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ORIGINAL PAPER

Environmental and economic effects of widespread introduction of electric vehicles in Greece

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Abstract
Purpose The scope of this paper is to present the results of the Project HyTech, which aimed, amongst other objectives, to quantify the environmental and economic effects of generalized introduction and use of electric vehicles in Greece.
Method The expected energy consumption and life cycle economic and environmental cost of electric vehicles for the present and immediate future is estimated after a relevant literature review. The future evolution of the Greek vehicle fleet relative to the Gross Domestic Product per capita is approximated by use of a Gompertz curve. The number of new vehicles registered every year, the age composition of the vehicle fleet, the resulting Green House Gas (GHG) emissions and energy use costs are calculated depending on a set of parameters. Choosing different sets of assumptions and calculating the resulting vehicle fleet statistics through year 2030, we investigated a number of scenarios.
Results The effect of market penetration by electric and hybrid vehicles and the resulting benefit on energy use cost and GHG emissions, compared to conventional vehicles is presented for each scenario. Fuel consumption and mileage of the vehicle fleet is a major factor that determines energy use cost and GHG emissions, regardless of fleet composition. In the case of an optimistic scenario that assumes a high renewal rate for the vehicle fleet, significant EV and HEV market penetration and use of renewable energy sources for battery recharging, a reduction of 668 kT CO2 in GHG emissions and 362 million € in energy costs per year in 2030 could be achieved.

Keywords Electric Vehicle · Emissions · LCA (Life Cycle Assessment) · Greece

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1 Introduction

Emissions of greenhouse gases attributed to the Greek passenger car fleet at the end of 2010 have increased by 54 % compared to 1990 [35], in spite of the technological advances in vehicle technology. This is mainly due to the increase of the fleet size, which has tripled during the same period. The increase of the market penetration of electric vehicles is one factor, which could help achieve the necessary reduction of GHG emissions targeted by EU policies and to reduce the environmental and economic impact of the passenger car fleet.

The scope of this paper is to present the results of Project HyTech, which aims, amongst other objectives, to quantify the environmental and economic effects of widespread introduction and use of electric vehicles in Greece. In the framework of this project, we have compiled relevant data from international and Greek sources in order to determine the current situation and predict the future development of the environmental and economic impact of the Greek passenger car fleet based on a number of assumptions and parameters.

2 Present status

2.1 Characteristics of the passenger vehicle fleet

At the end of 2010, there were 5.2 million passenger vehicles in circulation in Greece, resulting to a vehicle density of 458 vehicles per 1000 inhabitants [18] which approaches the average figure for the European Union, which was 473 vehicles per 1000 inhabitants in 2009 [15]. The number of vehicles has increased by 204 % between 1990 and 2010 and the average age of the fleet is 10.5 years [1], with 24 % of the fleet comprising vehicles older than 16 years, manufactured before the adoption of the EURO emission standards [34]. Vehicle age is a major factor contributing to poor environmental and economic performance of a vehicle fleet [36].

The high average age of the fleet is attributed to low rates of vehicles scrapped, except for periods when the scrapping of old vehicles was promoted by economic incentives given by the government for the purchase of new cars (1991–92, 2009, 2011–2012), as presented in Fig. 1. In the last two years (2011–2012) for the first time the vehicle fleet has contracted by nearly 1 %, owing mainly to the very low sales of new vehicles due to the economic crisis and the increased taxation of vehicle ownership.

2.2 Energy consumption–GHG emissions

Based on analysis of the data submitted by Greece in accordance with the Climate Change Convention [32], 80–83 % of gasoline consumption in Greece can be attributed to passenger cars. Diesel fuel consumption by passenger cars was virtually non-existent before 2010, because circulation of diesel passenger cars was prohibited in the two major metropolitan areas of Athens and Thessaloniki. Gasoline consumption attributed to passenger cars and estimation of the fleet mileage for the period 1990–2010 [35] is presented in Fig. 2. Based on these figures total and average CO_2 emissions (Tank to Wheel) attributed to passenger cars were calculated and are presented in Table 1.

2.3 Fuel Cost

The large reduction of mileage and fuel consumption after 2009 is, unfortunately, not a result of environmental or public transport policies but is directly related to the recent economic crisis in Greece. Taxes imposed on fuels have risen significantly in 2010 and combined with the reduction of the available income have resulted in a sharp decline in fuel consumption. Fuel taxes are a significant source of state revenue and in 2010 the state has collected 3.5 billion Euros in taxes attributed to the fuel consumption of the passenger car fleet (Fig. 3). The average operational fuel cost of the fleet in 2010 was 10.34 €/100 km compared to 6.40 €/100 km in 2000.

2.4 Import cost of new vehicles

Since no passenger vehicles are produced or assembled in Greece, all new passenger cars are imported. New vehicles (EURO 5) are subjected to import taxes ranging from 5–50 % depending on the cylinder capacity of the engine and 23 % VAT. Used vehicles are subjected to heavier import taxation depending on their EURO emission classification.

The total cost of importing new passenger car [7] and the taxes imposed on them [26] are shown in Fig. 4. The number of vehicles imported each year from 2001 to 2008 was steady around 300,000 (Fig. 1) but it is evident that there was a sharp rise in the value of imported new vehicles in the 2000 decade peaking in 2007, followed by a steep decrease of both number and value of cars imported, as a result of the economic crisis. The total value of imported vehicles has decreased from 3,288 million € in 2007 to 519 million € in 2012 and the taxes have decreased from 1,569 million € in 2007 to 180 million € in 2012. The average pre-taxes value of a new passenger car imported in Greece has risen from 5,089 € in 2001 to 10,415 in 2007 and then has fallen to 7,702 € in 2010.

