The Footprint of Road Transport Emissions: Electric Vehicles and Their Impact on Air Pollution Reduction in Greece †

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Abstract: This work focuses on examining the contribution of passenger cars to CO$_2$, NO$_X$, CO, PM$_{10}$, and NMVOC emissions, as well as the changes in future emissions resulting from the usage of different types of vehicles. Initially, the importance of the road transport sector is discussed, followed by a presentation of data regarding the vehicle fleet. Subsequently, a methodology for forecasting the fleet, and calculating emissions, is introduced. Finally, the results are presented, focusing on the release of gaseous pollutants under different possible scenarios regarding the extent of electric vehicle penetration into the passenger vehicle fleet, for the year 2030.

Keywords: air pollution; road transport; vehicle fleet; electromobility; road transport emissions; emission trends; vehicle registrations

1. Introduction

Road transport is one of the most significant contributors to greenhouse gas (GHG) and air pollutant emissions. It ranks as the second-largest source, across all categories, in the EU–KP, accounting for 21% of the total GHG emissions in 2020 [1]. Additionally, it plays a crucial role in air pollution, contributing 37% of total NO$_X$ emissions, and 9% of PM$_{10}$ emissions in the EU [2]. Although these emissions may not be substantial in absolute terms, they pose a significant risk, due to the direct and widespread exposure faced by people, particularly in densely populated urban areas [3,4]. Vehicle emissions are responsible for approximately 500,000 premature deaths annually [5,6].

Since the 1970s, the European Union has made efforts to restrict vehicle emissions, and reduce greenhouse gases [7,8]. These efforts have involved implementing a series of measures and policies, including the establishment of European emission standards, known as the Euro Emissions Standards. These standards regulate the maximum permissible limits of pollutant emissions from vehicles. Over the years, from Euro 1 to the most recent Euro 6d [9], the standards have become increasingly stringent. This has driven advancements in engine technologies and, subsequently, resulted in a significant decrease in vehicle emissions over the past few decades [10,11].

This study aims to analyze the impact of the vehicle fleet on CO$_2$, NO$_X$, CO, PM$_{10}$, and NMVOC emissions. Specifically, it will provide information on the vehicle fleet, categorized by type (passenger, LDVs, etc.) and characteristics (gasoline, diesel, average age, etc.), for the period 1990–2020. Additionally, it will examine the emissions of CO$_2$, NO$_X$, CO, PM$_{10}$, and NMVOC from the road transport sector during the same period. Furthermore, it will investigate the changes in these emissions resulting from the penetration of electric vehicles by the year 2030.
2. Materials and Methods

2.1. Fleet Registration 1990–2020

The data on the vehicle fleet were collected through online research, and by contacting official agencies. The Hellenic Statistical Authority (ELSTAT) [12], the European Automobile Manufacturers Association (ACEA) [13–17], and the COPERT database of EMISIA [18] were utilized for data collection. There has been a substantial increase in the vehicle fleet, both in overall numbers, and within individual categories. In 2020, the total number of vehicles, including cars and motorcycles, reached 8,530,050, which represents a remarkable 173.1% increase compared to 1990 (see Figure 1). Among these vehicles, passenger cars account for 64.4%, motorcycles for 19.2%, trucks (including HDVs and LDVs) for 16.1%, and buses for a mere 0.3% (26,539 vehicles) of the total fleet in the same year (see Figure 2).

![Figure 1. Fleet time series by category in Greece, 1990–2020.](image1)

![Figure 2. Vehicles in use per type, Greece, 2020.](image2)

Passenger cars constitute the largest category of vehicles, which means that their characteristics are crucial to addressing emissions from road transport, while the main data highlights in terms of the fleet are:

- The passenger car fleet numbered 5,492,176 vehicles in 2020, representing a 216.5% increase compared to 1990. Greece’s passenger car fleet is the largest and most polluting in the European Union, with an average age of 17 years, compared to the EU average of 12 years. In 2019, out of the 5,406,551 passenger cars, 84.27% were gasoline vehicles, 9.56% were diesel, 5.59% were dual-fuel, and about 0.5% used electric propulsion technologies (Hybrid, BEV, PHEV, etc.). The motorization rate in Greece was 496 passengers per 1000 inhabitants, which is lower than the EU average of 560 passengers per 1000 inhabitants.
- Trucks are the third-largest vehicle category, with 1,373,727 vehicles, accounting for 16.1% of the total fleet. The number of trucks in the fleet increased by 79.2%. A total of 80.4% of the truck fleet comprises LDVs (weight < 3 tn), while 19.6% comprises HDVs. In 2019, 58.3% of the truck fleet ran on diesel, 39.8% ran on petrol, and only 1.85% was dual-fuel. There were only 81 trucks with advanced technologies (Hybrid, BEV). The truck fleet in Greece has the highest average age in the EU, reaching 20.2 years for LDVs and 21.4 years for HDVs, compared to the EU averages of 11.9 and 13.9 years,
respectively. The motorization rate for trucks is 110 vehicles per 1000 inhabitants, which is higher than the EU average of 81 vehicles per 1000 inhabitants.

