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The impact of vehicle taxations system on vehicle emissions

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Contents

Summary

The scope of this study is to find the real-world savings achieved in total CO_2, NOx and PM10 emissions from the adoption of national policies and European legislation for the period 2010- 2017 for the new registered fleet based on appropriate scenarios developed for this study. In addition, a forecast of the relevant benefits until 2020 was also made.

Abbreviations

BEV: Battery Electric Vehicle

CO_2: Carbon Dioxide

EEA: European Environment Agency

EF: Emission factor

EV: Electrified Vehicle

FCEV: Fuel Cell Electric Vehicle

GHG: Greenhouse Gases

JRC: Joint Research Centre

NEDC: New European Driving Cycle

NOx: Nitrogen Oxides

PHEV: Plug-in Hybrid Electric Vehicle

PM10: Particulate Matter

VAT: Value Added Tax

1 Introduction

Global warming and air pollution are major threats for planet Earth that harm the environment and entail danger to human health. Despite the great efforts that have been made in recent years to solve these issues, the necessary progress has not been achieved and more actions need to be deployed if the world is to remain a supportive residence for humans and other species.

Road transport is widely recognized as a one of the most important source of pollution with both immediate and long-term effects on the environment. Passenger cars account for 44% of transport GHG emissions and are therefore a key target for emission reduction policies [1].

EU legislation (EC) No 443/2009 sets mandatory emission reduction targets for new cars. This legislation is the main EU's strategy to improve the fuel economy of cars sold on the European market. In particular, the average emissions level target of a new car sold in 2015 has been set to 130g CO2/km for 2015 (has been achieved) and a further target of 95g CO2/km should be met by 2021 [2]. Manufacturers have been forced to produce more efficient ICE vehicles and this was achieved to some extent through technological or design improvements such as implementation of direct fuel injection, reducing the physical size of the engine and increasing relative load ('downsizing'), turbocharging, start–stop systems, etc [3]. However, achieving the emission reduction targets beyond 2021 of this more and more tight regulation will be very challenging with ICE optimization alone and probably will require some form of electrification. Therefore, OEMs invest in alternative powertrains like hybrids (HEV), plug-in hybrids (PHEV), battery electric vehicles (BEV) and fuel cell electric vehicles (FCEV) that have zero or very low tailpipe emissions.

Current models of these technologies sell at higher prices compared to similar conventional internal combustion models. This price excess can burden their market penetration because it is still difficult for consumers to accept that they will pay for social benefits that would not directly benefit themselves in the short term.

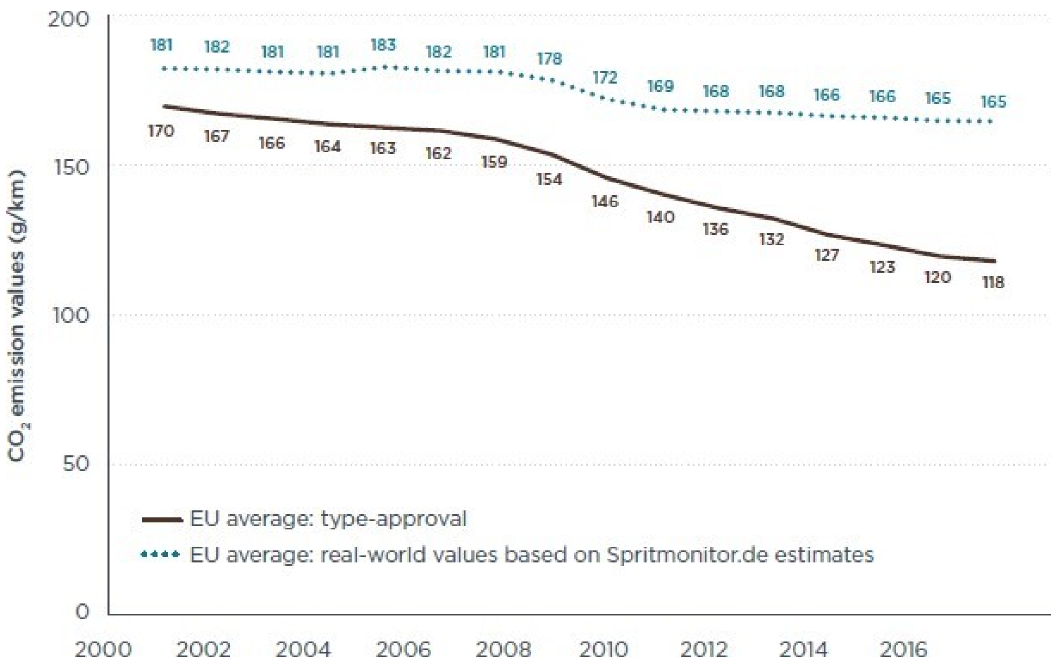
The main advantages of these new technologies are that they are more energy efficient, less polluting and has greater energy security. Many governments seek for a higher energy independence and a shift towards a less oil-intensive transport sector and therefore they are willing to introduce these advanced-technology vehicles in their fleet in greater numbers [4]. In order to encourage consumers to purchase these vehicles instead of internal combustion engine vehicles, governments are promoting these vehicles by providing a range of subsidies and other benefits to effectively reduce the purchase price and to influence car purchasing trends towards lower CO2-emitting vehicles.

Numerous national level policies and measurements, primarily in the form of financial mechanisms were adopted by an increasing number of Member States. The benefits for the consumers can be apparent at different times depending on the policy design and generally fall into two categories:

1. At the purchase of the vehicle (acquisition incentives), passenger car buyers can be offered up front subsidies on the cost of new vehicles e.g. registration tax reductions, subsidised pricing, scrappage schemes.
2. Reductions relating to operating costs of vehicles such as reductions in circulation tax or subsidized electricity for charging electric or plug in hybrid vehicles (recurring incentives).

Both the implementation of European legislation and national level policies of the Member States initiated an impressive declining trend in official CO2 emissions from new cars registered in the EU. The progress in vehicle efficiency was substantial as the average official CO2 emissions level of a new car sold in 2013 was 127 g CO2/km, notably below the 2015 target of 130 g CO2/km [19]. Nevertheless, recent research unveils that this improvement in official figures does not reflect in real-world CO2 emission and also an increasing divergence or "gap" between official and real-world CO2 emissions has been observed over the past years. The official CO2 emission levels of new passenger cars are assessed via the New European Driving Cycle (NEDC). Although NEDC provides reproducible figures, it has been accused of not replicating real-world driving conditions and for allowing a number of tolerances and loopholes that can be exploited to obtain more favorable results in the laboratory. These flexibilities of the driving cycle were identified as the main reason for the observed growth in the gap between official and real-world data [20]. It is, therefore, interesting to examine how the on-road emissions of vehicles have been evolved in comparison with the official emissions during the previous years. This comparison conducted from ICCT and presented in their study series "From Laboratory to Road" [18]. The results depicted in Figure 1 show that real world values have been slightly decreased by approximately 2% in the last 6 years, from 169 g/km of CO2 in 2010 to 165 g/km in 2016 while the corresponding figure for the type approval emissions was about 16%. On top of this, real world CO2 emissions did not show a decline but remained stable for the years 2011-12, 2013-14 and 2015-16. This widening gap is particularly worrying for several reasons. The most important is that undermines both the European legislation for CO2 emissions of passenger cars and the national vehicle taxation schemes (as most of them are based on official CO2 emission values), which are policies that target to mitigate the climate change.

Figure 1: Real-world versus type-approval CO2 emission values of new European passenger cars based on Spritmonitor.de estimates and type-approval data from the EEA.



<u>The objective of this study is to find the real-world savings that we have in total CO2, NOx and PM10 emissions from the adoption of national policies and European legislation for the period 2010-2017 for the new registered fleet. On top of that, a forecast for the situation until 2020 was made.</u>

To achieve this, scenarios were developed which have the following structure:

- Scenario in which the market was not influenced by the introduction of vehicle taxes
- Scenario that demonstrates the current situation which is based on the introduction of the policies.

Comparing the scenarios can give us an assessment for the savings in emissions, that can be attributed to the adoption of these policies.

This report considers and further complements the preceding comprehensive EIONET report "Vehicle Emissions and Impacts of Taxes and Incentives in the Evolution of Past Emissions" [5] which in its first part includes an inventory on taxation policies and their evolution over time across European countries in order to understand the differences between countries. The second part of the EIONET study analyses the role that national level actions such as taxes and other financial incentives have had in driving reductions in average CO2 emissions from new passenger cars across Europe. Seven countries (France, Germany, Greece, Ireland, Netherlands, Norway, Poland) have been examined and analyzed thoroughly due to their interesting approaches to the taxation system and incentives given to consumers for the purchase of low CO2 emitting vehicles. In this countries selection, there are cases where robust taxation measures and incentives have been applied, but also there are countries without any special fiscal incentives. This will help us to see if incentives can really help to reduce a country's emissions. In our study we will calculate the scenarios for these seven countries and we will focus on the quantitative results of the emission savings.

The report is structured as follows:

Chapter 2 presents the methodology used for our calculations and the assumptions made. Additionally, a brief description for the countries vehicle taxation policies is made. Finally, the calculation tool (COPERT) is presented.

Chapter 3 contains the calculation results of each country examined.

Finally, **Chapter 4** includes conclusions and discussion on the results of the calculations.

2 Methodology

2.1 General Methodology

This section describes the steps followed in order to assess the effect of vehicle taxation policies compared with a baseline scenario for seven countries. The baseline scenario has been firstly calculated before creating any other scenario. For the calculation of baseline emissions, it is necessary to find the fleet, which was derived from the CO2 monitoring database [6, 7]. In particular, the total number of new registrations was allocated at the corresponding technology categories and size classes (mini, small, medium, large) for each year from 2010 till 2017. This classification of the fleet is required by the calculation tool COPERT that we used.

The vehicle technologies that were considered in our study fall in two broad categories: **conventional vehicles** and **electrified vehicles** (EV)(Table 1).

Conventional group includes the common petrol and diesel fueled vehicles equipped with internal combustion engines (ICEV). Electrified vehicles (EV)category contains the lower-emitting CO2 vehicles i.e. battery electric vehicles (BEV), hybrid vehicles (HEV), plug-in hybrids vehicles (PHEV) and fuel cell electric vehicles (FCEV).

Table 1: Technology Categories of the vehicles

Conventional	Electrified vehicles
Petrol	Battery electric (BEV)
Diesel	Petrol Hybrid (HEV)
	Diesel Hybrid (HEV)
	Plug-in Hybrid (PHEV)
	Fuel cell electric (FCEV)

In the CO2 monitoring database, hybrid vehicles are normally registered as conventional vehicles and hence it is difficult to identify the hybrid (HEV) vehicles. In addition, many Plug-in hybrid models were mistakenly registered as conventional vehicles. Therefore, all vehicle models of the CO2 monitoring database were manually checked by their commercial name, emissions and other identification parameters in order to correctly allocate them to the relevant category (e.g. hybrid or plug-in hybrid).

In order to assess the overall impact of the taxation systems on vehicles in the period 2010-2017 and not the annual impact, the fleet that was used in our calculations is cumulative, ie the fleet of each single year is the new registrations of this specific year plus the aggregation of the new registrations of all previous years until 2010.

This cumulative fleet was used as the main input data of COPERT, which is the tool for calculating the final emissions and emission factors of each category of the vehicles. More information about COPERT is provided in the section 2.2. After baseline emissions were calculated, scenarios were created to simulate the impact of incentives and vehicle taxation policies. In the section 2.3 there is a brief description of the taxation system and incentives applied in the seven countries surveyed in the time frame 2010-2017. Finally, the scenarios that were created are explained in the section 2.4 and some clarifications made on the calculation process are analyzed in the section 2.5.

2.2 Copert

COPERT is a software that allows the user to calculate emissions from the road transport sector [8]. It is widely used in Europe and in several non-European countries for emissions monitoring and inventorying. The emission calculations include regulated (CO, NOx, VOC, PM) and unregulated pollutants (N2O, NH3, SO2, NMVOC speciation ...) and fuel consumption is also calculated. It is supported by the EEA and the JRC, while it has been developed, maintained and updated through the activities of the EEA's European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM). The calculation of the emissions in the COPERT takes into account the composition of the fleet as well as the activity and traffic data which is entered by the user.

COPERT allows the user to input a lot of parameters such as environmental characteristics, trip characteristics, activity levels (e.g. circulation data, annual mileage) and others that affect calculations. In our study we used COPERT specific countries data which are already prepared COPERT files that contain all the input information for a country. These files have been created using the road transport dataset and methodology of the TRACCS and FLEETS research projects, and reflect our best knowledge of national situation in each country. The quality, completeness, and consistency of TRACCS and FLEETS datasets, which have been extensively reviewed and cross-checked, together with the expertise of EMISIA on transport data, ensure that the compiled COPERT data are also of good quality. Therefore, the main input that was changed in our calculations was the fleet data as we wanted to examine the cumulative new registered fleet.

COPERT applies the Eurostat classification to define vehicle fleets, in which passenger cars (petrol and diesel) are distinguished into capacity classes (litres, L), as a method to group together vehicles with similar characteristics. These classes are then allocated to size classes based on the annual registrations per vehicle type, taken from the CO2 database.

- Mini: < 0.8 L
- Small: 0.8–1.4 L
- Medium: 1.4–2.0 L
- Large: > 2.0 L

COPERT provides real-world emission factors for each vehicle category and fuel type.

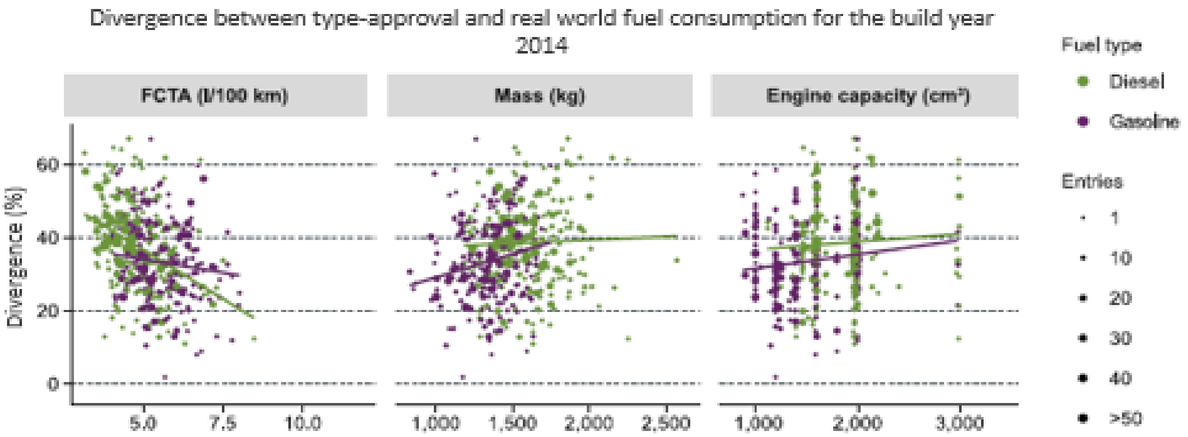
Official fuel consumption and carbon dioxide (CO2) emission values of European passenger cars are widely recognized to be unrepresentative of real-world driving as explained above in the Introduction section. Copert has the ability to estimate the exact discrepancy between legislative and real-world fuel consumption based on readily available vehicle characteristics, namely official fuel consumption values, vehicle mass, and engine capacity. In our model, the above vehicle characteristics were extracted from the CO2 monitoring database and inserted to Copert model for more accurate results in the real-world CO2 emissions.

Also, an important note is that the calculations made with the latest version of the Copert model which can simulate the growing divergence or "gap" between official and real-world CO2 values for European passenger cars [15, 16, 17, 18].

This new Copert feature is based on the study "From laboratory to road: Modeling the divergence between official and real-world fuel consumption and CO2 emission values in the German passenger car market for the years 2001–2014" [21]. This study noted that the divergence of type-approval and real-world values varies by segment, manufacturer, fuel, and transmission type. From 2001–2014, the divergence increased from 8% to 33% for gasoline cars and 10–39% for diesel cars.

Below is an excerpt of the results of this study. The data points represent model variants and the size indicates the number of vehicles in each vehicle variant. Also, there are best-fit lines that were created to specify the relation between the technical parameters (type approval fuel consumption, mass and engine capacity) and divergence.

Figure 2: Divergence between type-approval and real-world fuel consumption for the build year 2014 .



Some useful conclusions can be drawn from the above Figure 2. Generally, the divergence increases as the type approval fuel consumption value decreases for both petrol and diesel vehicles. However, the divergence for petrol vehicles are less sensitive to the change of type approval fuel consumption compared to diesel vehicles. For low type approval fuel consumption values, the divergence exceeds 40% for diesel vehicles.

Additionally, the divergence between type-approval and real-world fuel consumption values is typically increased for heavier vehicles and for vehicles with larger engines. With respect to powertrains, the above Figure 2 shows that diesel vehicles have generally higher divergence values compared to petrol vehicles across the whole mass and engine capacity values range. The divergence for diesel vehicles are affected only marginally by the mass and engine capacity of the vehicles whereas petrol vehicles are affected significantly by these parameters.

2.3 Selected Countries

Overall, most countries tend to employ a range of different environmental taxes and incentives. In continuation of "Vehicle Emissions and Impacts of Taxes and Incentives in the Evolution of Past Emissions" EIONET report the same seven key relevant countries were selected in order to assess the effect of vehicle taxation on real- world emissions, over the time period considered (from 2010 to 2017). This sample of countries chosen aim to cover the range of variations on vehicle taxation policies throughout all European countries.

The case studies presented are:

- Netherlands
- Greece
- Norway

- Germany
- France
- Ireland
- Poland

In **the Netherlands**, a CO_2-efficient car has been encouraged by (partial) exemptions from registration tax and annual circulation tax, while at the same time taxing diesel cars at a higher rate than petrol cars, for registration tax as well as in the annual circulation taxes. In the Netherlands around half of new car sales consist of company cars [23]. From 2010 to 2014, company BEVs and PHEVs were exempt from taxation of private use, which resulted in the number of EVs more than tripled from 2010 to 2015. The tax regime from 2015 for company BEV's and especially PHEVs became more unfavorable but remained much milder than for conventional cars [9]. In 2017, PHEVs are taxed like ICEVs and new sales of PHEVs dropped dramatically. The Dutch vehicle taxation system is considered one of the most stringent in Europe.

In **Greece**, the total number of new car registrations significantly decreased following the economic crisis. However, when the ban (since 1991) on diesel engines from central Athens and Thessaloniki (where 70% of the Greek population live), was lifted in 2012 [10], there was a significant increase in the sales of diesel vehicles. The diesel proportion of new sales exceeded 60% in 2015, significantly higher than the 4% in 2010. The penetration of EVs still remains very low, despite the financial incentives given, such as exemption from circulation tax.