3 Analysis of EV environmental and economic impact

3.1 Production phase

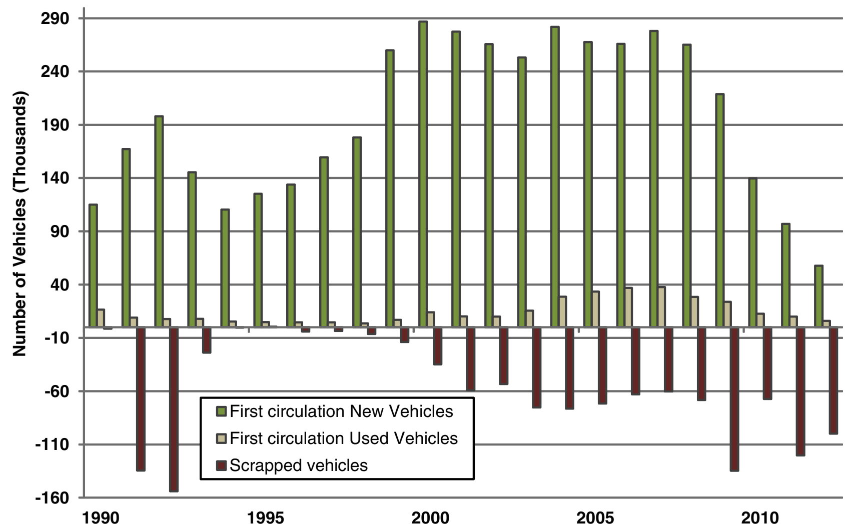
Manufacturing of Electric Vehicles requires increased energy and material usage, mainly due to the requirements of battery production. Energy requirements for Li-ion battery production are estimated at 1,700MJ per kWh of battery capacity [29]. A review of battery life cycle analysis [30], has shown manufacturing energy requirements of 2,680MJ/kWh for NiMH, 580MJ/kWh for PbA, 1,820MJ/kWh for NiCd, 1,800MJ/kWh for Na/S and 1,680 for Li-ion battery technologies.

GHG emissions depend on the GHG intensity of the production process and estimations for Li-ion batteries range from 120 [29] to 166 [30] kg CO_2/kWh of battery capacity.

The economic cost of Li-ion battery production is estimated at 380–450 €/kWh, with prospects to be reduced to 300–350 €/kWh until 2020 and 250 €/kWh after 2020, if the necessary economy of scale is achieved [22].

So, for an EV with 30 kWh of installed battery capacity, this results to additional embedded CO_2 production emissions of 3.6–5.5 tCO_2e and an increased production cost of 12,500–15,500 € compared to a conventional vehicle. According to a life cycle analysis of various vehicle types [28], the embedded production CO_2 emissions of a Mid-Size EV are 8.8 tCO_2e and account for

Fig. 1 Annual rates of first circulation and scrapping of vehicles in Greece



57 % of its lifecycle emissions compared to 5.6 tCO_2e of a Mid-Size Gasoline Vehicle, which account for 25 % of its lifecycle emissions. A report based on the projections of major automotive manufacturers [25] has concluded that the cost of Electric and Conventional vehicles is expected to converge around 2025.

3.2 Use phase

3.2.1 Tank-to-wheel energy consumption

Electric Vehicles benefit from the increased efficiency of the electrical drivetrain. Conversion of energy from batteries has an efficiency ratio of 85–92 % and the electrical drivetrain has an efficiency ratio of 85–87 % [3, 19, 33]. Also, kinetic energy is recovered during the braking phase, increasing the total efficiency of the EV. The total efficiency ratio of an EV (Tank-to-Wheel) is estimated at 58–62 % compared to 16–22 % of a conventional ICE vehicle [33].

The major drawback of the EV remains the weight of the battery pack, needed to ensure a practical range for the vehicle. Energy density of batteries at present is 100–130 Wh/kg with prospects to be increased to 180 Wh/kg until 2020 [3, 10, 22].

A compilation of estimations and measurements of the energy consumption of EV and PHEV/E-REV is presented in Table 2. As shown by Nissan measurements for the Nissan Leaf [27], consumption varies between 0.11 and 0.32 kWh/km and depends on a number of operating parameters as speed, traffic, outside temperature, use of climate control and others. Large variations between specified consumption and real-world performance are a problem not limited to EV but also of conventional vehicles [28]. Based on the above, values between 0.15 and 0.20

Fig. 2 Fuel consumption and mileage of Passenger cars in Greece (1990–2010)

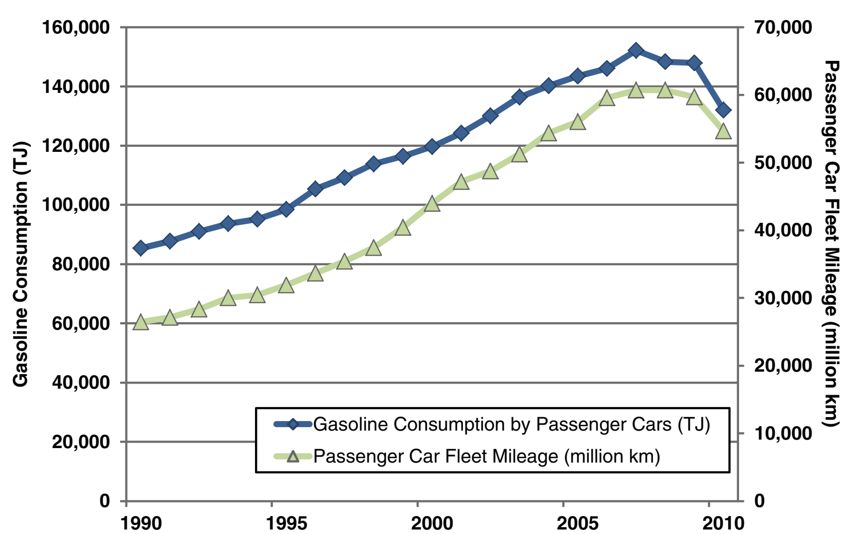


Table 1 Total and average CO_2 emissions attributed to passenger car fleet in Greece

CO_2 emissions	1990	1995	2000	2005	2010
Total ($ktCO_2$)	5859	6755	8213	9845	9056
Average (gCO_2/km)	221	212	187	176	166

kWh/km can be considered representative of the energy consumption of present EV [22].