- Motorcycles are the second-largest category of vehicles, with a total of 1,637,608 motorcycles in 2020, representing 19.2% of the fleet. The motorcycle fleet increased by 176.7% compared to 1990, while other vehicle categories experienced a decrease during the same period. Nearly the entire motorcycle fleet (99.9%) runs on gasoline, as of 2019.

2.2. Recording of Pollutant and CO\textsubscript{2} Emissions from Road Transport 1990–2020

The data on CO\textsubscript{2} emissions from road transport were collected from the National Greenhouse Gas and Other Gas Inventory Report 2022 [19]. The necessary data for CO, NMVOC, NO\textsubscript{X}, and PM\textsubscript{10} were obtained from the Centre for Emission Inventory and Forecasting (CEIP) of the Cooperative Programme for the Monitoring and Evaluation of Long-Range Transmission of Air Pollutants in Europe (EMEP) [20].

Some of the key elements are:

- Road transport accounted for 26.1% of the total CO\textsubscript{2} emissions in 2020, 36.5% of the total CO emissions, 25% of the total NMVOC emissions, 6.7% of the total PM\textsubscript{10} emissions, and 29.8% of NO\textsubscript{X} emissions.

- Passenger cars primarily contributed to CO\textsubscript{2} emissions, representing 35.5% of the sector’s emissions in 2020. The corresponding percentages for other vehicle categories were 24.1% for HDVs (including buses), 14.3% for LDVs, and 5.6% for motorcycles.

- Passenger cars and motorcycles were the main contributors to CO emissions, accounting for 35.5% and 34.1%, respectively. LDVs also showed a significant contribution, at 24.1%, while HDVs accounted for only 6.2%.

- Passenger cars were the main source of NMVOC emissions, with a significant percentage (21.7%) coming from exhaust in the fuel system. LDVs accounted for 13.8%, motorcycles for 16.2%, and HDVs and buses for just 8.3%.

- HDVs were primarily responsible for NO\textsubscript{X} emissions, with 66% of the emissions in 2020. The contributions from other categories were much smaller: 18.3% from passenger cars, 13.3% from LDVs, and 2.3% from motorcycles.

- Passenger cars, and emissions from tires and brakes, were the two main sources of PM\textsubscript{10} emissions, representing 37.7% and 34.9% of the emissions, respectively, in 2020.

2.3. Passenger Fleet Forecast Scenarios up to 2030

To forecast the passenger fleet, the authors relied on the following data:

- Annual registrations of used passenger cars by fuel, 2006–2022.
- Annual write-offs of vehicles.

Based on these data, and using the exponential smoothing methodology, specifically the ETS model [21], in conjunction with a methodology adopted from previous work by the authors [22], the forecast is generated for each year, until 2030, for the annual registrations of new passenger cars, annual registrations of used vehicles, and annual write-offs of vehicles. Considering these three parameters, the size of the passenger fleet in circulation by 2030 is estimated. Similarly, considering the propulsion technology of the new registrations, the expected fleet composition based on fuel/propulsion technology is calculated. Authors have formulated four scenarios that differ regarding the penetration rate of battery electric vehicles (BEVs) compared to the limitation of gasoline and diesel vehicles.

2.4. Methodology for Calculating Air Pollution from Passenger Vehicles for 2030

In the 2019 “Air Pollutant Emission Inventory Guide” of the European Environment Agency (EEA), specifically in Annex B [23], three different calculation methods are described. Considering the available data, the authors have chosen to proceed with Tier
1 calculations, based on Chapter 3 of the Guide. The Tier 1 approach for exhaust emissions utilizes the following general equation:

\[ E_i = \sum_j (\sum_m (F_{C,j,m}EF_{i,j,m})) \]  

(1)

where:
- \( E_i \) = emissions of pollutant \( i \) [g],
- \( F_{C,j,m} \) = fuel consumption of vehicle category \( j \) using fuel \( m \) [kg],
- \( EF_{i,j,m} \) = fuel-consumption-specific emission factor of pollutant \( i \) for vehicle category \( j \) and fuel \( m \) [g/kg].