Norway has the most sales of EVs, among the selected countries. This is mainly due to a long-term policy of relevant incentives dating back to the 90's [11], covering one-off benefits on acquisition (and exemption from registration tax) and recurring incentives (exemption from annual circulation tax). Additionally, since the early 00's EV's where excluded from VAT on purchase, providing a significant boost to the industry.

Germany, the leading country in automotive industry, records the highest sales of new cars across Europe [6]. Starting from 2009, the annual circulation tax is based on CO_2 emissions, although it is relatively low and has a rather small effect on car purchases and consumer behavior [5]. Also, until 2016 there was no kind of tax incentive or subsidy for BEVs or PHEVs. From 1 July 2016, the government has granted an environmental bonus of €4,000 for purely electric and fuel-cell vehicles and €3,000 for plug-in hybrid and range-extended electric vehicles and also 10 years exemption of the annual circulation tax for the fully electric vehicles [12]. In general, the car fleet in Germany includes mostly heavy (1443 kg on average), large and powerful cars. In July 2016, Germany adopted an incentive and investment program to encourage a switch to electric vehicles.

France is one of biggest European car markets, only behind Germany and the UK [6]. France has a large number of different taxes and incentives based on CO_2 emissions, including most notably a purchase bonus/malus system. This system rewards the buyer with an up-front bonus subsidy when buying a CO_2- efficient vehicle, and gradually penalizes buyers with a malus for purchasing high-emitting vehicles. EVs, PHEVs and hybrid vehicles receive the highest premium and are excluded from registration and circulation taxes. Furthermore, in 2009 a vehicle retirement program was established for cars which age exceeds ten years, combined with a subsidy for purchasing a new car. In March 2015, an additional scrapping scheme was put in place, for diesel passenger cars registered in 2006 or before. This incentive scheme grants €10,000 to electric vehicle buyers when they scrap an old diesel-powered vehicle [12].

Ireland represents relative small market from the selected countries. Since 2008, there has been established a CO_2-based tax mechanism (registration and circulation tax), which disregards engine size and focuses on CO2 emissions per kilometer [5]. Also, explicit incentives have been implemented for EVs and hybrid cars, for example a relief from registration tax. In Ireland from 2007, surcharges in diesel cars were lifted and this lead to rapid dieselization of the fleet up until 2010-2011. From 2011 to 2016, new sales of diesel cars were stabilized around 70% of new car sales on an annual basis.

In **Poland**, a relatively new member of the EU, the sales of second-hand cars are higher than new car registrations up until 2015. Poland is an example of a Member State which is completely lacking financial mechanisms to incentivize the consumers in buying EVs or Hybrid vehicles, for example there is no circulation tax at all [12]. Also, charging infrastructure for electric cars is non-existent [13]. Recently, significant progress has been made by Poland. In particular, in 2018 the Act on Electromobility and Alternative Fuels ("Act") was signed which is intended to promote electromobility and alternative fuel vehicles. The ultimate purpose of this action is to reduce emissions from transport by offering a portfolio of incentives including the exemption from excise-tax for BEV PHEV and FCEV, as well as other support targeting the construction of a basic alternative fuel infrastructure (including electricity, LNG, CNG and hydrogen).

2.4 Scenarios and assumptions

In order to quantify the impact upon emissions from the incentives and the vehicle taxation system that a country adopted over the time period 2010-2017, a number of scenarios were formed. Here are the scenarios along with their assumptions developed in our study:

- **Baseline scenario**. This scenario represents the actual real-world emissions of a country. The country fleet was extracted from the CO2 monitoring database and the execution made with the emission calculator tool COPERT. In this scenario, it is assumed that the "increased" share of EVs in the composition of the fleet in this period (2010-2017) is mainly due to the measures taken, incentives and the taxation system followed in national level. This scenario is used as a measure of comparison for the results of the other scenarios. The emission factors that have been calculated for each vehicle category for this scenario remains the same for EV and Dieselization scenarios.

- **EV scenario**. The EV scenario quantifies the benefit in CO2, NOX and PM10 emissions from the penetration of electrified vehicles in the national vehicle fleets. Basically, it is assumed that the taxation system and any incentives favoring these newer technology powertrains were never implemented in the passenger car market, from 2010 and onwards. Therefore, EVs new registrations in this scenario are reduced compared to the baseline scenario which means more conventional cars and this entails higher emissions. The difference in emissions from the baseline scenario represents the savings we have gained due to the measures taken. In other words, this scenario can be characterized as a no incentives scenario. For this scenario the number of EV cumulative registrations follows the overall passenger cars trend, i.e. their number is changed in proportion to the total number of cumulative registrations.

- **Dieselisation scenario**. In some countries (e.g. Greece) there has been a rapid increase of the diesel vehicles share in the fleet due to favorable diesel reforms. This scenario quantifies the benefit in the CO2 emissions due to the higher efficiency of diesel vehicles and the penalty in NOx and PM emissions deriving from the "dieselization" of the fleet. Diesel engines operate at higher temperature and pressure than petrol engines. These conditions favor the production of harmful pollutants such as NOx and PM. In this scenario the percentage of new diesel vehicles in total new registrations remains constant over the years and is equal to the base year value. This scenario has been examined only for Greece as it was the only country with strong dieselization of the new passenger cars fleet during the period 2010-2017.

- **Efficiency improvement scenario**. EU introduced mandatory emission reduction targets for new cars. With this legislation (EC No 443/2009) Europe is striving to achieve increased fuel economy of new vehicles sold in Europe. In addition, most of the Member states apply a vehicle taxation system that is based on CO2 emissions and favors the more efficient vehicles -mainly for conventional vehicles which are the majority but also for electrified vehicles. The combination of these two led to significant reductions in the weighted average CO2 emission factor from the new registrations. Manufacturers achieved efficiency improvement in cars by investing in the advancement of the engine and emission control technologies in order to comply with the stricter regulations. The purpose of this scenario is to calculate the emission savings from 2010 and onwards which are attributed to the European legislation and the national vehicle taxation system. For the implementation of this scenario it is assumed that the emission factors of all vehicle categories remained constant over the years and are equal to the respective base year (2010) values. In PM calculations there is no significant improvements and any reductions due to the introduction of Euro 6 standards are too low to be visible in 2015 and onwards.

All scenarios examine only tailpipe exhaust emissions (Tank-to-Wheel emissions). Indirect or upstream emissions, i.e. emissions associated with the electricity production that used for propulsion of electric vehicles, are not included in the study. Similarly, emissions released during the production of a fossil fuel are not taken into consideration.

At this point it should be noted that the national taxation systems effect is examined in both EV and Efficiency improvement scenarios. To clarify this issue, in the EV scenario we only take into consideration incentives for the purchase of electrified vehicles. In the Efficiency improvement scenario, apart from the improvement achieved from the manufacturers due to stricter legislation, we also take into account the effect of the national CO2 based taxation schemes which led to reduction in the weighted average CO2 emission factor from the new registrations (through affecting customers preferences). The CO2-based taxation schemes mainly concern conventional vehicles.

The number of the scenarios applied for each country, was based on the type of incentives used and the taxation policy followed. Based on the analysis of the EIONET report "Vehicle Emissions and Impacts of Taxes and Incentives in the Evolution of Past Emissions", the scope of the incentives varies among the selected countries for the examined time period (2010-2017). For example, the Netherlands did not have any incentives for encouraging the purchase of diesel cars instead of petrol cars (in fact there where surcharges), whereas in Greece, the ban on diesel-powered cars in certain urban areas was lifted in 2012, which is considered as an incentive towards dieselization. Therefore, a dieselization scenario was used in Greece, but it was obviously redundant in the Netherlands.

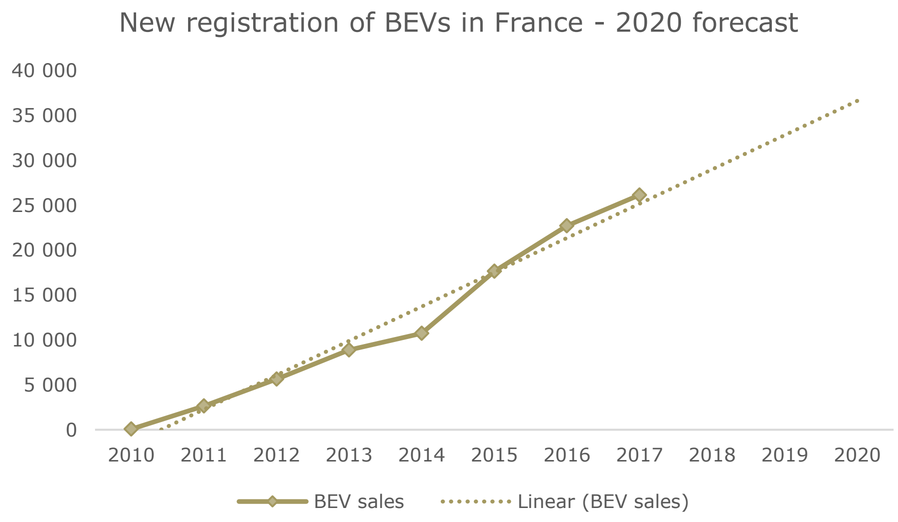
2.5 Projection

With a view to assess the future evolution of the emissions, the timeframe of the scenarios has been extended up to 2020, i.e. in the existing scenarios (baseline, EV, Dieselisation and Efficiency improvement), we added the calculations for the years 2018, 2019 and 2020. The calculation of the annual emissions is as follows:

*Emissions (t) = New Registrations (n) * EF (g/km) * Mileage (km/year) (1)*

Therefore, as can be seen from the above equation, there are some prerequisites for the estimation of the 2018-2020 emissions. Firstly, we have to estimate the sales trend by vehicle category for this period and also to assess the expected emission factors and annual mileage.

Figure 3: Forecast for BEV sales in France until 2020.



For the estimation of the new registrations for the period 2018-2020, a linear fit of the sales for the period 2010-2017 was made where possible (if this was not feasible due to lack of entries for one year the adjustment was made for a shorter time period, e.g. 2013 -2017). Then, an extrapolation of this trend line was made to assess the new registrations of the period 2018-2020. The above Figure 3 shows an example of the BEV sales in France. In the period from 2010 to 2017, the actual sales of BEVs are presented with a solid line. Actual new registrations are simulated by a linear trend (dotted line) which is then extended for the next three years. This is the way in which sales by category are calculated for the years 2018-2020.

The same approach was adopted and for the corresponding emission factors. Finally, the annual mileage for the period 2018-2020 was considered to be the same as in 2017.

It should be noticed that some countries such as Poland and Germany have taken strong measures to introduce electric vehicles into their fleet towards the end of 2010-2017. Nevertheless, these measures are not taken into consideration in the forecast for sales of electric vehicles for the period 2018-2020.

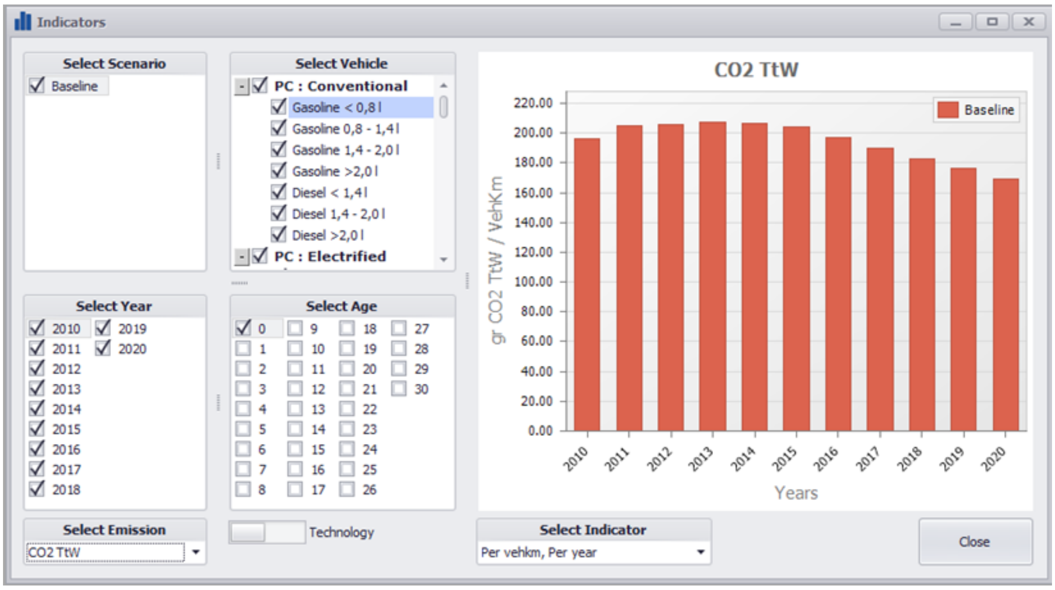
2.6 Clarifications on calculations

Here are some clarifications about the calculations of the above scenarios:

It was assumed that the total vehicle kilometers driven annually in a country should not differ between the scenarios. Although there are variations in the fleet distribution of each scenario, as is reasonable there should be no differentiation in the number of vehicle-kilometers made annually from the baseline scenario for the simple reason that the passenger car drivers will have the same driving habits and travel preferences and the demand for vehicle-kilometers will not change if for example there are more EVs in the country's fleet. Due to the fact that each vehicle category has a different annual mileage, if the composition of the fleet changes then there is a deviation in the vehicle-kilometers made each year compared to the baseline scenario. For this reason, a correction was applied to comply with the above condition.

COPERT did not provide yet Diesel hybrid and PHEV categories. For this reason, in the baseline scenario emission factors and annual mileage for Diesel hybrid and PHEVs were extracted from the Sybil software [14]. The EFs for NOX and PM were also produced from Sybil for PHEVs and Diesel-Hybrids. For BEVs, the annual mileage was extracted again by the Sybil tool. Sibyl (Figure 4) is a prediction tool that has preinstalled data that allows users to predict vehicle emission levels and stock on a country [14]. It has been developed, maintained and constantly updated by Emisia researchers.

Figure 4: Sibyl software.



For **Greece**, the CO2 monitoring database had incomplete data on engine capacity, for the years 2010 until 2012. Similarly, in **Ireland** there was a lack of such data for 2010 and 2011, so we cannot separate the new registrations into class sizes (mini, small, medium, large). Therefore, since COPERT requires the fleet allocated to the specific size classes these years were excluded, and the base years for the calculations were 2013 and 2012 for Greece and Ireland respectively. The only exemption was made in the dieselization scenario used in Greece where the percentage of new diesel vehicles in total new registrations remains equal to the 2010 value, because by 2013 new diesel registrations had already surpassed petrol ones.

Also, fleet-average EFs for conventional vehicles (petrol and diesel), were extracted from the CO2 database and compared with fleet-average EFs calculated from COPERT. This provides a comparison between measurements performed in the laboratory using the standard European vehicle test cycle and emission factors which reflect real-world driving performance, and prove to be more integrated in recent years.

3 Results and discussion

This section presents the results (such as CO2 emission factors, total emissions and emission savings) of the scenarios execution per country for the time period 2010-2017 and the projection made till 2020 as well as an interpretation of these results taking into account the vehicle taxation policy followed and the incentives given by the country to increase the rate of introduction of EVs in the fleet.

In general, it was observed that the difference between real world and legislative emissions varies considerably amongst countries. This can be attributed to the fact that each country has a lot of different parameters such as circulation data, different distributions of vehicle categories, segment, manufacturer, different environmental conditions etc. Moreover, in some cases it was observed that the real-world CO2 emission factor can be increased over the years. As abovementioned, on-road CO2 values for average European passenger cars only slightly decreased which means that in some countries minor rises in CO2 emission factors cannot be excluded.

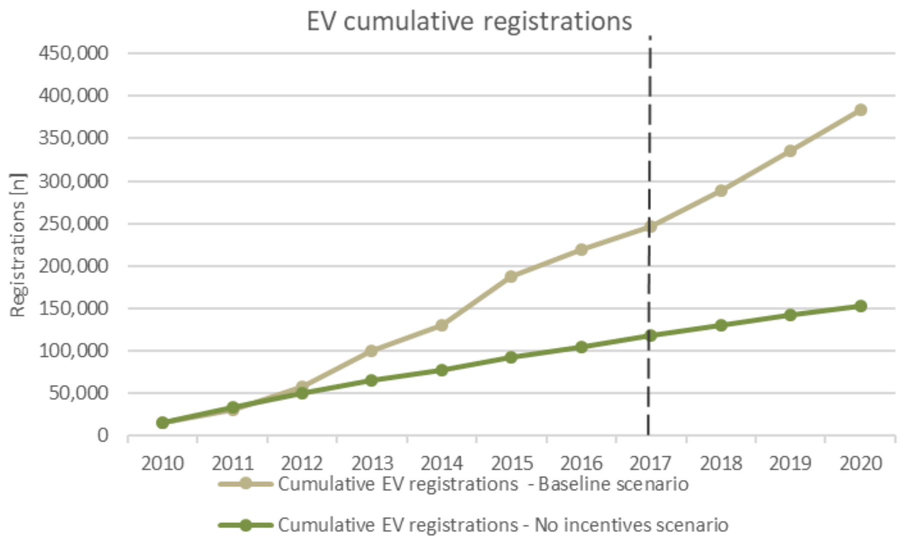
3.1 Netherlands

The Netherlands applied a tax system that favored EVs as well more efficient low-emission conventional vehicles in the period 2010-2017. The tax system becomes more stringent year after year and focuses on the introduction of zero emission vehicles. Fiscal incentives for plug-in hybrid vehicles have been gradually reduced to the same level as regular cars in 2017 [5, 9]. The scenarios created for the Netherlands are: Baseline scenario, EV scenario and Efficiency improvement scenario.

3.1.1 EV registrations

The actual cumulative new EV registrations are shown in Figure 5 (baseline scenario), which have been constantly growing due to strong fiscal incentives applied in the examined time period. By the end of 2017, there are about 250,000 new EVs in the Dutch roads. In the EV scenario i.e. the scenario where there are no incentives favoring EVs, the new EVs registrations follow a smaller and steadier growth rate, predicting new car buyers' behaviour without any kind of incentive mechanisms (registrations follow the overall passenger cars trend).