3.2.2 Electricity grid well-to-tank analysis

Electric Vehicles and Plug-In Hybrid Electric Vehicles/ Extended Range Electric Vehicles, when operated purely on battery power, are locally Zero Emission Vehicles. GHG emissions depend on the fuel mixture used by the electricity production process of the grid that is used to charge the batteries.

Electricity production in Greece largely depends on lignite (a type of coal) for the 46 % of the energy produced. As a result of the low calorific value of lignite, the steam-electric power plants using it show a high GHG intensity of 1,000 gCO_2/kWh with a prospect of reduction to 900 gCO_2/kWh after plant modernization [21]. Modernization of lignite plants is also needed to reduce the high emissions of SO_2 and NO_x, by using desulfurization methods and installing modern air filters.

In recent years there was an effort to increase the share of natural gas power plants and renewable energy sources in the electrical grid fuel mixture. Present estimations for the CO_2 intensity of the Greek electricity production vary between 650 gCO_2/kWh [11], 729 gCO_2/kWh [21] and 846 gCO_2/kWh [14] and it is predicted to be reduced to 530 gCO_2/kWh by 2020 [11]. According to the RetSceen energy analysis software the baseline GHG emission factor for the electricity system of Greece is 718 gCO_2/kWh [24].

The EU27 average in 2010 was 467 gCO_2/kWh and is predicted to be reduced to 365 gCO_2/kWh by 2020 [23]. Average retail cost of household electricity in Greece in November 2011, was 0.1403 €/kWh to 0.1623 €/kWh depending on the total level of consumption [12].

3.2.3 Well-to-wheel analysis of electric vehicle emissions

Given the energy consumption and the GHG intensity of electricity production we can estimate the Well-to-Wheel GHG emissions of an electric vehicle. In Fig. 5 they are presented for energy consumptions of 0.15 kWh/km, 0.20 kWh/km and 0.25 kWh/km. For comparison reasons, the Greek and EU average GHG intensity of electricity grid for 2010 and 2020 and the CO_2 average emission targets of the EU for 2012 and 2020 [8] are marked. The CO_2 average emission targets of the EU (130 gCO_2/km for 2012 and 95 gCO_2/km for 2020) have been adjusted to WTW emissions, so that they are comparable. As we can observe, when an EV is using electricity produced by an electrical plant with high GHG intensity, like coal operated steam plants, it can even exceed the CO_2 emission of conventional vehicles. So, it is necessary to promote the introduction of electric vehicles in parallel with the reduction of the GHG intensity of the electrical grid. Moreover an electric vehicle fleet cannot be considered a simple case of electricity consumption, but can be utilized in the framework of a "smart" electrical grid and acts as an energy buffer (Vehicle2Grid) to improve the stability of the grid or even generate revenue for their owners [31].

In Table 3, a comparison of WTW emissions and use cost based on current electricity and fuel prices in Greece, of a pure