Tier 1 emission factors (\( EF_{i,j,m} \)) have been calculated for countries with older vehicle fleets. However, an inherent consequence of this approach is that Tier 1 emission factors may yield higher emission values, compared to Tier 2 or Tier 3 methodologies, for countries that have newer vehicles complying with more recent emission standards (such as Euro 2/Euro II and later). Therefore, to address this issue, the authors revised the emission factors for each vehicle category, to relate to the pollutants of interest. Moreover, they utilized a reverse-solution method, using years when the necessary fleet data and total emissions were available, such as 2018 and 2019. By extrapolating coefficients from these years using exponential smoothing, similar to fleet forecasting, the authors predicted the annual rate of change, until 2030. They calculated the evolution in the passenger fleet, its distribution according to propulsion technology, its annual fuel consumption using the guidebook coefficients, and its annual mileage based on the COPERT dataset, to determine the corresponding emissions.

3. Results

3.1. Passenger Fleet Forecast Scenarios for 2030

According to calculations, the passenger fleet in circulation is expected to reach 7,153,484 cars in 2030, representing a growth of 30.2% compared to 2020. Based on the specific passenger forecast derived from the new registration data, four scenarios were formulated, to estimate the penetration of BEVs. These scenarios are as follows:

- Scenario 1: The share of BEVs in total new registrations (new passenger and used imports) is projected to reach 4.3% by 2030. This scenario was developed using exponential smoothing, based on the new registration data from 2006 to 2022.
- Scenario 2: The share of BEVs in total new registrations (new passenger and used imports) is expected to reach 12.3% by 2030. This scenario is based on the forecast from the National Energy and Climate Plan (NECP).
- Scenario 3: The share of BEVs in total new registrations (new passenger and used imports) is anticipated to reach 18.4% by 2030. This scenario is an extension of the NECP scenario, with a 50% increase.
- Scenario 4: The share of BEVs in total new registrations (new passenger and used imports) is projected to reach 2.2% by 2030. This scenario is derived from a reduction of 50% from Scenario 1.

All these scenarios (Figure 3) and their details can be found in Table 1.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Year</th>
<th>Total</th>
<th>Petrol</th>
<th>Diesel</th>
<th>BiFuel</th>
<th>Hybrid</th>
<th>BEV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2019</td>
<td>5,406,551</td>
<td>4,555,853</td>
<td>516,855</td>
<td>302,097</td>
<td>27,326</td>
<td>2336</td>
</tr>
<tr>
<td>Scen.1</td>
<td>2030</td>
<td>7,153,494</td>
<td>4,916,522</td>
<td>978,361</td>
<td>365,849</td>
<td>802,466</td>
<td>64,922</td>
</tr>
<tr>
<td>Scen.2</td>
<td>2030</td>
<td>7,153,494</td>
<td>4,980,397</td>
<td>833,916</td>
<td>365,849</td>
<td>802,466</td>
<td>145,492</td>
</tr>
<tr>
<td>Scen.3</td>
<td>2030</td>
<td>7,153,494</td>
<td>4,976,470</td>
<td>769,289</td>
<td>365,849</td>
<td>802,466</td>
<td>214,046</td>
</tr>
<tr>
<td>Scen.4</td>
<td>2030</td>
<td>7,153,494</td>
<td>4,942,503</td>
<td>980,650</td>
<td>365,849</td>
<td>802,466</td>
<td>36,652</td>
</tr>
</tbody>
</table>
3.2. Forecast Emissions from Passenger Cars in 2030

The calculations based on Tier I of the EEA guidebook, and on data from 2019 and 2020, lead to the following results (Table 2).

Table 2. Scenario results and percentage change compared to 1990, 2019, and 2020.