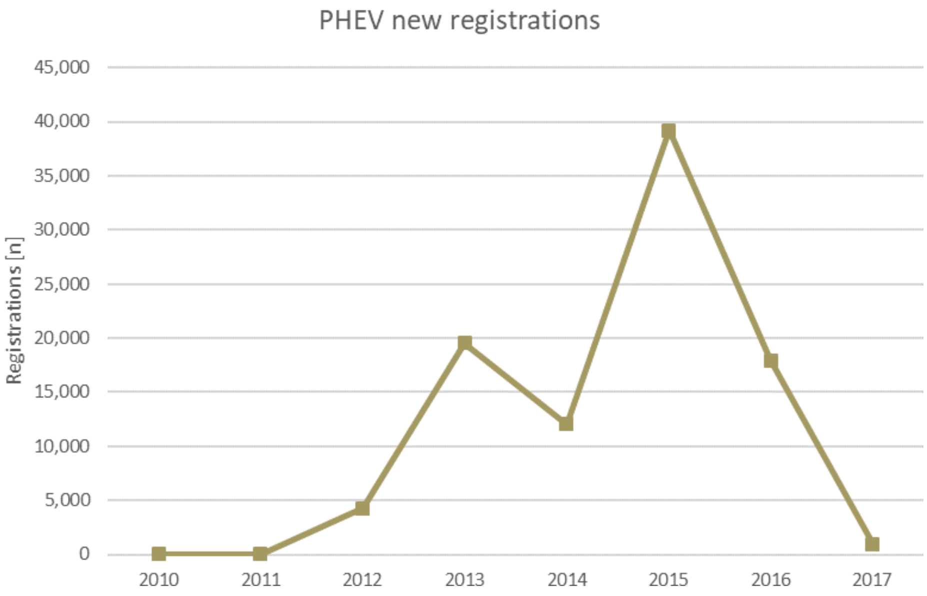
Figure 5: EV new registrations fleet in Netherlands.



The Netherlands case is a very good example to understand that consumer preferences and the penetration of EVs are still strongly linked to the tax regime. In 2017, PHEV company drivers were taxed at 22% of the gross list price, which is the same as the taxation of conventional vehicles. It is therefore interesting to see how the PHEV market went in 2017 but also in previous years when the tax regime was more favorable for PHEV. Figure 6 shows the PHEV new registrations in the time period 2010-2017. The most noteworthy on this chart is the dramatic declining sales figures of PHEVs from 2015 until 2017 where the taxation for PHEVs became less favorable and that is a strong evidence of PHEV sales dependence on government's subsidy schemes.

This contradictory behavior of PHEV sales ie the sharp increase until 2015 and then sharp decline until 2017 makes difficult the prediction for the years 2018-2020 with the linear extrapolation method followed. Our projection model increased the total PHEV new registrations by 73000 in the 3 years period (2018-2020) while the actual new registrations of PHEVs are about 1000 in 2017. Therefore, the forecast made for the Netherlands is characterized by high levels of uncertainty.

Figure 6: PHEV new registrations in Netherlands.



3.1.2 CO2 emissions

Figure 7 shows the fleet-average emission factors of conventional vehicles (diesel and petrol) derived from COPERT (real-world) and the corresponding emission factors derived from the CO_2 monitoring database (EU regulation-based measurement in NEDC driving cycle). There is a clear downward trend in official and real- world CO_2 emissions from new cars registered. Both petrol and diesel vehicles have made significant progress.

Figure 7: Conventional vehicles CO2 EFs in Netherlands

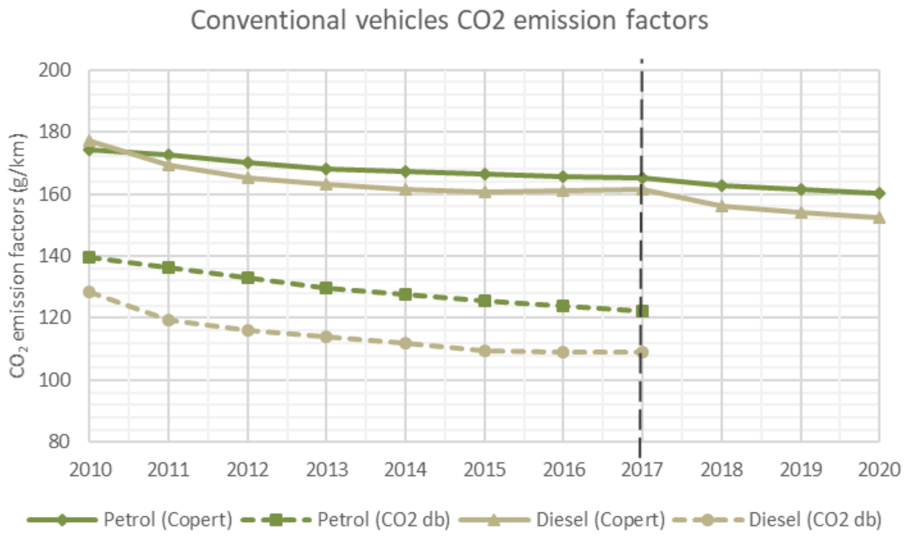


Figure 8: CO2 emissions for different scenarios in Netherlands

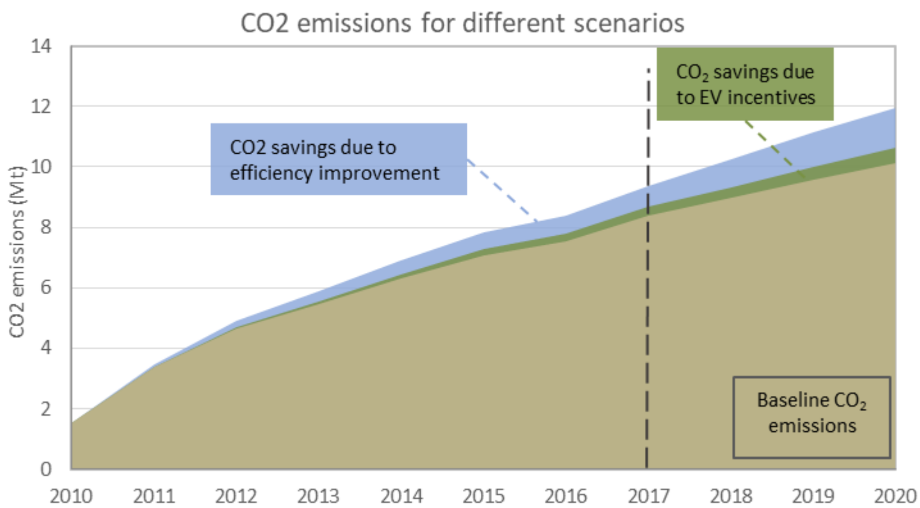


Figure 9: CO2 emission factors for different scenarios in Netherlands.

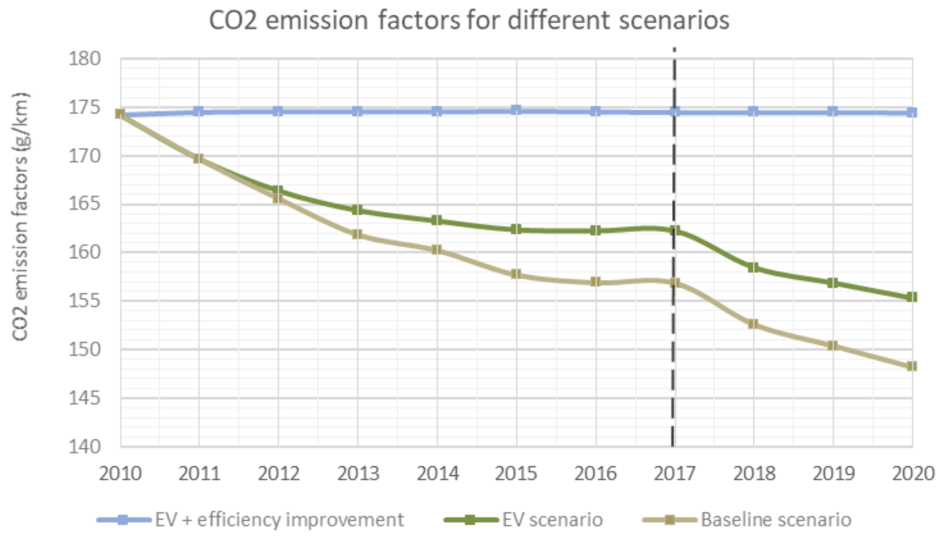


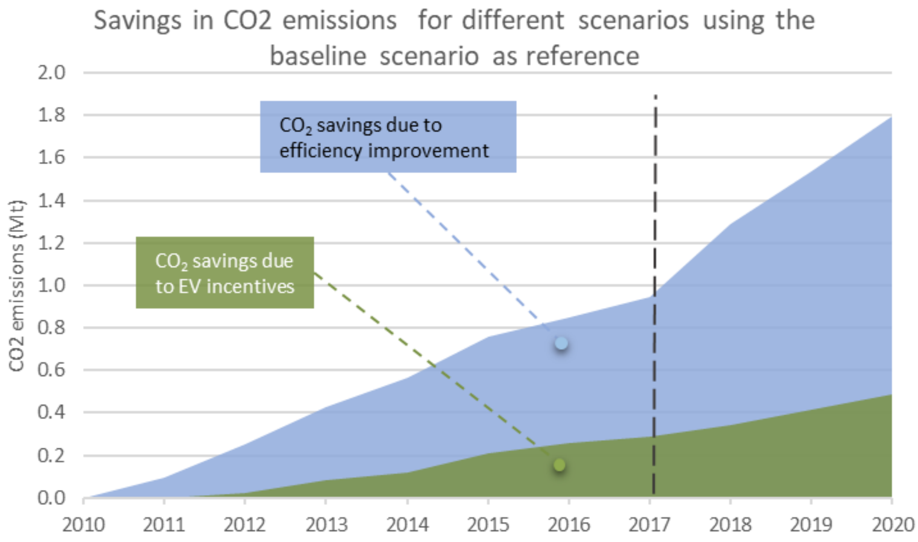
Figure 8 shows the CO2 emissions calculated for all three scenarios examined. The cumulative new registrations of each year have been studied, so it makes sense to have an upward trend in all scenarios. The brown area represents the baseline scenario, whereas the green area shows the savings achieved that are attributed to the incentives given for the purchase of EVs, and the light blue area shows the savings achieved ascribed to the EU legislation implemented which had the target to improve the fuel economy of new sold vehicles and national CO2-based vehicle taxation system.

The findings of this comparison are very interesting. More specifically, at the end of the examined period, the total savings in CO2 emissions due to EV incentives and efficiency improvements are approximately 1 Mt. It is worth noting that, the CO2 savings from the efficiency improvements motivated by European legislation and national vehicle taxation are higher than those achieved by the mechanisms for the promotion of EVs implemented at national level.

In addition, in Figure 9 the CO2 emission factors of all scenarios are shown. Following the same colors semantics, the brown line represents the baseline scenario. This scenario has the smallest emission factors due to the measures taken, incentives and the taxation system that favored the introduction of EVs in the fleet. Green line stands for the CO2 emission factors, assuming that no incentive has been given for the purchase of EVs (which means less EVs in the fleet). Finally, the light blue line depicts the CO2 emission factors without any kind of policy that helps EVs to be more attractive to the costumers but also without any advancement in engine and emission control technology which are motivated by European legislation aimed at reducing emissions. Therefore, the CO2 emission factor remains constant for the whole period and is equal with the emission factor of the reference year 2010.

Figure 10 has been created for comparing the EV scenario with the efficiency improvement scenario. It illustrates their CO2 savings by taking as reference the baseline scenario. The results show that a significant proportion of total savings is due to Dutch policy aimed at changing purchasing behavior towards lower CO2- emitting passenger cars. Specifically, in 2020, according to our projection, 27% of total CO2 savings will be due to the national strategy for EVs followed. As noted above the emissions forecast for the years 2018-2020 in the Netherlands has high levels of uncertainty due to the change of the taxation schema mainly for the PHEVs.

Figure 10: Savings in CO2 emissions compared to the baseline scenario in Netherlands



3.1.3 NOx emissions

In the Netherlands, there were no incentives towards the diesel vehicles and in fact there are surcharges for this vehicle category. Therefore, a dieselization scenario was not considered due to the fact that the share of diesel vehicles in the fleet did not increase significantly in the examined period.

A major drawback of diesel engines is that they emit much higher NOx emissions compared with corresponding petrol engines. The rise in EV registrations at the expense of conventional (petrol and diesel) registrations, due to the implemented fiscal incentives led to savings in NOx emissions. This indirect reduction in sales of diesel vehicles had a positive impact on NOx emissions, as shown in Figure 11. The NOx emission factors depicted in Figure 12. As expected, baseline NOx emission factors are lower than those in the EV scenario (no incentives for EVs). Moreover, it can be observed that NOx emission factors have a slight increasing trend over the period 2010-2012. This can be attributed to the fact that the share of diesel vehicles in the fleet has increased significantly over this period. It should be noted that diesel vehicles have also a higher real-world vs legislation gap than petrol for NOx emissions [25].

Figure 11: NOx emissions for different scenarios in Netherlands

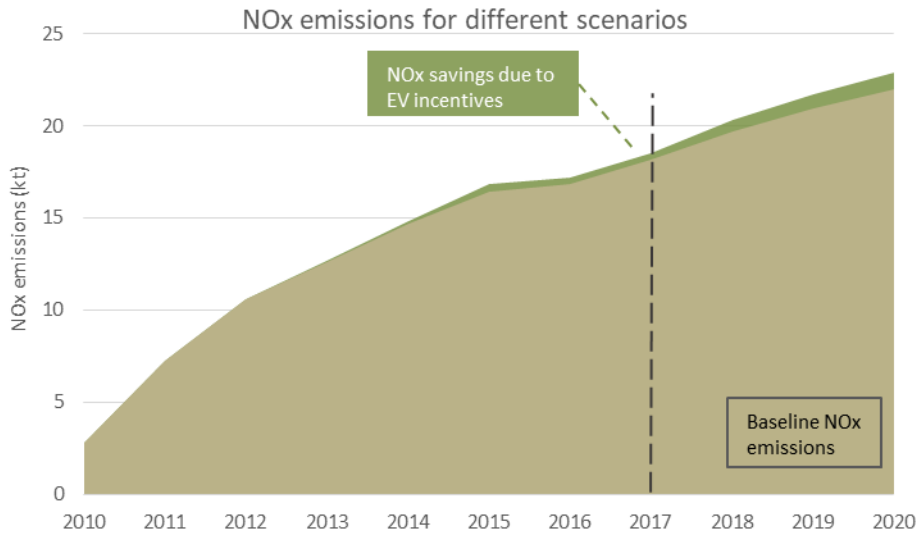
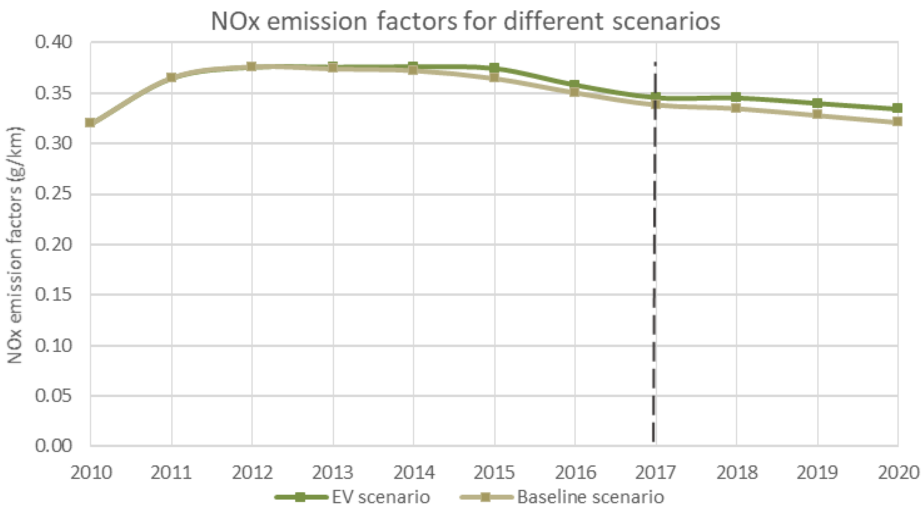
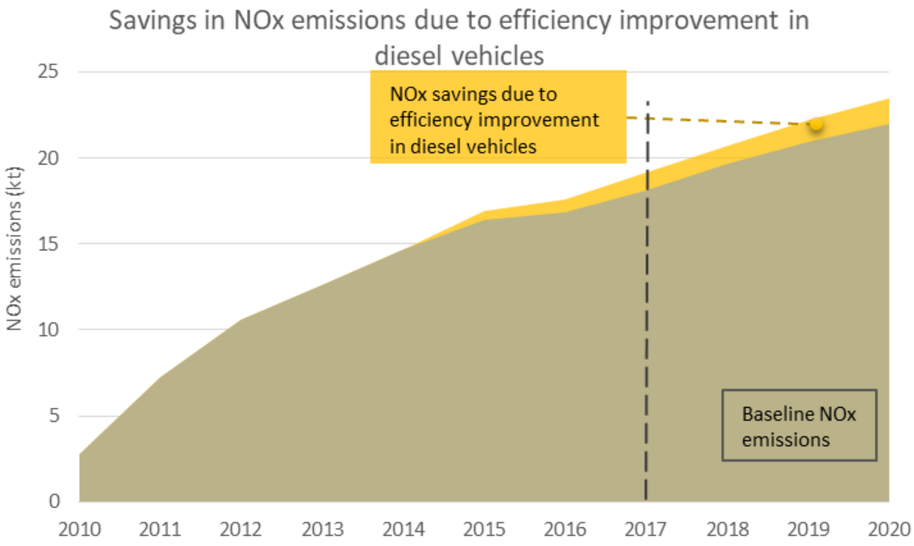


Figure 12: NOx emission factors for different scenarios in Netherlands



European emission standards for passenger cars are differentiated for petrol and diesel vehicles. Diesel vehicles are permitted to emit higher NOx emissions than petrol vehicles. However, between Euro 5 and Euro 6 standards, diesel vehicles are obliged to reduce a lot their NOx emissions whereas this is not the case for petrol vehicles. With the introduction of Euro 6 standards, the authorities are optimistic that a significant reduction in NOx emissions will be achieved. In our study the effect of the in the introduction of Euro 6 standards seems to have great impact on NOx emissions. Euro 6 standards were introduced in 2015, so the effect of legislation becomes apparent from 2015 onwards as can be seen in the Figure 13.