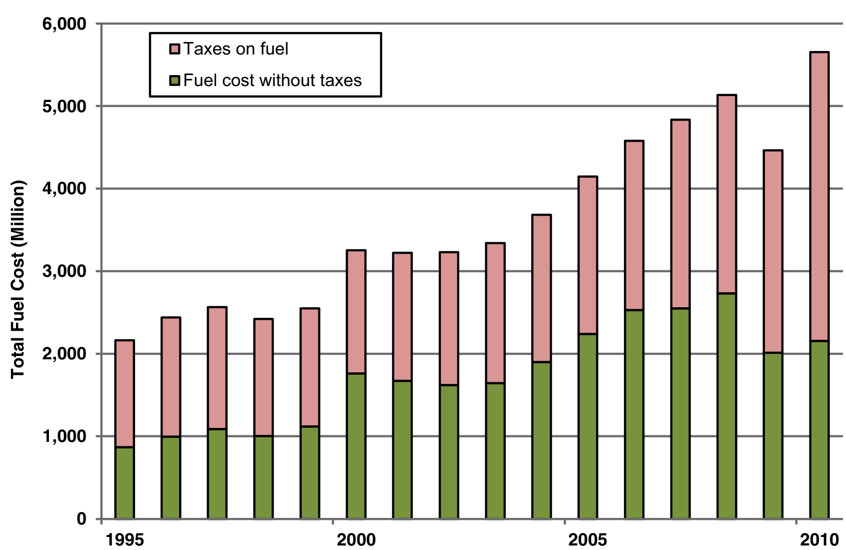


Fig. 3 Total fuel cost and taxes related to Passenger Cars

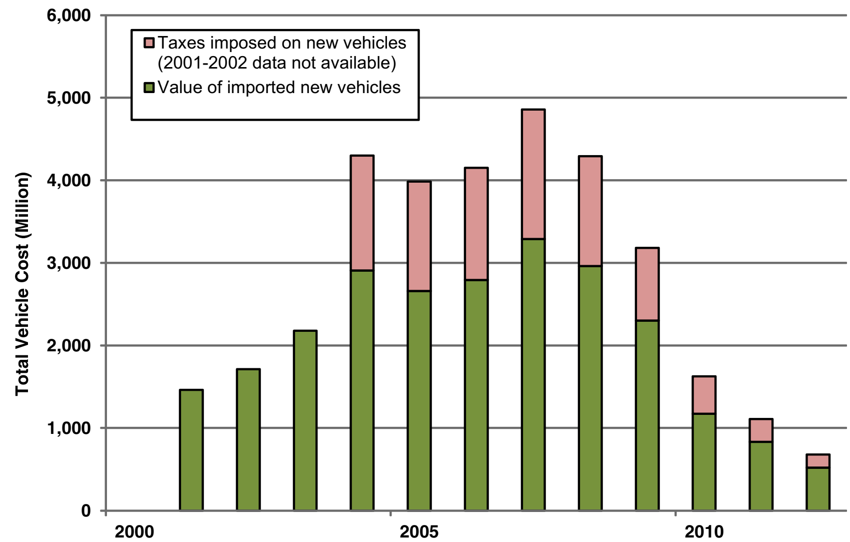


Fig. 4 Import cost and taxes imposed on new passenger vehicles

EV (Nissan Leaf), an EREV (Chevrolet Volt/Opel Ampera), a typical HEV (Toyota Prius), the 3 best-selling conventional Segment A, B, C vehicles (Fiat Panda, Opel Corsa, Opel Astra—city cycle consumption) and targets set by the EU for 2012 and 2020. Emissions have been calculated with GHG electricity intensity of 650 gCO_2/kWh and operation cost with price of electricity energy of 0.15 €/kWh and gasoline price of 1.650 €/lt. CO_2 emissions of EV and HEV are considerably lower than conventional vehicles. Operation cost of EV is 60–80 % lower compared to both the HEV and Conventional Vehicles.

3.3 Life-cycle evaluation

Based on the previous analysis of EV production and use phase emissions, we can perform a Life Cycle analysis of an EV and compare it with conventional and hybrid vehicles. For the analysis we used the parameters presented in Table 4, to compare a hypothetical pure Electric Vehicle (EV), an Extended Range Electric Vehicle (EREV), a Hybrid Electric Vehicle (HEV) and a conventional gasoline ICE vehicle (CV) [19].

The data presented for the production phase emissions includes other GHG emissions, like CH_4 and NO_2 and is given in CO_2 equivalent units (CO_2e). For the use phase, we can assume tailpipe CO_2e emissions are equal to CO_2 emissions since the emissions of other GHG gases are small [28].

Results of the analysis are presented in Fig. 6 and it is evident that all vehicles with alternative power sources show reduced life cycle emissions when compared with a conventional vehicle.

Table 2 Review of energy consumption of Electric Vehicles

Vehicle Type	Range as pure electric (km).	Consumption (kWh/km)		Source
		Min	Max.	
Generic BEV	120–160	0.130	0.160	[23]
Generic E-REV	60–80	0.130	0.180	[23]
Generic PHEV	20–40	0.160	0.190	[23]
Generic BEV	160	0.177		[4]
Generic BEV	90–136	0.183	0.269	[19]
Generic PHEV	50	0.178		[19]
Generic BEV	100–400	0.180	0.185	[3]
Generic BEV		0.150		[2]
Generic PHEV		0.197		[2]
Nissan Leaf	76–222	0.11	0.32	[27]
Nissan Leaf	117–120	0.20	0.21	[5, 9, 28]
Chevrolet Volt	40–80	0.16	0.32	[16]
Chevrolet Volt	56	0.20		[5, 9]

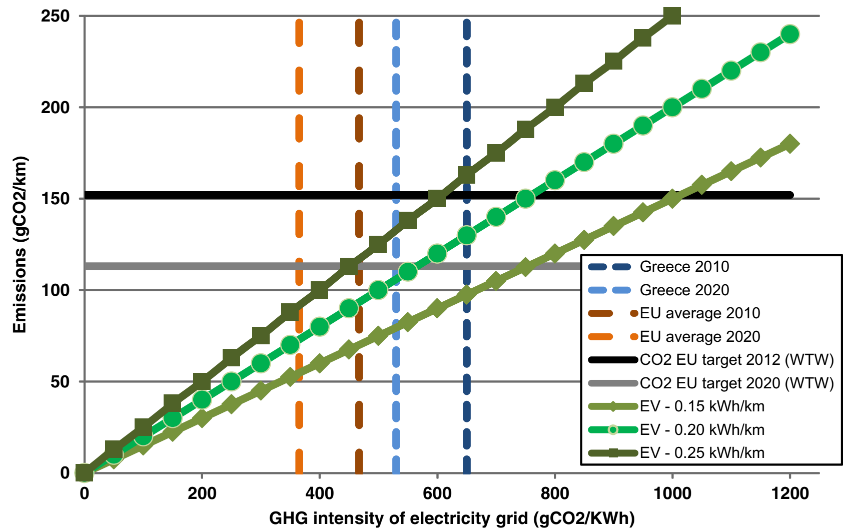


Fig. 5 Electric Vehicle WTW CO_2 emissions based on GHG intensity of electricity grid

The EV and EREV perform similarly with the HEV, if we assume they are charged by a medium GHG intensity electrical grid (450 gCO_2/kWh), with the EV having slightly lower total Life-Cycle emissions. Also the EV has much more potential for further emission reduction if it is charged by renewable energy sources or for energy consumption reduction as a result of improvements in battery technology.

