity is the easiest type of energy to use. However, its main drawback is that it does not exist naturally in the environment. Therefore, it is produced from other energy sources found on Earth. However, under current conditions, renewable energy sources are not in a good position in terms of cost and their ability to synchronize with energy demand. For this reason, to implement a system based on the use of more expensive renewable energy, an additional tax plan is being prepared, aiming to impose higher taxes on countries and businesses that utilize dirtier sources in terms of greenhouse gas emissions as a deterrent measure. In the developed tax system, a parameter called carbon footprint has been defined as a unit of measure. This parameter aims to measure the carbon equivalent burden of the produced services and technological products, and consequently, the pollution effect it causes. However, literature research has revealed that calculating the carbon footprint of products and services is quite complex. For example, accurately determining the carbon footprint of a car composed of thousands of parts produced in very different countries is nearly impossible. Each country has different electricity production technologies and energy sources it uses. In today’s world, it is not very feasible for a country to produce all parts of a car within its own borders. There is a necessity to import certain parts from other countries. At least, the raw materials required for car parts cannot be fully sourced domestically. As a result, it has been predicted that it will be very difficult for countries and companies that produce and consume energy in today's world to pay a fee based on their carbon footprint. Therefore, it is considered more rational and fair to impose an additional tax based on the amount of greenhouse gas produced per person, acknowledging that polluted air has equal rights for all individuals. This would prevent the burden from being shifted entirely onto consumers by making energy production that produces excessive greenhouse gases more expensive from the outset through state intervention. This will prevent firms and individuals from opting for more expensive energy. In this way, it will be possible to prevent achieving high economic benefits through very cheap energy production that generates high greenhouse gases. States will protect their consumers through additional taxes within the country and additional customs duties on imported products at their borders. The amount of greenhouse gas produced per person will serve as a fair reference for determining these additional taxes.

In the first phase of this study, the contribution of countries that extract and produce fossil fuels to greenhouse gas emissions was investigated. It was calculated that the per capita average of greenhouse gas production from fossil sources, such as oil, natural gas, and coal, is approximately 5,295 kg in a world population of 8 billion. When looking at individual countries, Saudi Arabia and the UAE, which are among the largest oil exporters, contribute to greenhouse gas emissions at 15 times the average, while Kuwait causes emissions at 23 times the average. Additionally, for Australia, which has a low population and lacks significant political weight globally, this value rises to 19,110 kg. In contrast, the situation for Turkey remains significantly below average at 301 kg. These rates should be used as parameters in taxation related to greenhouse gases. If taxation is imposed on produced goods, countries with very low populations will pay less tax.

In the second phase of the analysis, calculations were made for countries that use fossil energy. India, being a developing country with a large population, has a value of 2,804 kg, which is significantly below the world average. France, on the other hand, derives approximately 70% of its electricity from nuclear power plants, leading to lower fossil fuel usage and resulting in a value of 4,596 kg, which is slightly below average. China demonstrates its status as a superpower by producing greenhouse gases at twice the average. Considering China's very high coal consumption, this result can be seen as normal. The superpowers of the world, the USA and Russia, have produced three times the average amount of greenhouse gases. In contrast, our country, with its status as a developing nation, has performed above average with a value of 7,040 kg per capita. It would be more equitable for countries that contribute significantly to greenhouse gas production through both production and consumption to pay a higher carbon tax. It would not be fair for end users to bear a higher tax based on carbon footprints.

One of the proposed solutions brought forward in terms of individual environmental sensitivity today is Electric Vehicles (EVs). These vehicles do not emit greenhouse gases directly during daily use, unlike internal combustion engine vehicles. However, attention must be paid to the sources from which the electricity they use is produced. The greenhouse gas burden associated with electricity is calculated as an average of 0.2883 kg CO_2/kWh in the EU, while it is 0.0456 kg CO_2/kWh for Sweden and 1.0595 kg CO_2/kWh for Poland. In Turkey, the emissions are 0.439 kg CO_2 equivalent per kWh of electricity produced. This value of 0.439 kg CO_2/kWh is higher than the EU average. Therefore, while the use of EVs would be a sound choice for a cleaner environment in Sweden, the situation is debatable for Poland and Turkey.

Assuming that vehicles with internal combustion engines consume 5 liters of fuel every 100 km, gasoline vehicles can emit 11.47 kg, diesel vehicles 13.22 kg, and LPG vehicles 8.21 kg of greenhouse gases. The fuel consumption values for every 100 km will vary significantly due to many parameters. Based on the number of vehicles used in Turkey in 2023 and actual fuel consumption values, analyses indicate that these consumption values are approximately 19 kg for gasoline vehicles and 10.3 kg for LPG vehicles per 100 km. For a domestically produced electric vehicle in Turkey, this calculation is given as 7.42 kg/100 km. It can be said that the assertion that EVs are environmentally friendly is reflected in reality when looking solely at usage data. For an internal combustion engine vehicle to reach the same emission values as EVs, the fuel consumption must be 3.25 liters for gasoline, 2.81 liters for diesel, and 4.5 liters for LPG. Achieving these values will be very challenging for gasoline and diesel vehicles under current technological conditions. However, if LPG vehicles meet the target of 5 liters/100 km, it is highly likely that they will emit less greenhouse gas than electric vehicles and be more environmentally friendly.

There is a particularly interesting situation regarding the comparison between EVs, which cause higher greenhouse gas emissions during the production phase, and LPG vehicles. Analyses conducted based on data from Turkey indicate that gasoline vehicles will become more environmentally friendly after approximately two years of use, while LPG vehicles will do so after five years of use. Today, the lifespan of li-ion batteries used in EVs is at most 10 years, and considering the performance drop over time and uncertainties regarding the amount of greenhouse gas produced during battery manufacturing, it can be said that LPG vehicles could cause nearly the same environmental pollution as EVs. In conclusion, the analyses suggest that advocating for the use of EVs for a cleaner environment is appropriate for gasoline and diesel vehicles in Turkey, while the situation for LPG vehicles remains contentious.

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