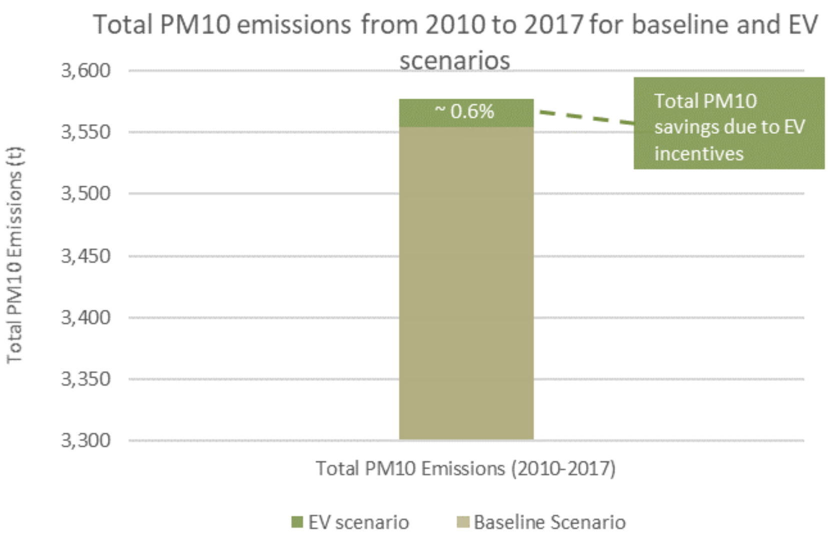
Figure 13: Savings in NOx emissions due to efficiency improvement in diesel vehicles



3.1.4 PM10 emissions

For PM10 emissions, the annual differences between the baseline scenario and the EV scenario are very small and not visible, therefore the total PM10 emissions for the whole-time period (2010-2017) have been calculated. In this time frame the total savings, due to the EV incentivization is barely 23 tonnes PM10, showing that the rise in EV sales had a somewhat limited effect in reducing PM10 emissions (Figure 14). In addition, Euro 6 emission control technology has the same emission limits for PM emissions with Euro 5 technology for both petrol and diesel cars [24].

Figure 14: Total PM10 emissions (2010-2017) for different scenarios in Netherlands



3.2 France

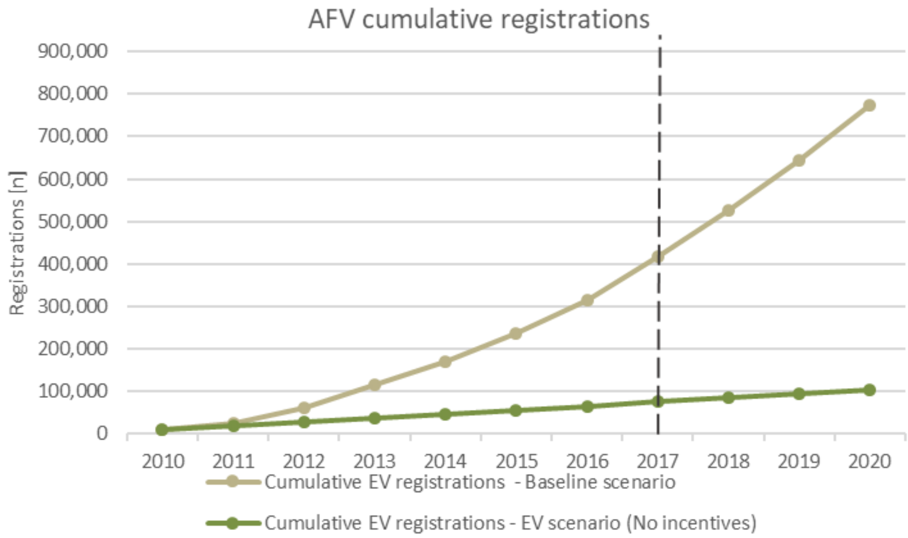
France has been one of the countries that has been very active in recent years in the area of vehicle tax policy aiming to reduce CO2 from road transport. In particular, France implemented the 'bonus / malus' scheme that has been introduced to boost sales of new, fuel-efficient cars and drop the number of older and more polluting cars. This system seems to have a massive impact on the French consumers and resulted to rank France among Europe's leading in the uptake of energy efficient vehicles in the fleet.

3.2.1 EV registrations

The actual cumulative new EV registrations are presented in Figure 15 (baseline scenario). Incentive mechanisms led to a rapid upward trend in the EV sales. Approximately 420,000 EVs were sold by 2017, suggesting that the tax mechanisms developed eventually boosted the purchase of energy efficient vehicles.

Also, Figure 15 shows the assessed cumulative EV registrations for the scenario where no incentives were applied by French authorities.

Figure 15: EV new registrations fleet in France



3.2.2 CO2 emissions

The fleet-average CO2 emission factors of conventional vehicles (diesel and petrol) derived from COPERT (real-world) and the corresponding emission factors derived from the CO2 monitoring database are shown in Figure 16. While there is a steadily declining trend in official CO2 emission factors for both petrol and diesel new cars registered, the real-world emission factors until 2012 are slightly increased. This can be attributed to the constantly widening gap between real world and official values that was analyzed previously. From 2012 until 2017 petrol vehicles declined approximately 1 g/km and diesel vehicles about 2 g/km.

Figure 16: Conventional vehicles CO2 EFs in France

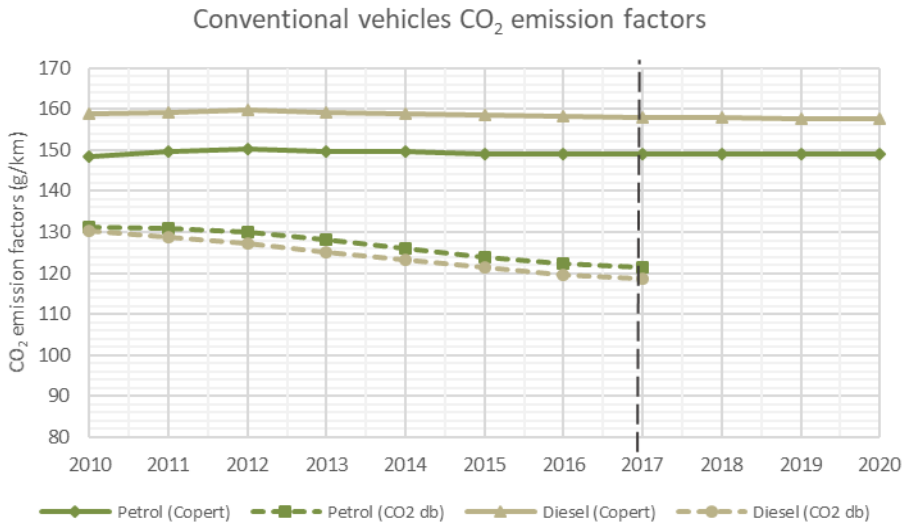


Figure 17: CO$_2$ emissions for different scenarios in France

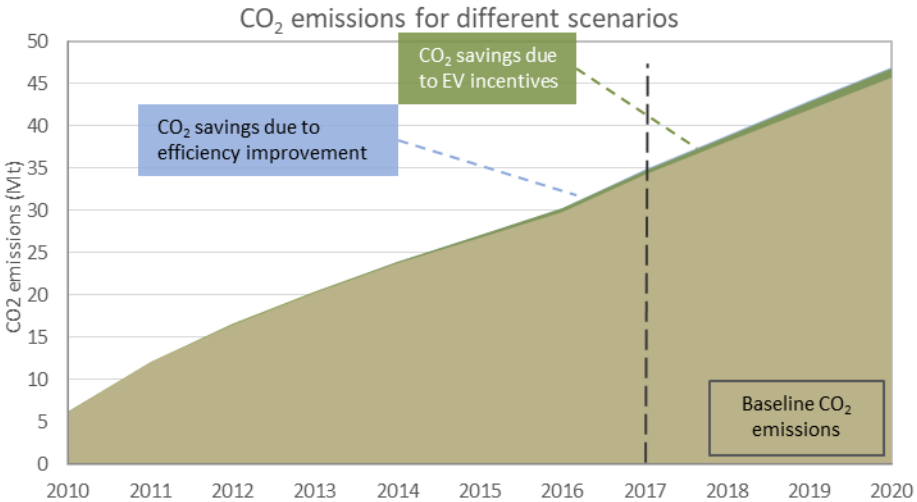
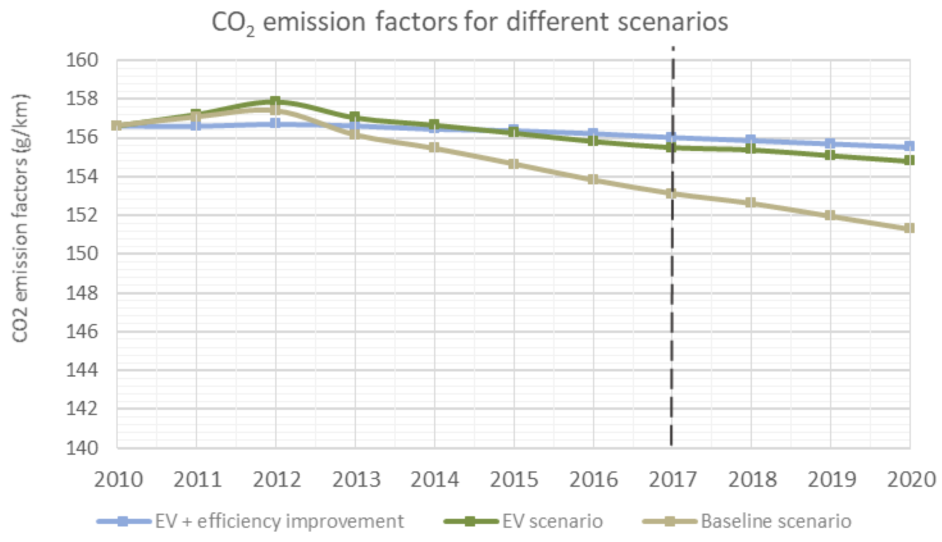


Figure 18: CO_2 emission factors for different scenarios in France



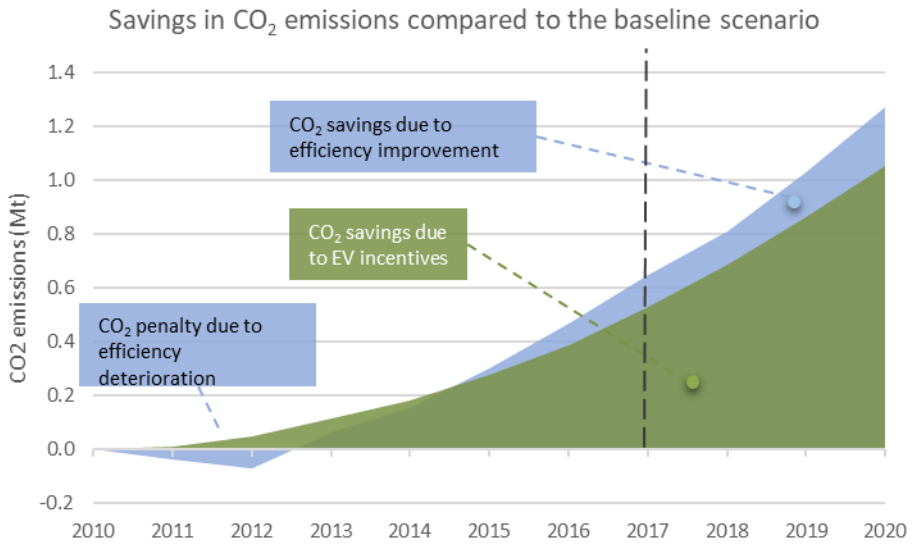
The calculated CO2 emissions of the three scenarios (baseline, EV and efficiency improvements) for the time series (2010-2017) are illustrated in the Figure 17.

Comparing the data, it appears that in France the CO2 benefit gained from the incentives given for EVs is much higher than the corresponding benefit gained from the efficiency improvement of the vehicles (mainly due to the European legislation but also from the national CO2 based vehicle taxation scheme).More specifically, due to the the incentives for EVs given in the 7-year period 2010-2017, about 0.5 Mt less CO2 were emitted. On the contrary, efficiency improvement helped to save only about 0.1 Mt of CO2. In a hypothetical scenario where no measure / legislation has been taken, then in 2017, new vehicles sold in France in the period 2010-2017 were expected to emit about 34.8 Mt of CO2. which means that CO2 emissions in 2017 have been reduced by about 2% due to all kind of policies. This fall might seem quite small, but it is at the same level as the decrease observed in EU average real-world emission factors for the period 2010- 2016.

Figure 18 shows the CO2 emission factors for all the scenarios. Baseline scenario emission factor increases from 2010 until 2012 and then decreases slightly until 2017. The emission factor for 2017 is about 2% less than 2010 emission factor. The diesel vehicles share in France for the years 2010-2012 was very high (about 75%). As explained above the divergence between real world and type approval values is higher for diesel than petrol vehicles [21] and grows over time. The very high share of diesel vehicles explain why the real-world CO2 emission factor increased for the years 2010-2012. After 2012 the share of diesel drops to reach 56% in 2017 and the real-world CO2 emission factor follows a downward trend during this period (2012-2017).

The following diagram (Figure 19) depicts the contribution that the two scenarios (EV and efficiency improvement) had and is expected to have in reducing CO2 emissions until 2020. For the first two years of the examined time period, instead of having savings in CO2 emissions, France has seen an increase in emissions. This led the proportion of the savings attributed to EV incentives to be much larger than the savings attributed to the efficiency improvement of the vehicles.

Figure 19: Savings in CO2 emissions compared to the baseline scenario in France



3.2.3 NOx emissions

The savings in NOx emissions due to national incentives, as shown by the Figure 20, are somewhat limited which make sense as incentives and vehicle taxation in general are based on CO2 emissions rather than NOx emissions. Figure 21 shows the NOx emission factors for the period considered confirming the previous sentence. In contrast, EU legislation aimed at reducing NOx by introducing Euro 6 vehicles that appeared in the fleet in 2015 and having much lower NOx emission limits than Euro 5. Also, the diesel vehicle market remains dominant, therefore, a large impact on overall emissions NOx of the fleet as shown in Figure 22.

Figure 20: NOx emissions for different scenarios in France.

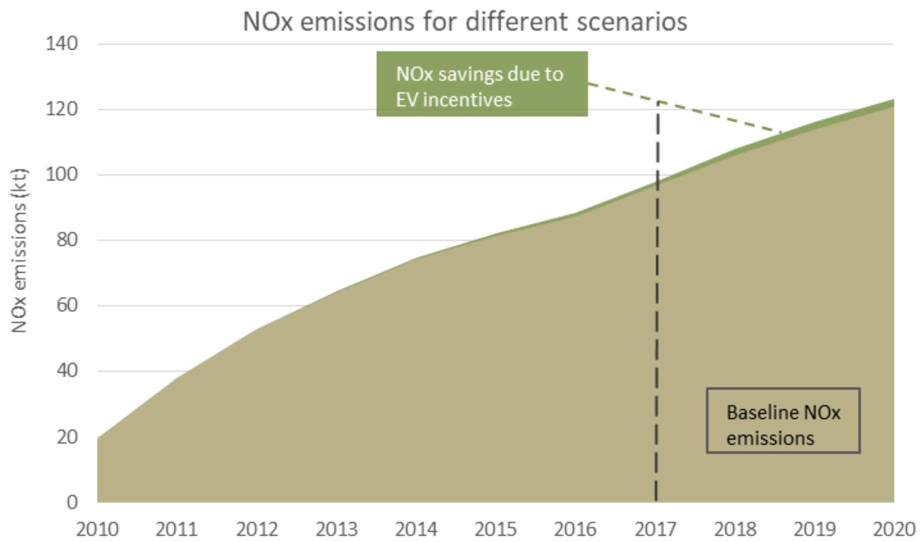


Figure 21: NOx emission factors for different scenarios in France.

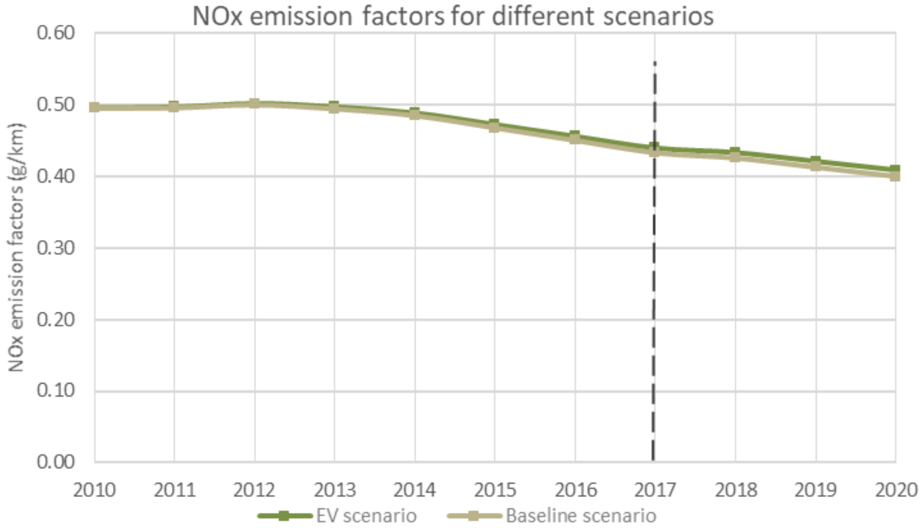
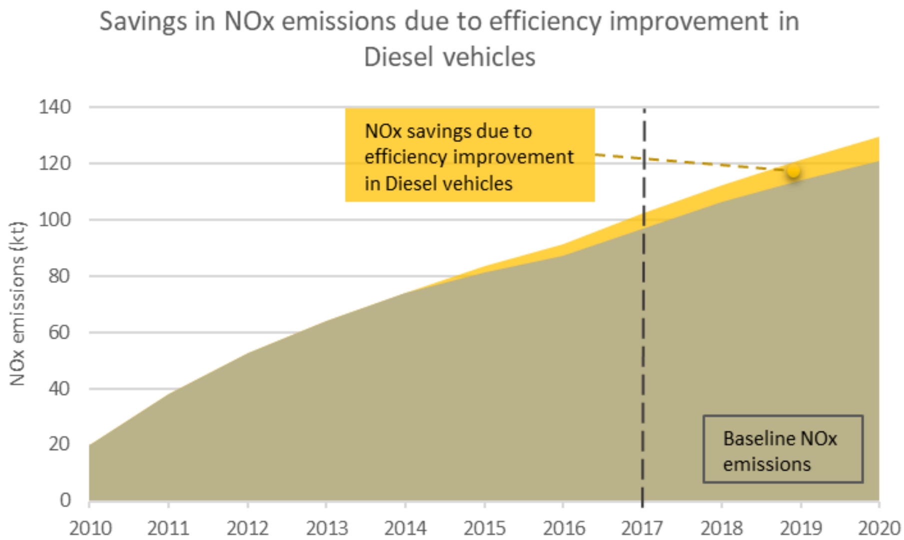


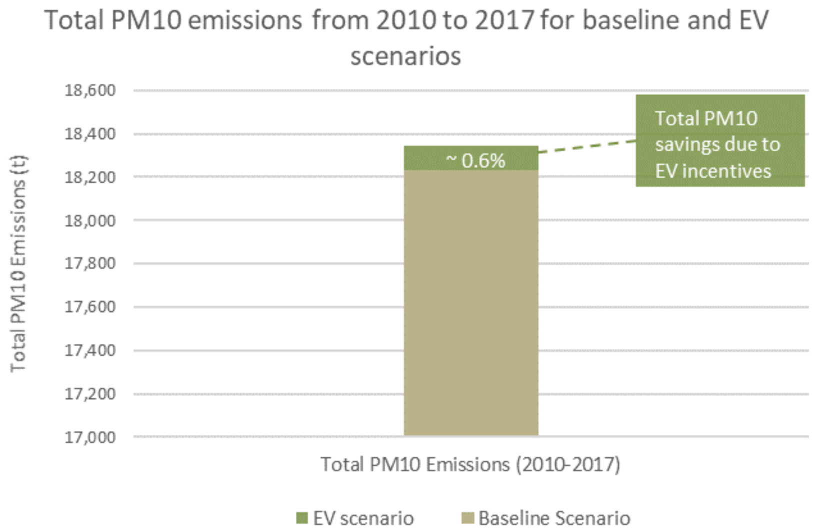
Figure 22: Savings in NOx emissions due to efficiency improvement in diesel vehicles.