4 Future evolution scenarios

In the framework of project HyTech, we estimated the future evolution of the environmental and economic impact of the Greek passenger car fleet by compiling different scenarios on the basis on a number of assumptions and parameters. The effect of market penetration by electric and hybrid cars and the resulting benefits on energy use cost and GHG emissions, compared to conventional ICE cars were calculated for each scenario.

4.1 Evolution of vehicle fleet size

For many reasons (economic crisis, high level of taxation etc.), it is clear that the passenger car fleet in Greece is not going to expand with the same rate as in the previous decade. A prediction for the rate of sales of new cars is essential in order to estimate the number of possible EV and HEV that can be introduced in Greece in the next decades.

Car ownership can be directly linked with the national per capita income [6, 20, 17]. Every country has a different behaviour, depending on urbanization, transport infrastructure and motoring culture but it has been shown that empirically the relationship between vehicles per 1,000 residents and GDP per capita can be approximated with the use of a Gompertz function [6].

The biggest challenge in this case is to predict the evolution of the car fleet during large periods of recession and economic uncertainty, as Greece is experiencing for the last years. In this case we cannot use a single Gompertz curve because GDP per capita is not monotonically increasing. We assume that the new Gompertz curve will have similar characteristics, after the

Table 3 Comparison of emissions and use cost based on current electricity and fuel prices in Greece

Vehicle	Fuel—Electricity consumption	WTW emissions (gCO_2/km)	Cost (per 100 km)
Nissan Leaf	0.21 kWh/km	137	3.15 €
Chevrolet Volt (electrical)	0.23 kWh/km	150	3.45 €
Chevrolet Volt (ICE)	6.3 lt/100 km	172	10.40 €
Toyota Prius (HEV)	4.7 lt/100 km	127	7.76 €
Fiat Panda	6.6 lt/100 km	178	10.89 €
Opel Corsa	6.9 lt/100 km	187	11.39 €
Opel Astra	7.9 lt/100 km	213	13.04 €
EU average CO_2 target 2012	5.63 lt/100 km	152	9.29 €
EU average CO_2 target 2020	4.11 lt/100 km	113	6.78 €

Table 4 Life Cycle analysis parameters

	Urban	Extra-Urban	Highway	
Usage	70 %	20 %	10 %	
CV	7.5 l/100 km	5.2 l/100 km	6.7 l/100 km	
BEV	20.4 kWh/100 km	20.8 kWh/100 km	24.9 kWh/100 km	
EREV (electrical usage)	17.8 kWh/100 km	10.6 kWh/100 km	3.3 kWh/100 km	
EREV (ICE usage)	0.6 l/100 km	2.6 l/100 km	6.0 l/100 km	
HEV	4.6 l/100 km	4.2 l/100 km	4.9 l/100 km	
	CV	BEV	EREV	HEV
Production emissions	5.5 tCO_2e	9 tCO_2e	7.5 tCO_2e	6 tCO_2e
Electric grid GHG intensity	450–650 gCO_2/kWh			
Life cycle mileage	150,000 km			

period of negative GDP growth is over. In Fig. 7 we present a prediction based on previous historical data for the evolution of car ownership in Greece and the estimations for the growth of Greece's GDP and population until 2030 [13, 15]. If predictions for return to economic growth by 2015 are fulfilled we can then expect the vehicle fleet in Greece to grow from around 5.3 million vehicles in 2010 to 6 million vehicles in 2020 and 7 million vehicles in 2030.

4.2 Fleet age composition and EV-HEV market penetration

Fleet age composition depends on the ratio of end-of-life vehicles that are withdrawn from circulation versus vehicles entering circulation. As we can see in Fig. 1, from 2001 to 2008 this ratio in Greece was steady around 20–25 % but this was increased to 45–55 % in 2009–2010 mainly due to economic incentives provided by the state and the drop in sales of new cars. The ratio was increased over 100 % at 110–150 % in 2011–2012, which meant that for the first time vehicles exiting the fleet were more than new vehicles, but this should be treated as an exception not expected to be repeated if the economic situation stabilizes. For our scenarios we will assume that 20 % is the low and 60 % is the high-expected ratio of withdrawal of end-of-life vehicles.

Market penetration of EV and HEV in Greek market depends on global factors, as the widespread introduction of new EV models, the reduction of their cost and the improvement of range, as well as national factors, mainly the development of the charging infrastructure and the support of EV circulation with economic or other incentives. According to various announcements and commitments by governments and automotive manufacturers [22], the objective for 2030 is to achieve market penetration of 20–30 % for HEV and 5–10 % for EV.

4.3 Energy consumption–emissions and energy cost

The next step was to choose the low and high expected values for energy consumption and emissions. The energy