<table>
<thead>
<tr>
<th>Year</th>
<th>CO₂ (kt)</th>
<th>CO (kt)</th>
<th>NMVOC (kt)</th>
<th>PM₁₀ (kt)</th>
<th>NOₓ (kt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>11,793.06</td>
<td>871.84</td>
<td>170.17</td>
<td>6.85</td>
<td>154.00</td>
</tr>
<tr>
<td>2020</td>
<td>8,765.5</td>
<td>51.9</td>
<td>12.0</td>
<td>0.1</td>
<td>11.0</td>
</tr>
<tr>
<td>Scen.1 2030</td>
<td>6563.01</td>
<td>54.77</td>
<td>1.8</td>
<td>0.017</td>
<td>8.57</td>
</tr>
<tr>
<td>diff (%) 1990</td>
<td>16.88%</td>
<td>−90.81%</td>
<td>−97.89%</td>
<td>−98.21%</td>
<td>−84.48%</td>
</tr>
<tr>
<td>diff (%) 2020</td>
<td>−0.04%</td>
<td>5.53%</td>
<td>−84.69%</td>
<td>−70.94%</td>
<td>−21.86%</td>
</tr>
<tr>
<td>Scen.2 2030</td>
<td>6012.54</td>
<td>54.75</td>
<td>1.78</td>
<td>0.015</td>
<td>9.02</td>
</tr>
<tr>
<td>diff (%) 1990</td>
<td>7.07%</td>
<td>−90.81%</td>
<td>−97.96%</td>
<td>−98.40%</td>
<td>−83.66%</td>
</tr>
<tr>
<td>diff (%) 2020</td>
<td>−8%</td>
<td>6%</td>
<td>−85%</td>
<td>−74%</td>
<td>−18%</td>
</tr>
<tr>
<td>Scen.3 2030</td>
<td>5755.00</td>
<td>54.55</td>
<td>1.75</td>
<td>0.00</td>
<td>8.23</td>
</tr>
<tr>
<td>diff (%) 1990</td>
<td>2.49%</td>
<td>−90.85%</td>
<td>−97.99%</td>
<td>−100.00%</td>
<td>−85.09%</td>
</tr>
<tr>
<td>diff (%) 2020</td>
<td>−12%</td>
<td>5%</td>
<td>−85%</td>
<td>−100%</td>
<td>−25%</td>
</tr>
<tr>
<td>Scen.4 2030</td>
<td>6581.07</td>
<td>54.91</td>
<td>1.84</td>
<td>0.02</td>
<td>9.04</td>
</tr>
<tr>
<td>diff (%) 1990</td>
<td>17.20%</td>
<td>−90.78%</td>
<td>−97.88%</td>
<td>−98.20%</td>
<td>−83.62%</td>
</tr>
<tr>
<td>diff (%) 2020</td>
<td>0.24%</td>
<td>5.82%</td>
<td>−84.67%</td>
<td>−70.87%</td>
<td>−17.57%</td>
</tr>
</tbody>
</table>

Regarding the CO₂ emissions from passenger cars; in Scenario 1, they are projected to reach 6563 kt, which is a 16.88% increase compared to the 1990 levels. This is approximately the same as the emissions recorded in 2020, when travel restrictions were implemented, resulting in a 12% reduction compared to 2019. In Scenario 2, where BEVs have a higher market penetration, emissions decrease by 8.4% compared to Scenario 1, and remain 7.07% higher than the 1990 emissions. Scenario 3 highlights the significance of BEVs, with an estimated 18.4% market share in annual new registrations, and 3% of the passenger fleet.

In this scenario, emissions approach the 1990 levels, with a slight increase of 2.49%, and a fleet size that has grown by 216.5%. In Scenario 4, the emissions closely resemble those in Scenario 1, with a minor increase of 0.28%. This underscores the importance of hybrid and dual-fuel passenger cars as, despite a decrease in BEVs, and an increase in the share of conventional vehicles, emissions remain at the same levels as in Scenario 1.

Regarding CO emissions, authors anticipated a substantial decline, of over 90%, across all scenarios. Similarly, NMVOC emissions exhibit a reduction of more than 97.88% in all scenarios, with Scenario 3 achieving a reduction of up to 98%. In the case of PM₁₀, a significant reduction of over 98% is observed, while, in Scenario 3, the emissions of this pollutant reach almost zero. NOₓ emissions are expected to decrease by between 83% and 85% in all scenarios, with Scenario 3 showing the greatest reduction. An interesting observation regarding the contribution of diesel vehicles to these pollutants is that, between Scenario 3 and Scenario 4, where the representation of diesel in the fleet increases by 3%, the NOₓ emissions increase by almost 10%.
4. Conclusions

After an investigation into the different possible electrification rates of the passenger vehicle fleet in Greece by 2030, this work led us to the following conclusions:

- The penetration of BEVs plays a crucial role in reducing emissions. However, significant results can only be achieved when this penetration is combined with a concurrent reduction in the conventional vehicle fleet.
- Hybrid vehicles can also contribute significantly to emission reduction, as demonstrated in Scenario 4. Despite a decrease in fully electric vehicles, and an increase in conventional vehicles, emissions remain at the same level as in Scenario 1.
- Even under the most optimistic scenario, it is not anticipated that CO₂ emissions will fall below the 1990 levels.
- All pollutants are expected to experience a significant reduction, following the trend observed since 1990.
- The implementation of policies to address the COVID-19 pandemic in 2020 resulted in a substantial reduction in emissions. However, it is projected that emissions will reach and surpass the levels observed in 2020 after a radical fleet renewal.

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