3.2.4 PM10 emissions

In the 2010-2017 period, due to the incentives given for more energy-efficient vehicles from the French government, there was also a small reduction in PM10 emissions. Total savings in PM10 emissions for the whole-time period (2010-2017) were around 110 t.

Figure 23: Total PM10 emissions (2010-2017) for different scenarios in France.



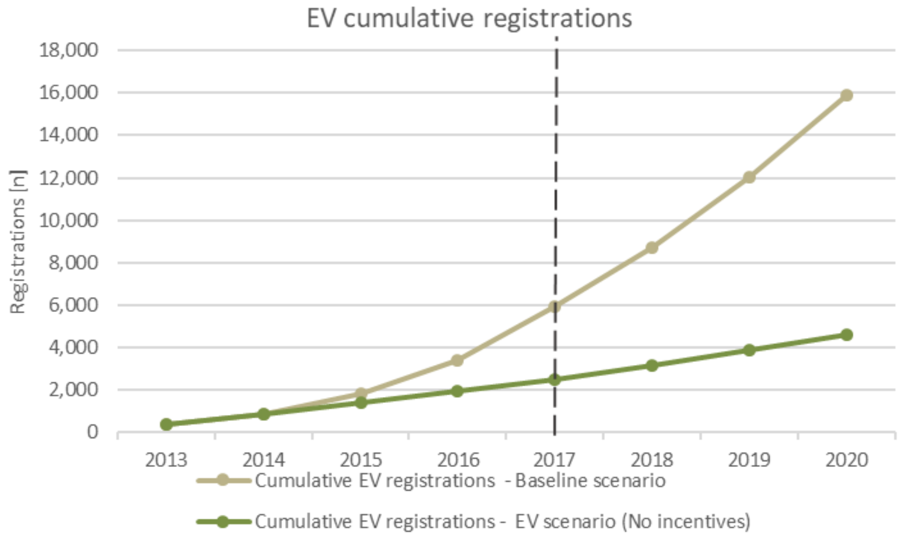
3.3 Greece

Greece is a special case-study because it had important external factors that influenced the composition of the new registrations fleet. In Greece, there has been a long-standing ban on diesel cars in the two largest cities, Athens and Thessaloniki. Lifting the ban and lower taxes on diesel fuel has acted as a huge incentive for those struggling with travel costs and has resulted in dieselization of the fleet. Then, Greek economy has been strongly tested in recent years, which led to a reduction in the demand for new passenger cars and in particular for large passenger cars that have been subject to an extra duty (luxury tax). These two factors significantly improved the average CO_2 emitted by a vehicle in Greece but unfortunately aggravated the air quality. Finally, although there are some measures favoring the uptake of EVs, they are too small to entice consumers to turn to EVs. The scenarios created for Greece are: Baseline scenario, EV scenario, Dieselization scenario and Efficiency improvement scenario.

3.3.1 EV registrations

The actual cumulative new EVs registrations are shown in Figure 24. The incentives given to Greek citizens were of low intensity and therefore EVs did not penetrate significantly in the Greek market.

Figure 24: EV new registrations fleet in Greece.



3.3.2 CO2 emissions

Figure 25 shows the average CO2 emission factors of petrol and diesel vehicles from the CO2 monitoring database and those calculated by COPERT. It is worth noting that the diesel vehicles emission factors are very low. In particular, diesel emission factors ranged from 111 to 105 g/km in the period from 2013 to 2017, while the corresponding emission factors in France were 125-118 g/km. This fact shows that Greeks preferred small cars with great fuel economy. CO2 monitoring database for Greece had incomplete data on engine capacity, for the years 2010 until 2012 and since COPERT requires the fleet allocated to the specific size classes (mini / small / medium / large), we remind that these years were excluded and the base year for the calculations was 2013.

Figure 25: Conventional vehicles CO2 EFs in Greece

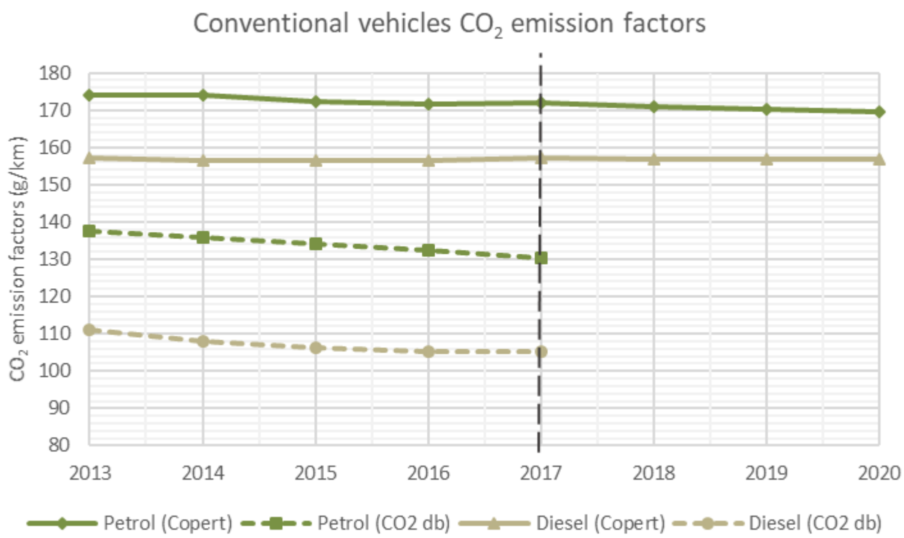


Figure 26: CO2 emissions for different scenarios in Greece

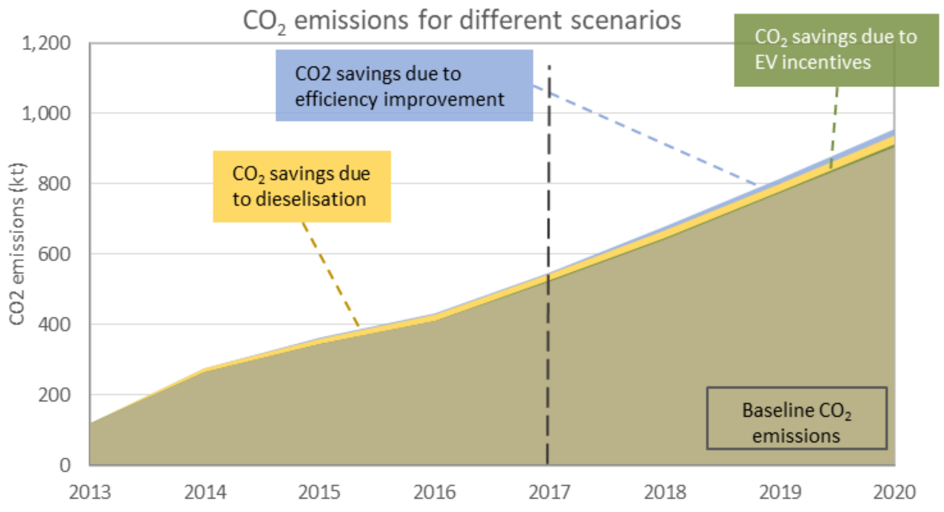
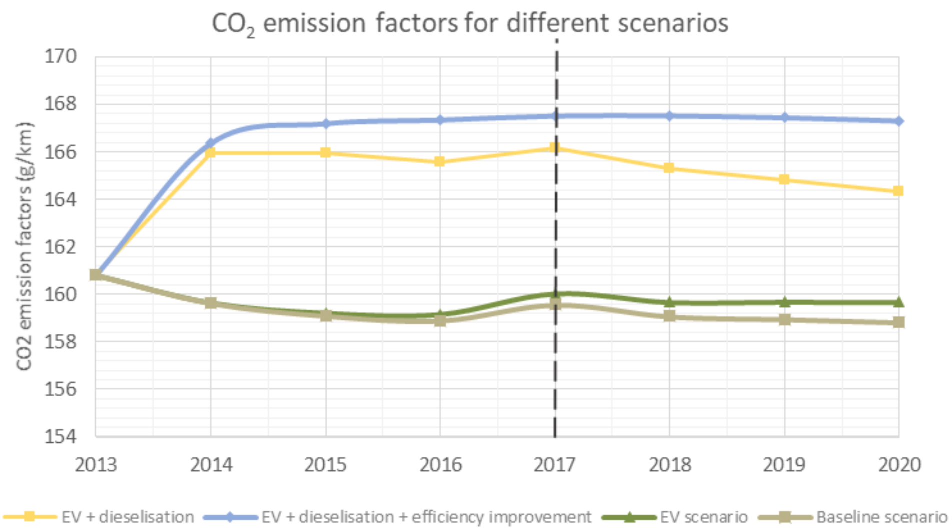


Figure 27: CO2 emission factors for different scenarios in Greece.



The calculated CO2 emissions of the four scenarios (baseline, EV, dieselization and efficiency improvements) for the time series (2013-2017) are illustrated in the Figure 26. As in other countries examined, brown area represents the baseline scenario, green area represents EV scenario, and the light blue area the efficiency improvement scenario. The addition here is the yellow area which represents the savings gained from the dieselization of the fleet.

Figure 26 also shows that 2014 and 2017 are years in which total CO2 emissions have raised remarkably. This is due to the fact that in 2014 there was a significant recovery in the passenger car market, as out of about 58,000 annual sales in 2012 and 2013, sales in 2014 surpassed 70,000. Still a big increase was observed in 2017 where annual sales reached 87,500.

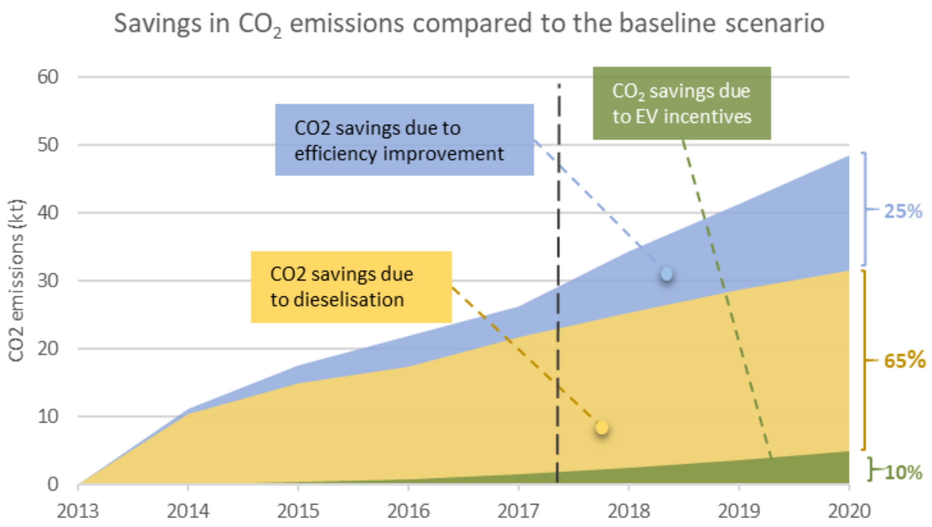
Greece managed to reduce CO2 emissions by 26 kt in 2017 and this is due to European legislation that has pushed the development of more efficient vehicles and the tax policy it has pursued to promote EVs. In addition, the lifting of the diesel ban was a political move that led the introduction of many diesel vehicles into the fleet. These vehicles are more energy efficient than the corresponding petrol and therefore a percentage of total CO2 emissions reduction is due to fleet dieselization.

As mentioned above, the incentives given by the Greek government for EVs were rather weak and had a very low monetary value. Therefore, it is reasonable that the savings of emissions from the EVs adoption barely can be seen in Figure 26. However, the emission savings for the dieselization and the efficiency improvement are much higher.

The Greek CO2 emission factors have been influenced very much from the dieselization of the fleet as depicted in the Figure 27. If there was not such demand for diesel vehicles in Greece the CO2 emission factor would be elevated by about 6 g/km.

Figure 28 shows the contribution of the three scenarios to the reduction of CO2 emissions. In 2017 dieselization of the fleet was the predominant reason of emission reductions as prevented the emission of about 20 kt of CO2, while the savings gained from the efficiency improvement were about 4.5 kt of CO2. Based in our projection, at the end of 2020, the gains in CO2 emissions are expected to originate from EV incentives up to 10%, 65% from dieselization of the fleet and 25% from European legislation and national CO2 based taxation system.

Figure 28: Savings in CO2 emissions compared to the baseline scenario in Greece



3.3.3 NOx emissions

The dieselization of the fleet has definitely provoked an improvement in CO2 emissions in the country as we have seen above. However, this gain was accompanied by side effects in air quality. Greece's decision to lift the ban on diesel vehicles in major cities may have underestimated the risk posed by toxic NOx emissions, which are produced to a much greater extent in diesel than in petrol vehicles.

Figure 29 shows the NOx emissions resulting from the various scenarios examined. The brown area represents the baseline scenario, ie the NOx emissions from the new registrations in Greece. The green area shows the savings in NOx emissions that are attributed to the measures taken and favored the EVs. As explained above, the incentives were not very attractive to consumers, and these few measures were not aimed at reducing NOx but mainly CO2. This explains why the green area, i.e. the savings due to EV incentives, is very small. The yellow area shows how the NOx emission would be if there was no dieselization of the fleet and as expected NOx emissions are much smaller in this case.

The NOx emission factors are illustrated in the Figure 30. Incentives for purchasing EVs practically did not affect the NOx emission factor whereas if the dieselization of the fleet was somehow avoided, the NOx emission factor would be dramatically reduced.

The difference of the diesel scenario with the baseline scenario gives us the extra NOx emissions we have due to fleet dieselization as shown in Figure 31. The negative sign means that there are no savings but instead there is an increase in total emissions.

Figure 32 shows the emissions savings due to the enforcement of the legislation where Euro 6 vehicles that arrived in 2015 have much lower NOx emission limits compared to Euro 5 vehicles.

Figure 29: NOx emissions for different scenarios in Greece.

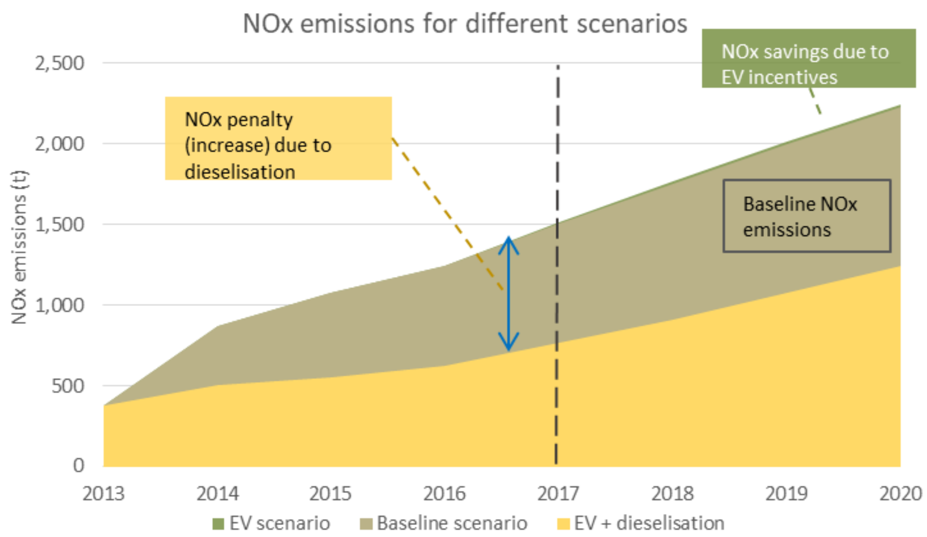


Figure 30: NOx emission factors for different scenarios in Greece.

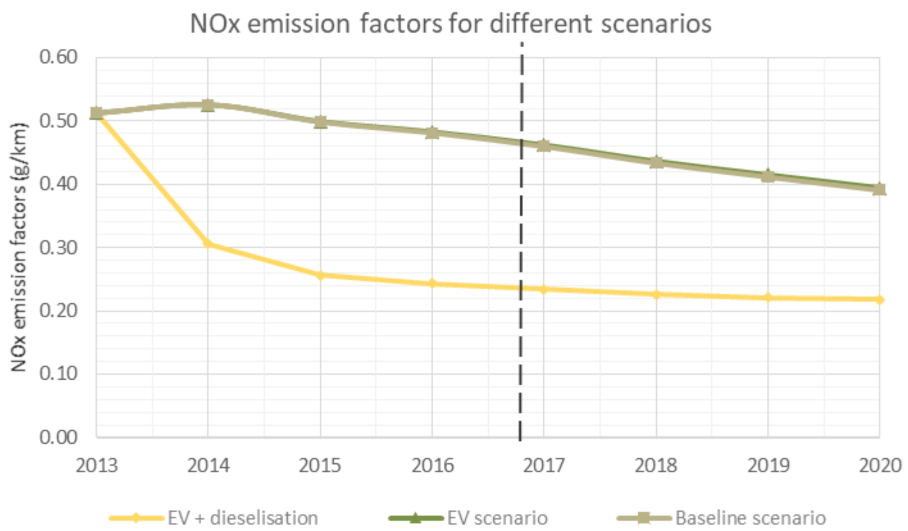


Figure 31: NOx emissions for different scenarios in Greece.