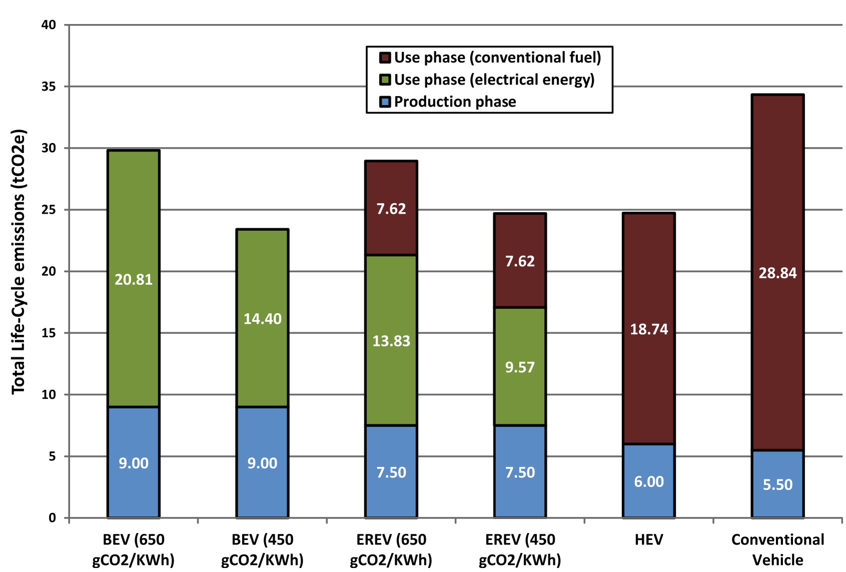


Fig. 6 Comparison of total Life-Cycle emissions

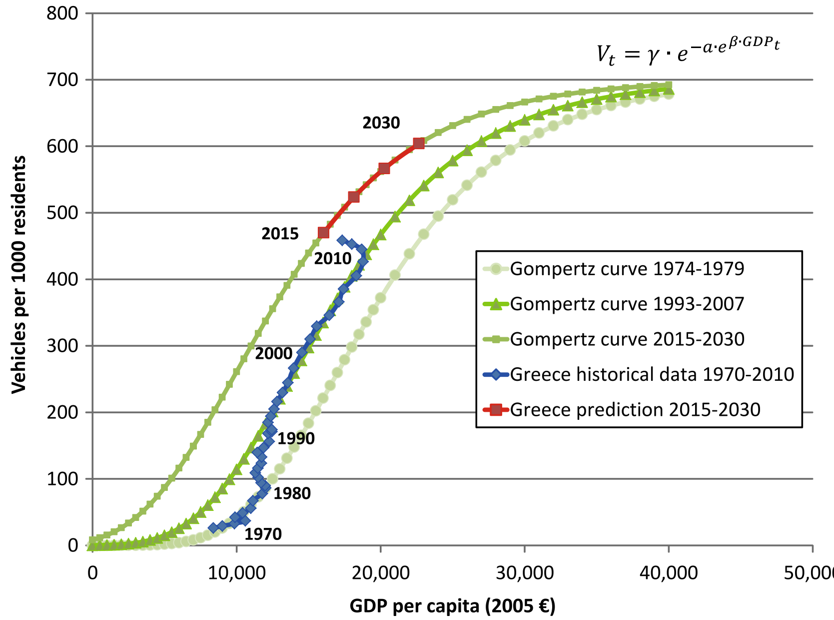


Fig. 7 Prediction of car ownership in Greece using Gompertz curves

consumption of EVs was assumed to be reduced from 0.18–0.22 kWh/km in 2015 to 0.15–0.19 kWh/km in 2030. Similarly, CO_2 intensity of electricity production in Greece is expected to be 500–620 gCO_2/kWh in 2015 and 350–520 gCO_2/kWh in 2030. We also assumed a "very low emission" scenario where EVs are charged exclusively from renewable sources.

For HEV we assume emissions to be reduced from 95–110 gCO_2/km to 75–90 gCO_2/km, and for conventional vehicles from 120–150 gCO_2/km to 90–110 gCO_2/km in 2030 based on EU targets.

Expected mileage for the vehicle fleet is difficult to predict. From 2009 to 2011 a reduction of 25 % was observed based on fuel consumption. The average mileage of a passenger vehicle is expected to be reduced from 10,200–11,500 km in 2015 to 9,600–10,500 km in 2030, as vehicles per inhabitants increase.

Finally, energy cost is associated with global fuel prices, which is very volatile and unpredictable. However we can assume that there will be a long-term increasing trend. We expect gasoline price to increase from 1.56–2 €/lt in 2015 to

Table 5 Scenario parameters for the calculation of environmental and economic impact

Parameters	End-of-life vehicle withdrawal rate		EV – HEV market penetration		Price of new vehicles	
Scenario 1	low		low		high	
Scenario 2	medium		medium		medium	
Scenario 3	high		high		low	
	EV consumption	Electricity CO_2 intensity	HEV - CV CO_2 emissions	Fleetmileage	Fuel price	Electricity price
Scenario 1a	medium	medium	high	high	high	medium
Scenario 1b	medium	medium	medium	medium	medium	medium
Scenario 1c	medium	medium	low	low	low	medium
Scenario 2a	high	high	high	medium	medium	medium
Scenario 2b	medium	medium	medium	medium	medium	medium
Scenario 2c	low	low	low	medium	medium	high
Scenario 3a	high	high	medium	medium	medium	medium
Scenario 3b	low	low	medium	medium	medium	medium
Scenario 3c	low	very low (renewable)	medium	medium	medium	medium

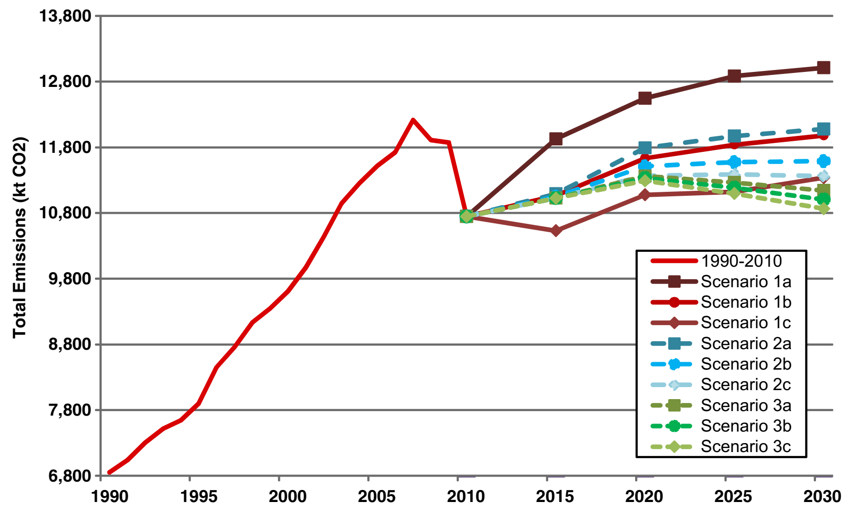


Fig. 8 Comparison of evolution of Greek passenger vehicle fleet CO_2 emissions

1.75–2.20 €/lt in 2030 and electricity prices from 0.14–0.17 €/kWh in 2015 to 0.18–0.26 €/kWh in 2030.

4.4 Scenario parameters

In order to evaluate the environmental and economic impact of future vehicle evolution, we calculated a number of scenarios. The parameters used for each scenario are presented in Table 5.

Three basic scenarios were created for the evolution of vehicle fleet size and composition, based on end-of-life vehicle withdrawal rate, EV-HEV market penetration and new vehicle prices. Scenario 1 assumes that the price of new vehicles will be high and therefore fleet renewal rate and market penetration of EV-HEV will be low, while Scenario 3 assumes the opposite. Scenario 2 assumes medium figures for fleet renewal and market penetration of EV-HEV.

For every basic scenario, three sub-scenarios were considered, based on EV, HEV and conventional vehicle–energy consumption, CO_2 intensity of electricity production, fleet mileage and fuel—electricity prices.

4.4.1 Scenario 1

According to Scenario 1, there will be 2.5 million new vehicles inserted in circulation and 670 thousand old vehicles withdrawn until 2030. The increase of the fleet size and low rate of withdrawal of end-of-life vehicles will result in an increase of the average age of the fleet from 11.08 years in 2010 to 16.43 years in 2030, with more than 5 million vehicles being in circulation for more than 15 years. EV and HEV market penetration is assumed to be low, with 40 thousand EV and 130 thousand HEV being in circulation in 2030.

Sub-scenario 1a, assumes that fuel consumption of new conventional and hybrid vehicles, fleet mileage and fuel prices

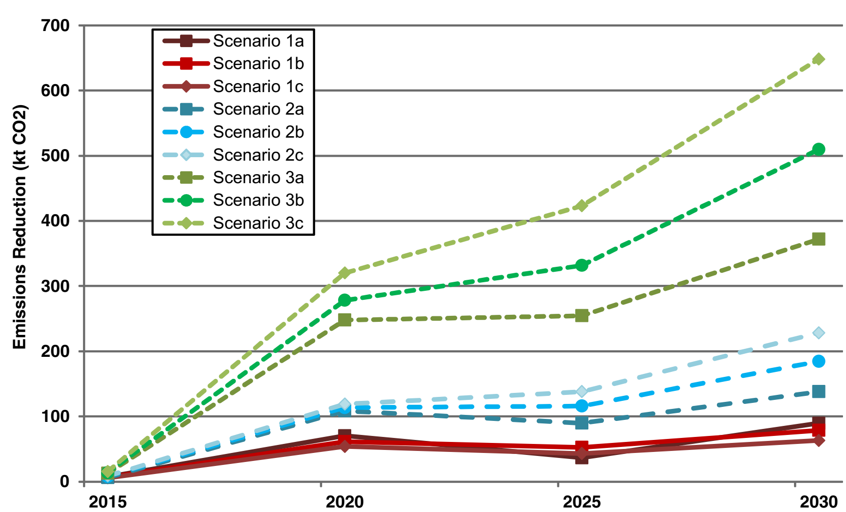


Fig. 9 Comparison of reduction of CO_2 emissions due to EV-HEV introduction

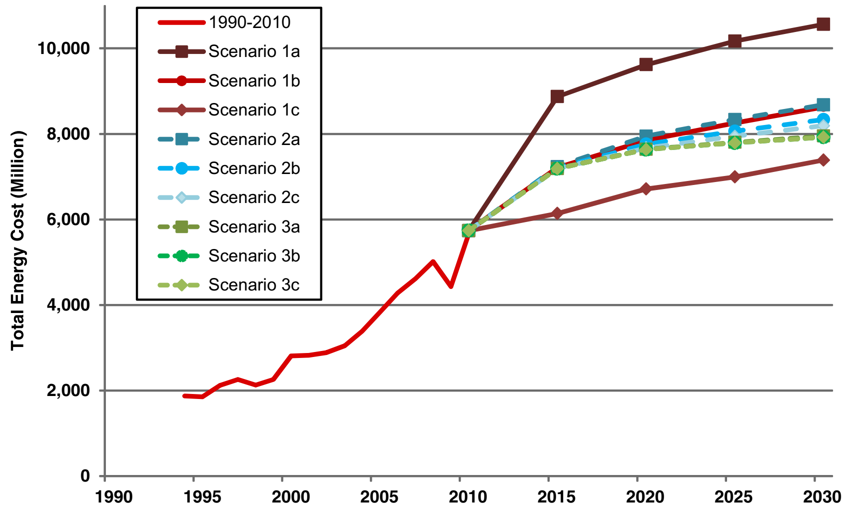


Fig. 10 Comparison of evolution of Greek passenger vehicle fleet energy consumption cost

will be high, while scenario 1b assumes they will be medium and scenario 1c low. Consumption of EV and CO_2 intensity of electricity production are assumed to be medium in all 3 sub-scenarios.

The yearly reduction of CO_2 emissions in 2030, attributed to the introduction of EV and HEV, is 92 kT CO_2 for scenario 1a, 81 kT CO_2 for scenario 1b and 65 kT CO_2 for scenario 1c.