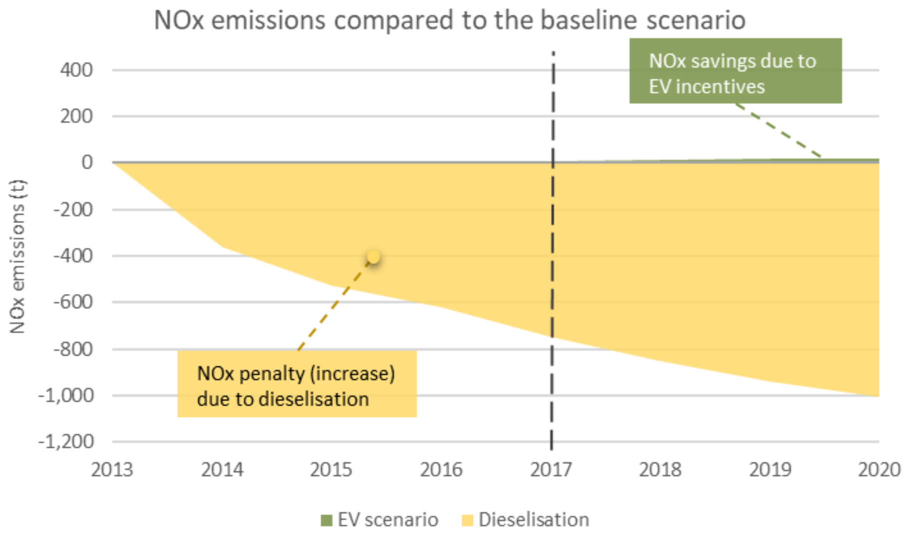
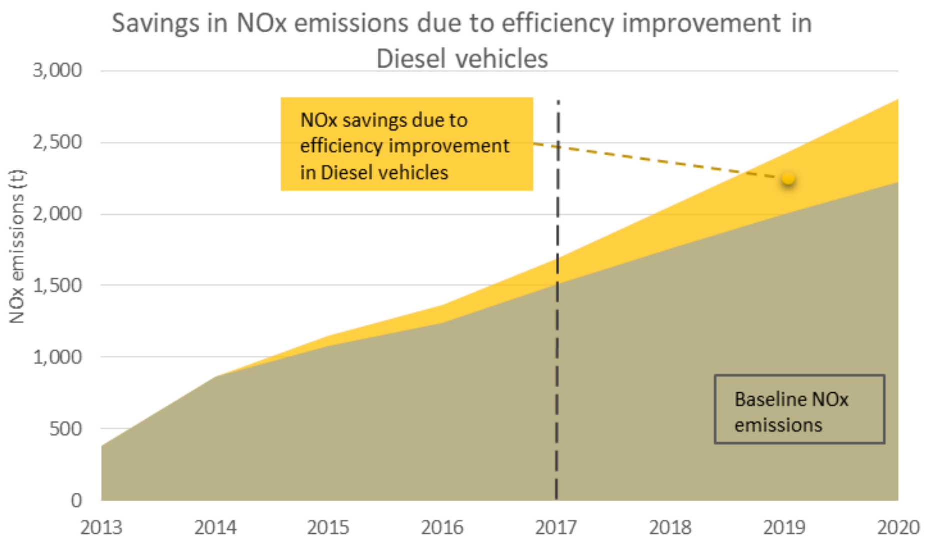


Figure 32: Savings in NOx emissions due to efficiency improvement in diesel vehicles.



3.3.4 PM10 emissions

As expected, the savings in PM10 emissions due to national tax reforms that favored EVs are negligible (Figure 33). However, due to fleet dieselization, it appears that there is a remarkable increase in PM10 emissions for the whole period 2010-2017 of the order of 4% (Figure 34).

Figure 33: Total PM10 emissions (2013-2017) for different scenarios in Greece.

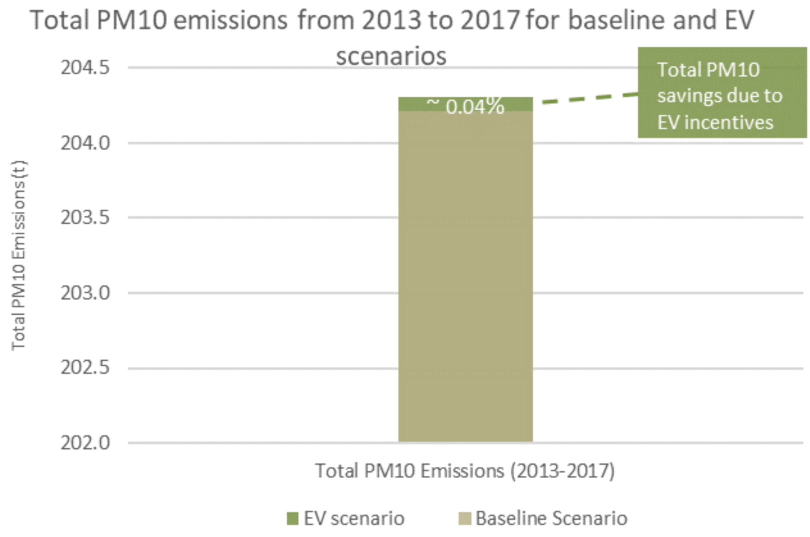
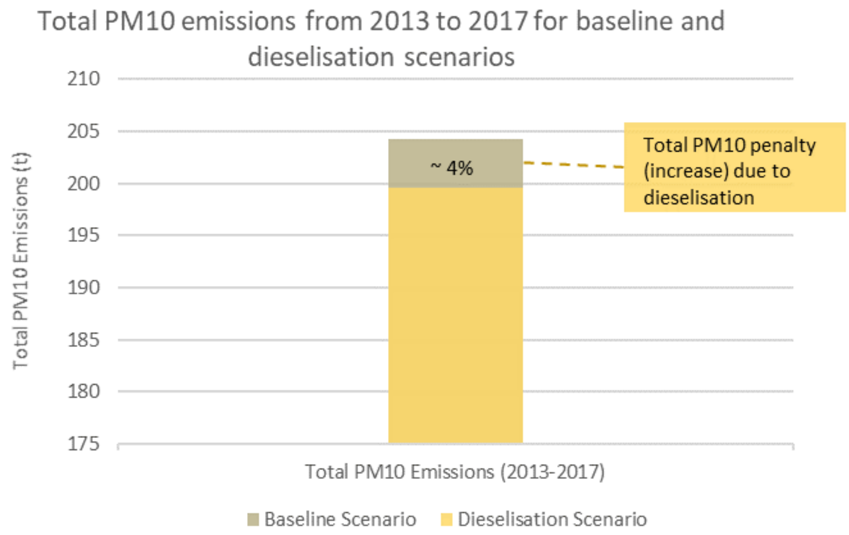


Figure 34: Total PM10 emissions (2013-2017) for different scenarios in Greece



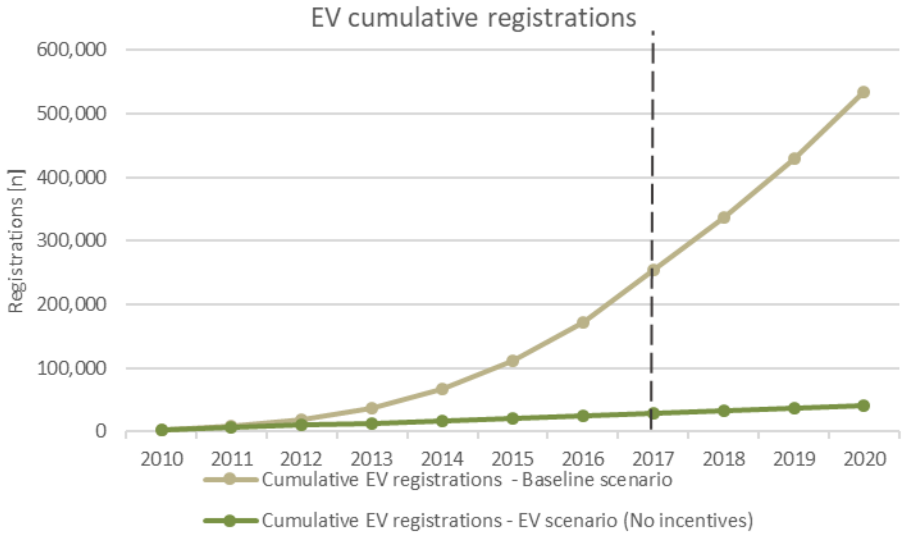
3.4 Norway

Norway cannot be absent from our research as it is the country that possess the leading position in the EVs market globally and achieved a significant electrification of the fleet, in recent years. This is the result of a long-term policy that was followed by the Norwegian government which favored low-emission vehicles. The incentives started to be implemented since the 1990s first as a means of fostering the Norwegian industry. Nevertheless, in recent years, the Norwegian electric vehicles industry is no longer operates, and the main driver for the incentives has been climate and environmentally related issues. The Norwegian car tax system makes electric vehicles to cost about the same as conventional vehicles do [22].

3.4.1 EV registrations

The cumulative sales of EVs were particularly high as presented in the Figure 35. In 2017 the new EVs were about 250,000, which is an impressive number for a relatively small country like Norway. Clearly, this number is mainly attributed to the policy pursued by the Norwegian Government on vehicle taxation.

Figure 35: EV new registrations fleet in Norway



3.4.2 CO2 emissions

Figure 36 presents the evolution of the emission factors for conventional (petrol and diesel) vehicles according to the CO2 monitoring database and also according to the COPERT calculations.

It can be noticed that real-world EFs of conventional petrol vehicles remain relatively stable over the years as opposed to official EFs where they follow a downward trend. From one point of view, this can be attributed to the fact that official emissions have become more and more unrealistic as years go by (but this is true for all countries). Apart from that, the distribution of new Norwegian petrol registrations has moved to higher size classes. Indicatively, we mention that in 2011 sales of small vehicles held 67% of the total conventional petrol new registrations, but this figure has been reduced to 54% in 2017. Concerning conventional diesel vehicles, it should be noted that the fall in official emission factors values was not particularly high in the period 2010-2017. Especially, the emission factor decreased only 6 g / km, which places Norway in the final position among the other countries examined. Real-world CO2 emission factors for conventional diesel vehicles present an increasing trend over the period 2010-2017. Behind this anomaly lies the fact that the market share of new large diesel vehicles among all diesel vehicles is gradually rising starting at 14% in 2010 reaching as much as 25% in 2015. Afterward, the share of large diesel vehicles is gradually decreasing to 11% in 2017. According to the study "From laboratory to road: Modeling the divergence between official and real-world fuel consumption and CO2 emission values on the German passenger car market for the years 2001-2014 "the divergence between type approval and real-world fuel consumption rises as the engine capacity increases.

Figure 36: Conventional vehicles CO2 EFs in Norway.

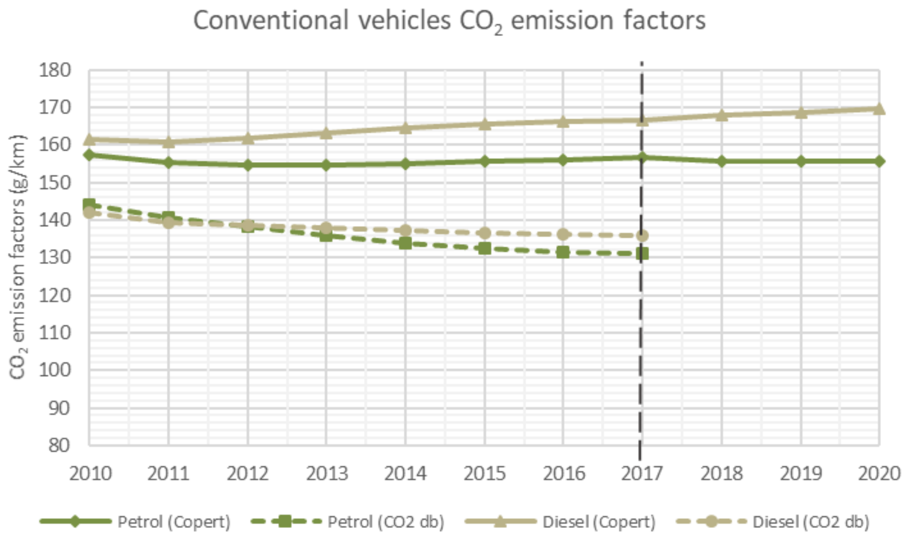
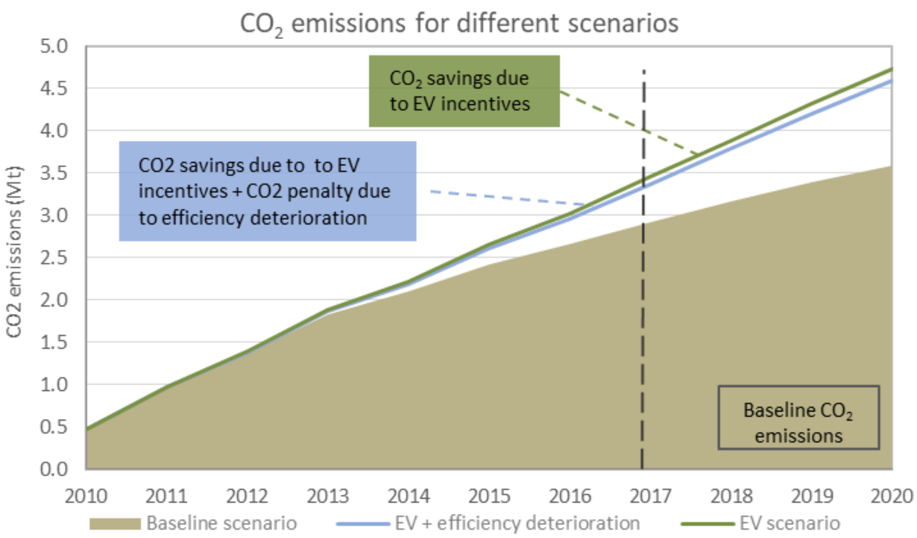


Figure 37: CO2 emissions for different scenarios in Norway.

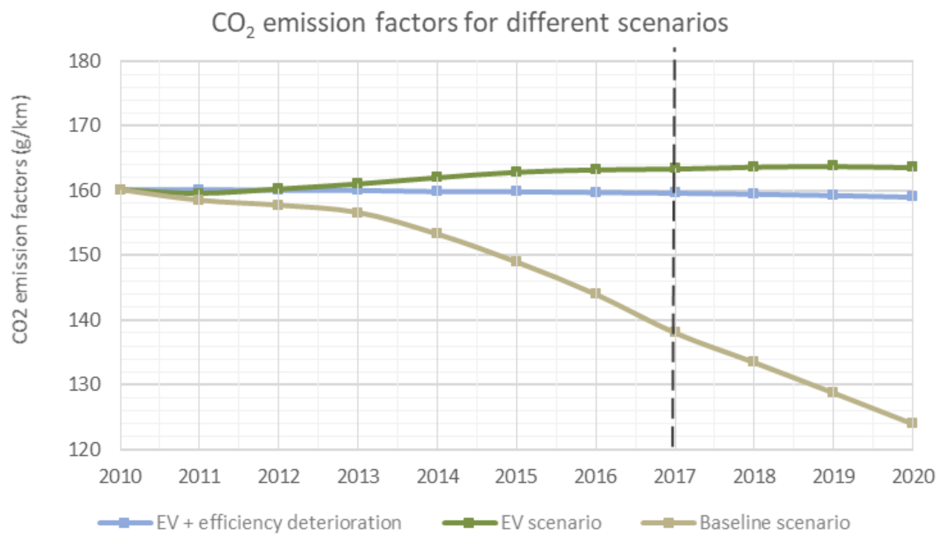


The calculated CO2 emissions of the three scenarios (baseline, EV and efficiency improvements) for the time series (2010-2017) are illustrated in the Figure 37.

Noteworthy in this diagram is that the blue line that generally corresponds to the emissions that would existed if European legislation has not been implemented and if no incentives were provided for EVs (cumulative) is below the green line which shows the magnitude of the emissions if there were no incentives for EVs only. As noted above, the real-world CO2 emission factor of conventional vehicles is rising over the years. Thus, recalling that in the efficiency improvement scenario it is assumed that the emission factors of all vehicle categories remain constant over the years and are equal to the respective base year (2010) values, it appears that there was a small increase in total CO2 emissions as vehicle efficiency deteriorated instead to be improved. The gap between the blue and green line represents this increase in total CO2 emissions due to vehicle efficiency deterioration.

The analysis of the results shows that the CO2 emissions of 2017 are about 2.9 Mt. If no measure in the national vehicle taxation policy had been taken in this period, then, new vehicles sold in Norway were expected to emit about 3.5 Mt of CO2. Therefore, the total savings attributed to EVs' incentives are about 0.5 Mt CO2, which in relative terms means that CO2 emissions in 2017 have been reduced by about 16%.

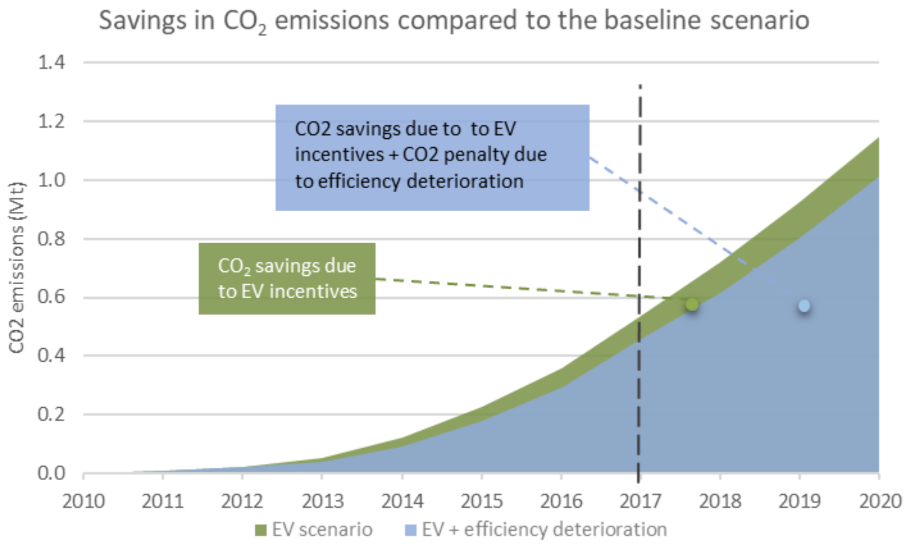
Figure 38: CO2 emission factors for different scenarios in Norway.



The results of the successful policy followed are also evident in the CO2 emission factor, as if there were no incentives to favor EVs the CO2 emission factor was expected to be about 25 g / km higher in 2017 (Figure 38). Here the blue line depicts the CO2 emission factors without any policy that helps EVs be more attractive to customers but also without aggravation (compared to 2010) of CO2 EFs for conventional vehicles, which observed in Norway.

The following diagram (Figure 39) shows that the Norwegian policy followed has contributed greatly to the overall reduction in emissions. In particular, it is expected that in 2020, the CO2 savings from incentives for EVs will transcend 1.1 Mt. This is a very interesting outcome indicating that it is possible to introduce EVs massively into a country's fleet and to effectively reduce the emissions as long as there are appropriate incentives for consumers. However, as we see the final benefit in CO2 emissions is a bit smaller due to the fact that Norway's conventional vehicle fleet has become less efficient over the seven-year period.

Figure 39: Savings in CO2 emissions compared to the baseline scenario in Norway



3.4.3 NOx emissions

Figure 40 shows the baseline scenario NOx emissions, and the savings in NOx emissions attributed to Norway's tax system and incentives policy. It appears that the massive introduction of EVs into the Norwegian fleet has resulted in significant savings in NOx emissions. The NOx emission factors are depicted in the Figure 41. It should be noted that the NOx emission factor has been decreased by about 15% due to the EV incentives given.