The yearly economic benefit in 2030, from decreased energy consumption is 76 million € for scenario 1a, 57 million € for scenario 1b and 39 million € for scenario 1c.

4.4.2 Scenario 2

According to Scenario 2, there will be 3.1 million new vehicles inserted in circulation and 1.3 million old vehicles withdrawn until 2030. The medium rate of withdrawal of end-of-life vehicles will result in an average age of the fleet of 15.59 years in 2030. EV and HEV market penetration is assumed to be medium, with 100 thousand EV and 300 thousand HEV being in circulation in 2030.

Sub-scenario 2a, assumes that fuel consumption of new conventional and hybrid vehicles, electricity consumption of EV and CO_2 intensity of electricity production will be high, while scenario 2b assumes they will be medium and scenario 2c high. Fleet mileage and fuel prices are assumed to be medium in all 3 sub-scenarios.

The yearly reduction of CO_2 emissions in 2030, attributed to the introduction of EV and HEV, is 141 kT CO_2 for scenario 2a, 189 kT CO_2 for scenario 2b and 233 kT CO_2 for scenario 2c.

The yearly economic benefit in 2030, from decreased energy consumption is 106 million € for scenario 2a, 136 million € for scenario 2b and 146 million € for scenario 2c.

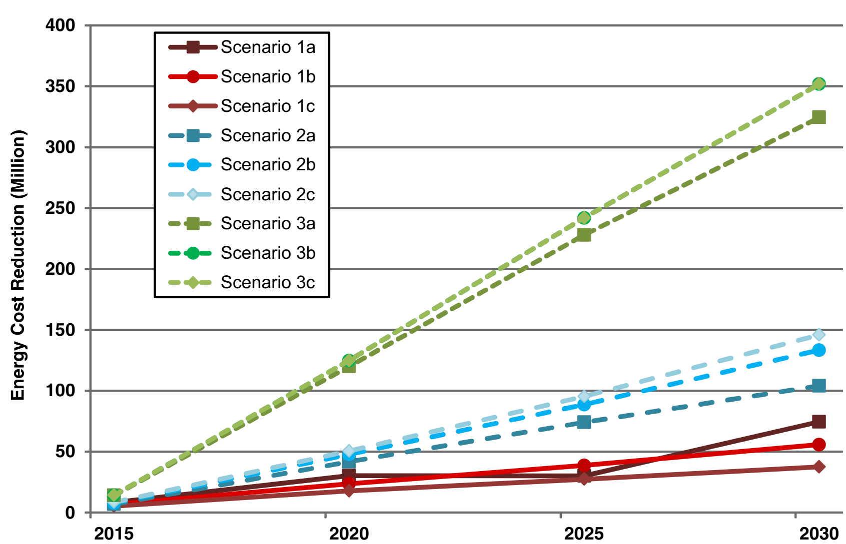


Fig. 11 Comparison of reduction of energy cost due to EV-HEV introduction

4.4.3 Scenario 3

According to Scenario 3, there will be 3.7 million new vehicles inserted in circulation and 1.9 million old vehicles withdrawn until 2030. The high rate of withdrawal of end-of-life vehicles will result in an average age of the fleet of 14.75 years in 2030. EV and HEV market penetration is assumed to be medium, with 300 thousand EV and 630 thousand HEV being in circulation in 2030. This scenario is the most optimistic, regarding the renewal of the fleet and the market share of EV and HEV.

Sub-scenario 3a, assumes that, electricity consumption of EV and CO_2 intensity of electricity production will be high, while scenario 3b and 3c assumes they will be low. Especially for scenario 3c, it is assumed that EV will be charged from renewable sources. Fuel consumption of new conventional and hybrid vehicles, fleet mileage and fuel prices are assumed to be medium in all 3 sub-scenarios.

The yearly reduction of CO_2 emissions in 2030, attributed to the introduction of EV and HEV, is 385 kT CO_2 for scenario 3a, 526 kT CO_2 for scenario 3b and 668 kT CO_2 for scenario 3c.

The yearly economic benefit in 2030, from decreased energy consumption is 334 million € for scenario 3a, 362 million € for scenario 3b and 362 million € for scenario 3c.

4.5 Future scenario analysis conclusions

The comparison of future evolution scenarios described previously related to the environmental and economic impact of the Greek passenger vehicle fleet is presented in Fig. 8, 9, 10, 11.

Regarding environmental impact we calculated the total Well-to-Wheel CO_2 emissions and the benefit of EV-HEV penetration when compared to equal number of conventional vehicles they replace and regarding economic impact, we calculated the total cost of energy consumed by the Greek passenger vehicle fleet and the benefit of EV-HEV introduction.

In the case of scenario 1, the influence of fuel consumption and mileage on the final results is evident, regardless of fleet composition. The low fuel consumption and mileage scenario 1c shows similar emissions with the optimistic scenario that assumes high rates of fleet renewal and high EV-HEV market penetration. For scenarios 2 and 3, medium values were selected for fuel consumption and mileage, in order to compare the influence of other parameters. The environmental benefit is primarily attributed to the fleet renewal rate and the EV-HEV market penetration and secondarily to EV-HEV energy consumption and electricity production CO_2 intensity.

The introduction of Electric and Hybrid vehicles in the Greek passenger vehicle fleet shows clear potential environmental and economic benefits, mainly due to reduction in energy consumption. Especially in the case of EV the reduction in operational cost could be important, with the increased initial purchase cost being a significant drawback. The convergence of EV-HEV initial purchase cost with conventional vehicles, as a result of technological advances or public policies will accelerate the market penetration of EV and HEV.

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