Figure 40: NOx emissions for different scenarios in Norway.

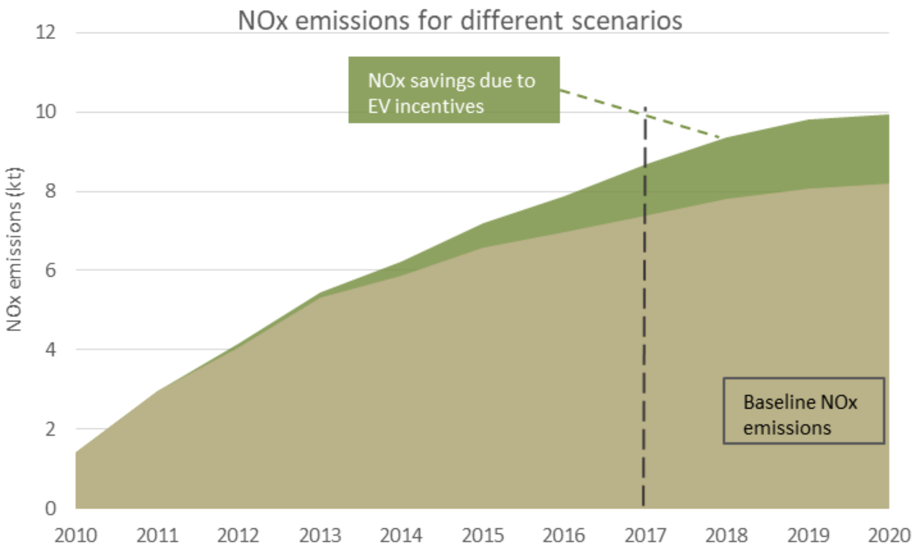
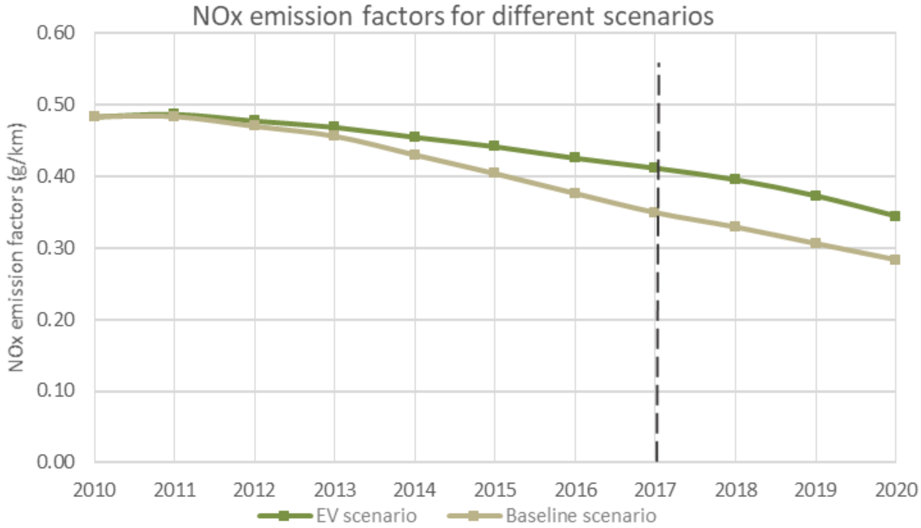
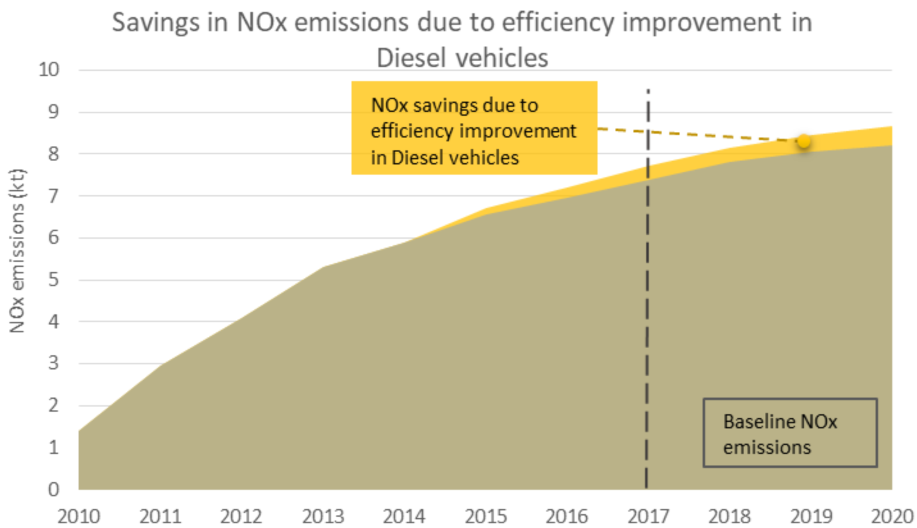


Figure 41: NOx emission factors for different scenarios in Norway.



Additionally, in the Figure 42 presents the savings in NOx emissions due to efficiency improvement (as Euro 6 vehicles with stricter NOx limits entered in the fleet). However, since diesel vehicles sales have a declining trend in the recent years and the Euro 6 limits for NOx affects only the diesel vehicles, these savings are not as large as in other countries.

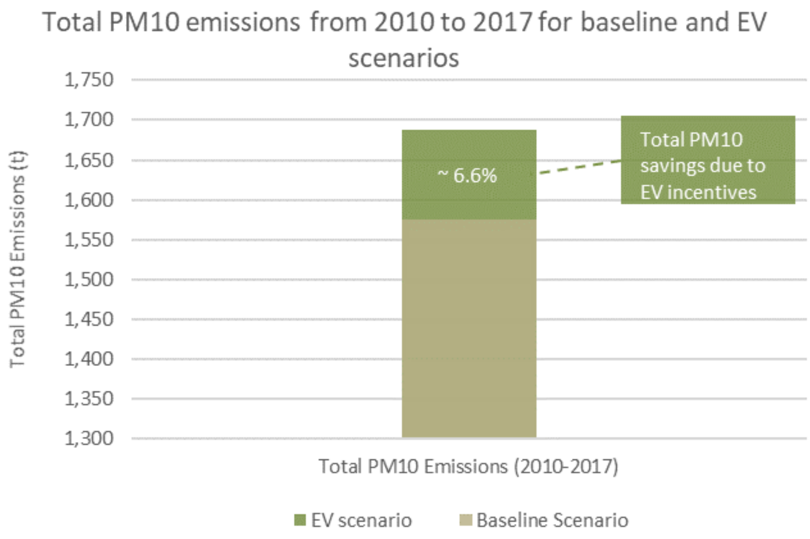
Figure 42: Savings in NOx emissions due to efficiency improvement in diesel vehicles.



3.4.4 PM10 emissions

Concerning PM10 emissions, considerable savings have been observed attributed to the incentives given to consumers to purchase EVs. Total savings in PM10 emissions for the whole-time period (2010-2017) were around 110 t.

Figure 43: Total PM10 emissions (2010-2017) for different scenarios in Norway.



3.5 Ireland

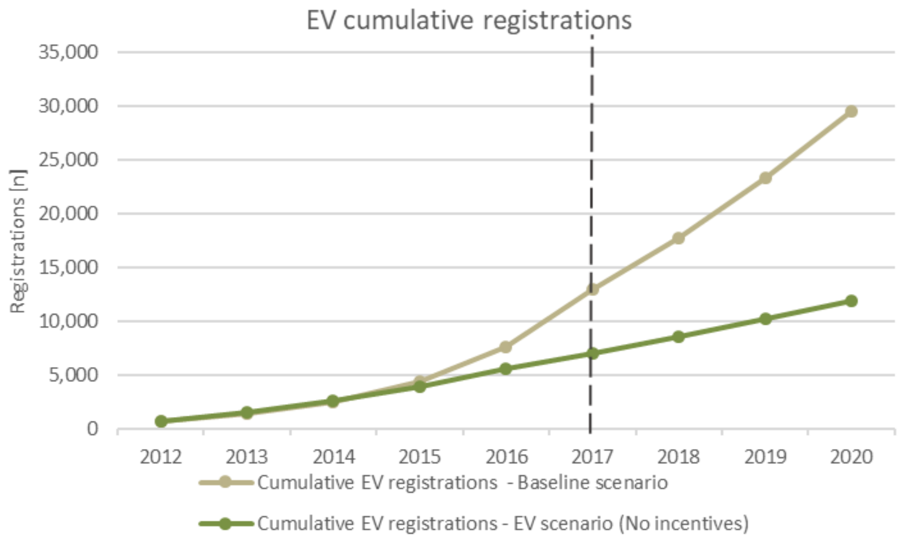
Ireland is a case where, although incentives have been provided for the EV market, consumers have not responded enthusiastically. The incentives are outlined: Electric vehicles benefit from VRT (registration tax) relief up to a maximum of € 5,000. For plug-in hybrids, the maximum relief is € 2,500 and for hybrid maximum relief is € 1,500. In addition, since 2015 electric and plug-in hybrid vehicles receive a grant of up to € 5,000 on purchase [12]. So, it is a country that while motivated EV market, it did not get the desired results.

3.5.1 EV registrations

Cumulative sales of EVs did not exceed 13,000 in 2017 despite the incentives given (approximately 2% of the cumulative fleet of new registrations in 2017). In addition, sales of EVs in the early years (2012-2013) actually follow the market trend (no incentives scenario), which suggests that the incentives of that period hardly attracted the consumers to invest in an EV.

Clearly, the measures have not been enough to encourage a higher level of EV purchases in Ireland and more actions needs to be taken to stimulate the EVs market.

Figure 44: EV new registrations fleet in Ireland.



3.5.2 CO2 emissions

Official CO2 emission factors for petrol and diesel conventional vehicles follow a descending trend and are shown in Figure 45, while real-world CO2 emission factors are rather stable over this period (2012-2017). In 2017, diesel vehicles emit 1 g/km less CO2 and petrol vehicles emit 0.5 g/km more CO2 compared to 2012 values based on COPERT calculations while according to the CO2 monitoring database, the CO2 emission factor for diesel vehicles have been reduced by 10 g/km and for petrol vehicles 9 g/km between 2010-2017.

Figure 45: Conventional vehicles CO2 EFs in Ireland.

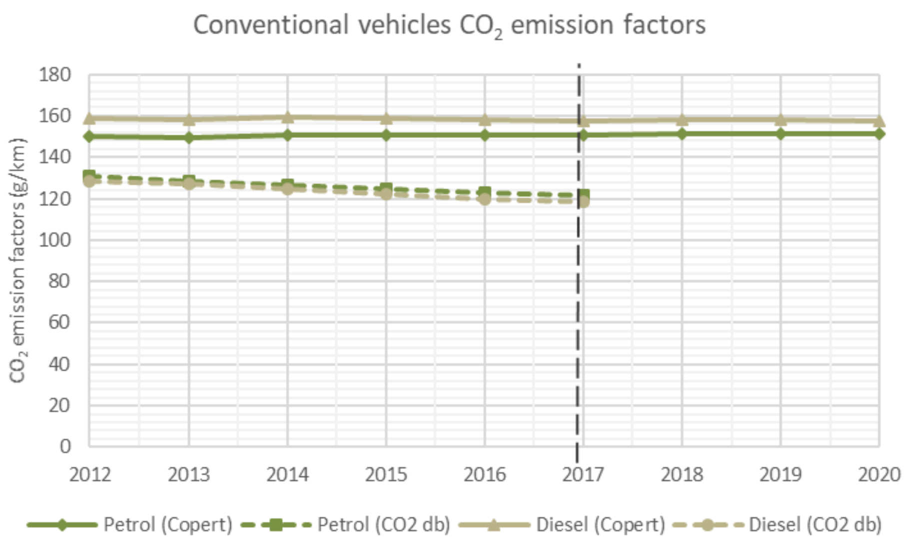


Figure 46: CO2 emissions for different scenarios in Ireland.

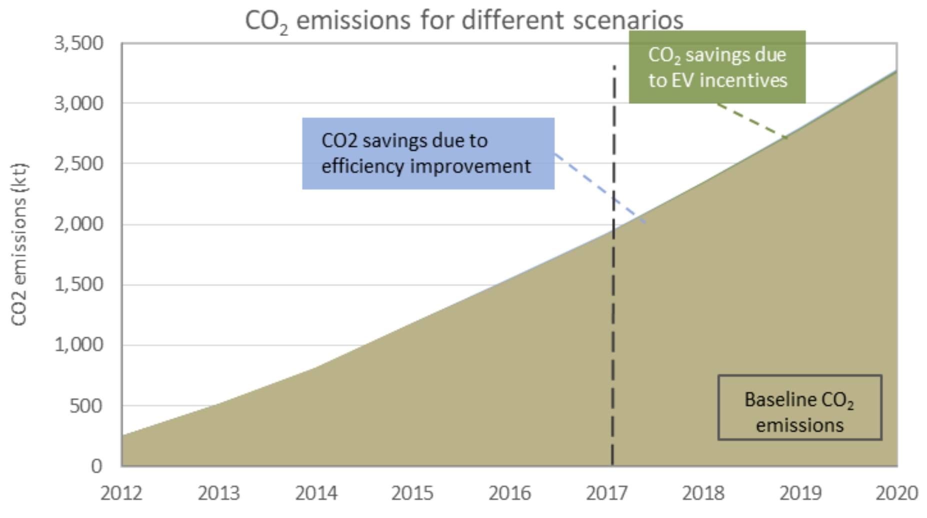
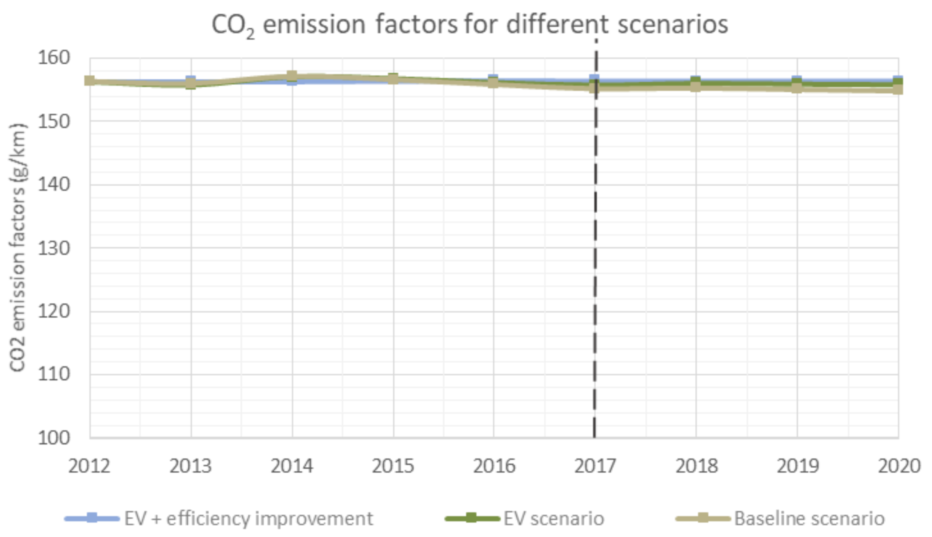
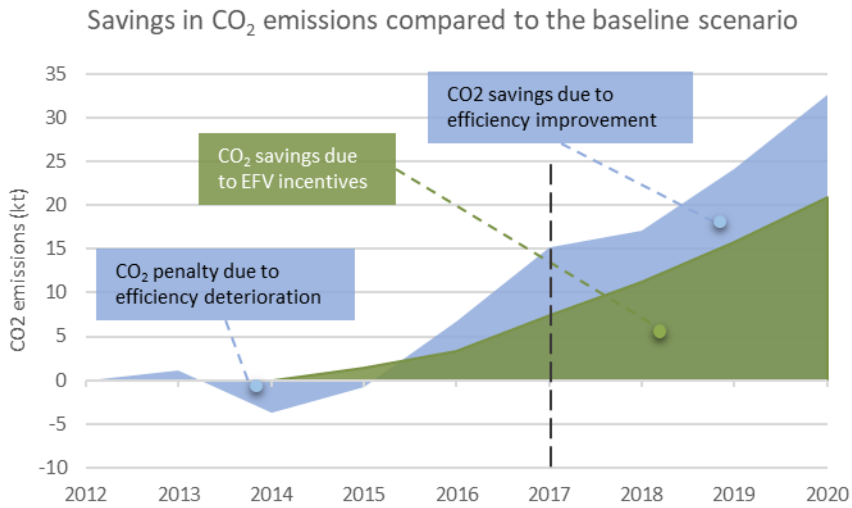


Figure 47: CO_2 emission factors for different scenarios in Ireland.



As abovementioned, consumers did not choose EVs and this had a direct impact on the CO2 emissions savings. This is the reason why in Figure 46 it is difficult to see the green area and in Figure 47 the baseline and EV scenario CO2 emission factor lines (brown and green lines) are so close. In 2017, a total of 15.2 kt CO2 were saved, of which only 7.5 kt were attributed to the effect of Irish incentives. The remaining 7.7 kt CO2 have been saved due to European legislation. These savings are very small as total CO2 emissions in 2017 were about 1.9 Mt, therefore total savings account for only 0.8% of total emissions. Figure 48 shows that if this rate of uptake of EVs in Ireland continues, then the CO2 savings should not be expected to be much more than 20 kt by 2020. Also, in 2014 the real-world CO2 emission factor is slightly increased compared to other years leading to an increase in CO2 emissions.

Figure 48: Savings in CO2 emissions compared to the baseline scenario in Ireland.



3.5.3 NOx emissions

The same picture is observed in NOx emissions where savings can be considered negligible (Figure 49). On the contrary, due to the many conventional diesel sales, there are remarkable savings due to the transition from Euro 5 standard vehicles to Euro 6, as shown in Figure 51.

Figure 49: NOx emissions for different scenarios in Ireland.

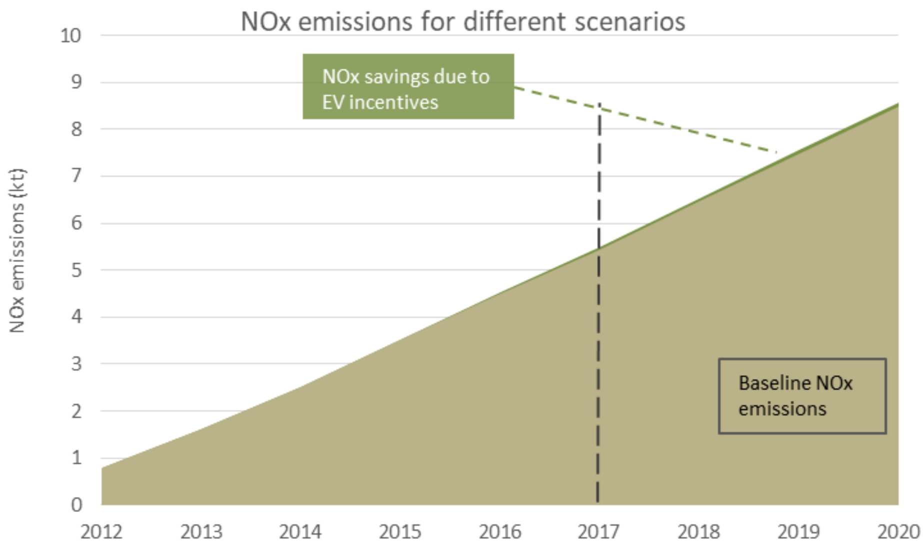


Figure 50: NOx emission factors for different scenarios in Ireland.

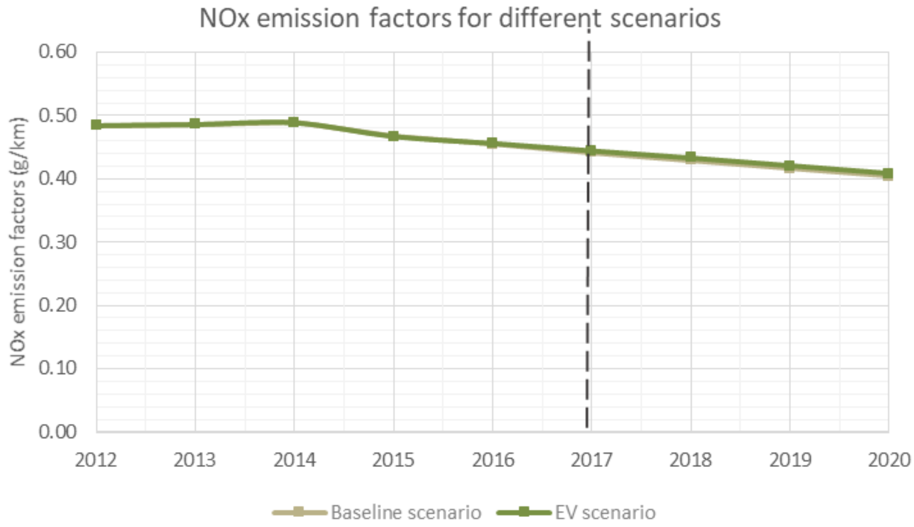
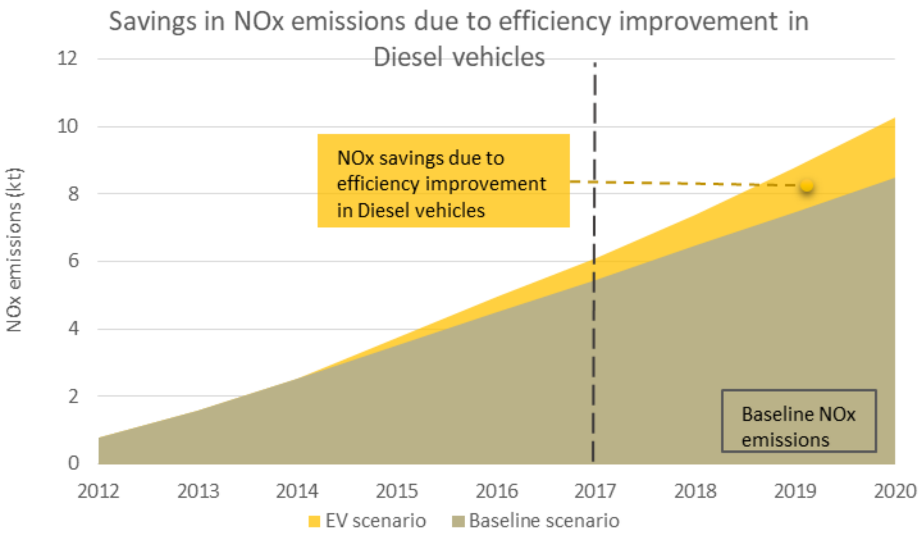


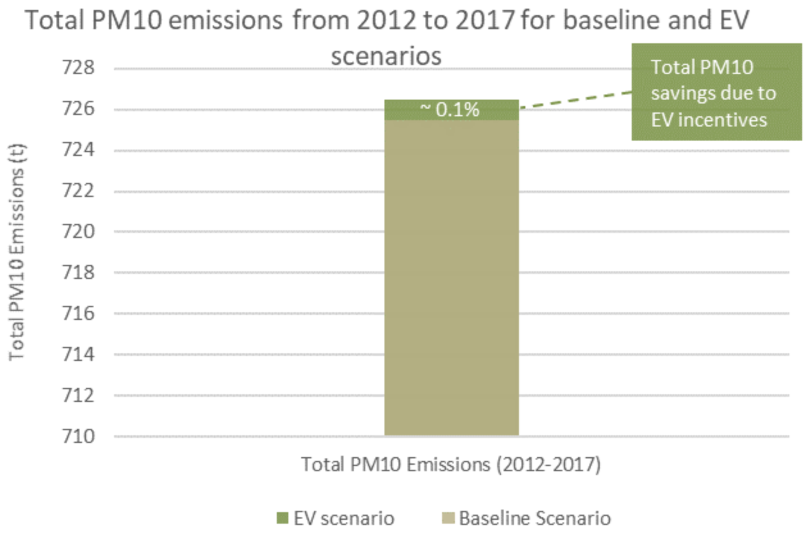
Figure 51: Savings in NOx emissions due to efficiency improvement in diesel vehicles.



3.5.4 PM10 emissions

Similarly, for PM10, there were no significant savings that can be attributed to the Irish government's incentives given for the purchase of EVs. About a ton of PM10 has been saved in the whole period 2012- 2017.

Figure 52: Total PM10 emissions (2012-2017) for different scenarios in Ireland.



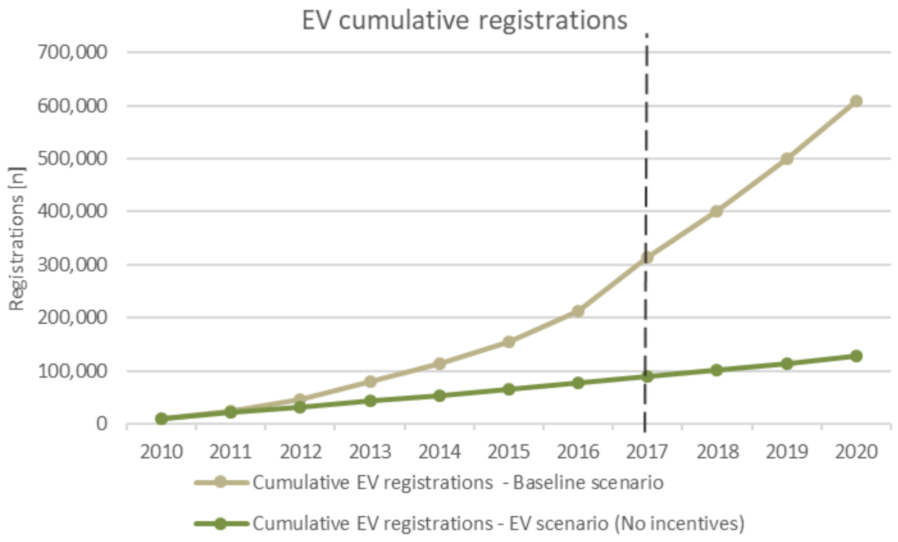
3.6 Germany

German automotive industry is considered one of the most competitive and innovative in the world while Germany has the largest sales volume of new cars across Europe. Nevertheless, considerable incentives for EV market appeared very slowly compared to other countries (such as France or the Netherlands) and were made available to consumers in July of 2016, when Germany approved an incentive and investment program to encourage switch to EVs.

3.6.1 EV registrations

Figure 53 shows the total cumulative EV sales. From 2010 to 2017, there are a few more than 300,000 sales. However, for Germany, this figure is rather small, accounting for about 1.3% of the total fleet of new registrations by 2017.It is worth noting that the annual sales of EVs in 2017 (which it is the first year with strong incentives), have increased impressively in relation to those in 2016. Especially, the annual sales of BEVs and PHEVs have more than doubled in 2017 (54,000 sales) compared to 2016 (25,000 sales). This fact shows that consumers responded well in the new incentive program. This new incentive scheme started on 1 July 2016 and ends in 2020. Therefore, new EV registrations are expected to continue to increase strongly in the years 2018-2020 as shown in the Figure 53.

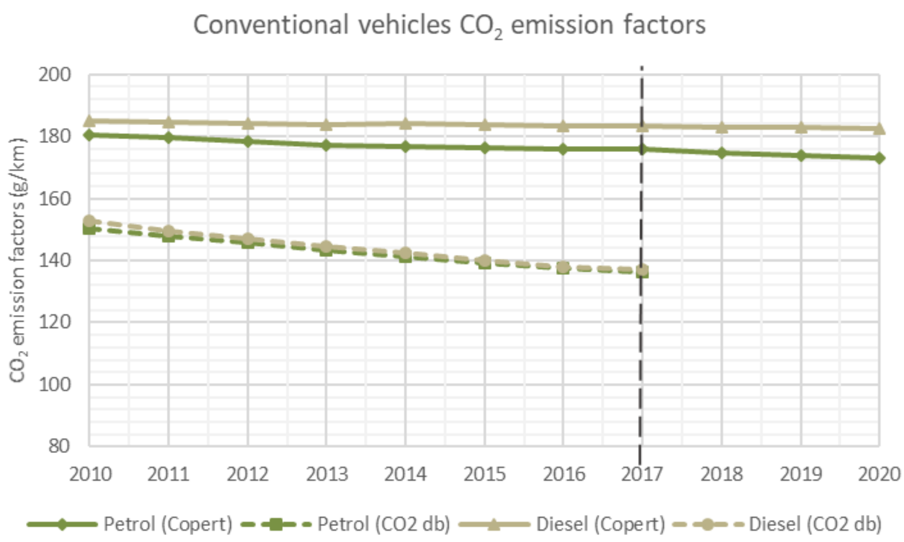
Figure 53: EV new registrations fleet in Germany.



3.6.2 CO2 emissions

The fleet-average CO2 emission factors of conventional vehicles (diesel and petrol) derived from COPERT (real-world) and the corresponding emission factors derived from the CO2 monitoring database are depicted in Figure 54.

Figure 54: Conventional vehicles CO2 EFs in Germany.



There is a progressively falling trend in official and real-world CO2 emissions from new cars registered. For diesel vehicles there is a drop of 2 g/km in the real-world emission factors in the period 2010-2017 while the corresponding figure for petrol vehicles is about 4.5 g/km. These reductions are significantly lower than those resulting from the CO2 monitoring database.

Figure 55: CO2 emissions for different scenarios in Germany.

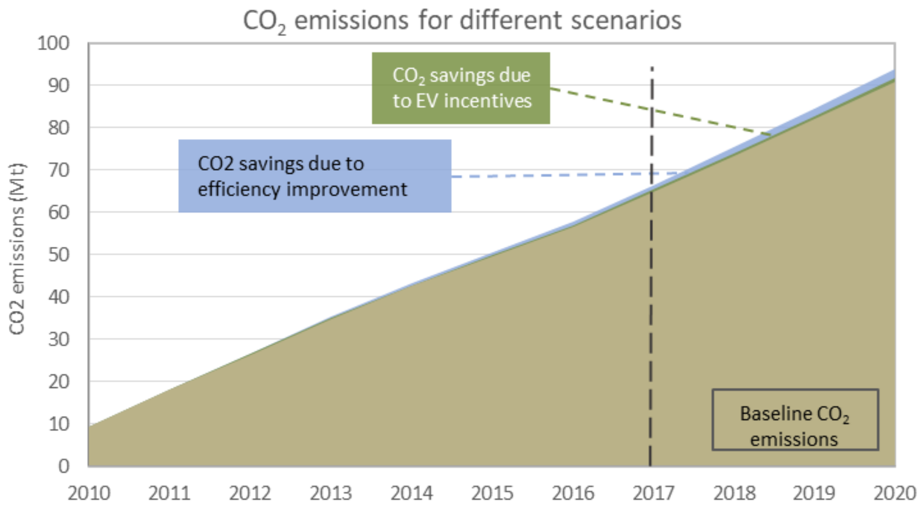
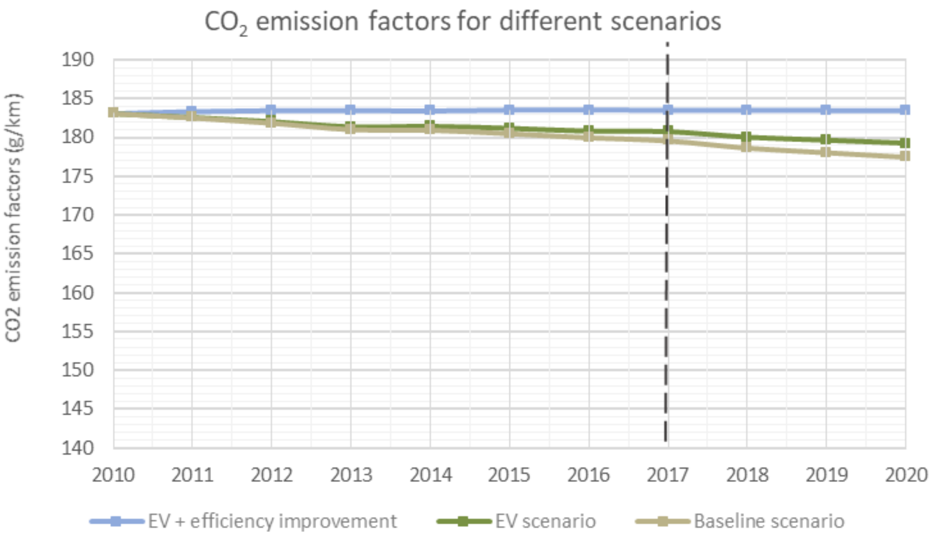


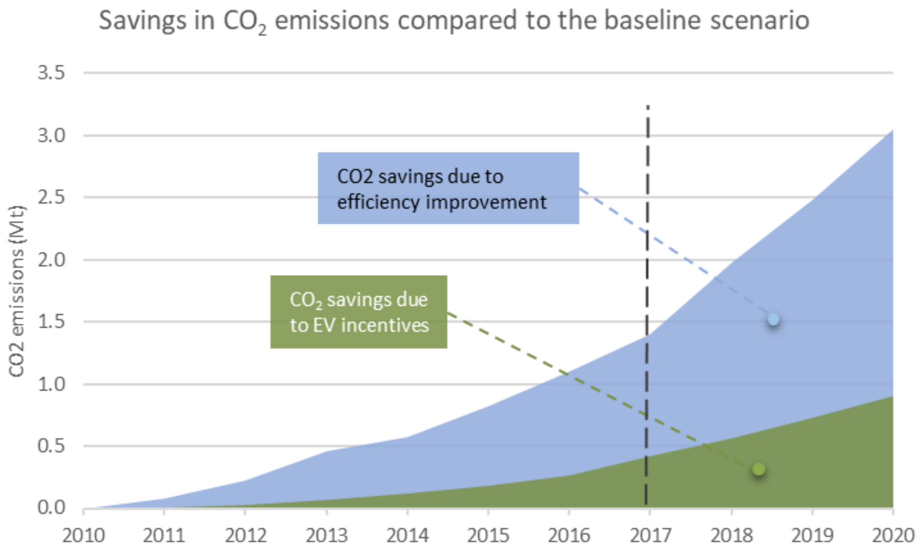
Figure 56: CO2 emission factors for different scenarios in Germany.



As mentioned above, Germany did not give any substantial incentives to potential buyers of EVs until mid- 2016, so CO2 savings due to these incentives are also not expected to be large. Figures 55 and 56 confirm this claim. More specifically, in 2017 there were total savings of around 1.4 Mt of which only 0.4 Mt can be attributed to the incentives given in the period 2010-2017 (Figure 57).

The projection for the period 2018 to 2020 that we made, is based on the measures taken in the period 2010- 2017, where they are relatively weak in most of the period. Therefore, in Figure 57 it appears that with this particular slow rate of EVs uptake, CO2 savings due to the incentives given by the country will not exceed 1Mt by 2020 and savings due to the EU regulation will be about 2.1 Mt. Hence, the country can expect an overall 3% reduction in CO2 emissions due to its incentives for low-emitting vehicles and the European legislation that applied.

Figure 57: Savings in CO2 emissions compared to the baseline scenario in Germany.



3.6.3 NOx emissions

Unfortunately, due to the relatively few EVs, there were virtually no savings in NOx emissions due to the incentives from German government (Figure 58). The NOx emission factors are depicted in Figure 59. It can be observed that NOx emission factors had increased slightly over the period 2010-2013. The reason for this raise is the increasing share of diesel vehicles in the fleet over this period. The tightening of NOx limits through the introduction of the Euro 6 standards, however, as shown in Figure 60, is responsible for an important amount of NOx emissions savings, as diesel vehicles possess a large share in the examined fleet.

Figure 58: NOx emissions for different scenarios in Germany.

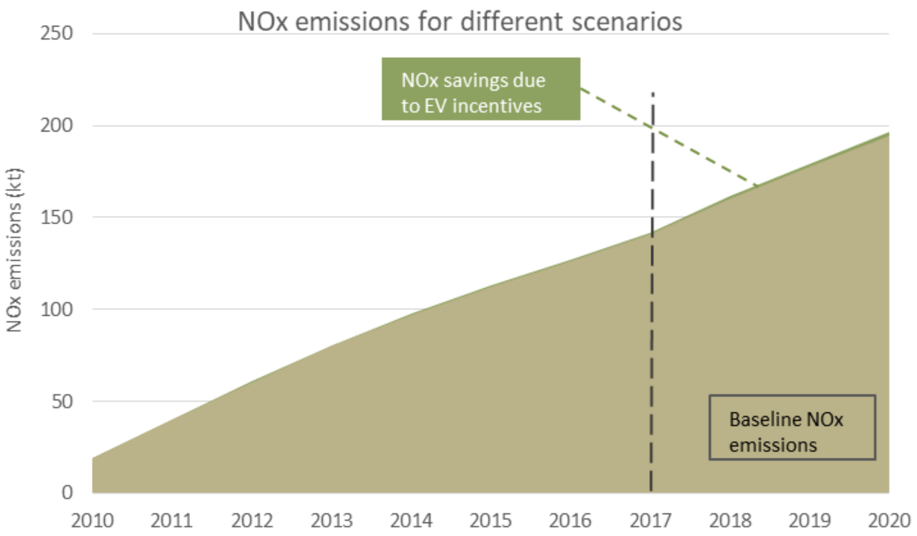


Figure 59: NOx emission factors for different scenarios in Germany.

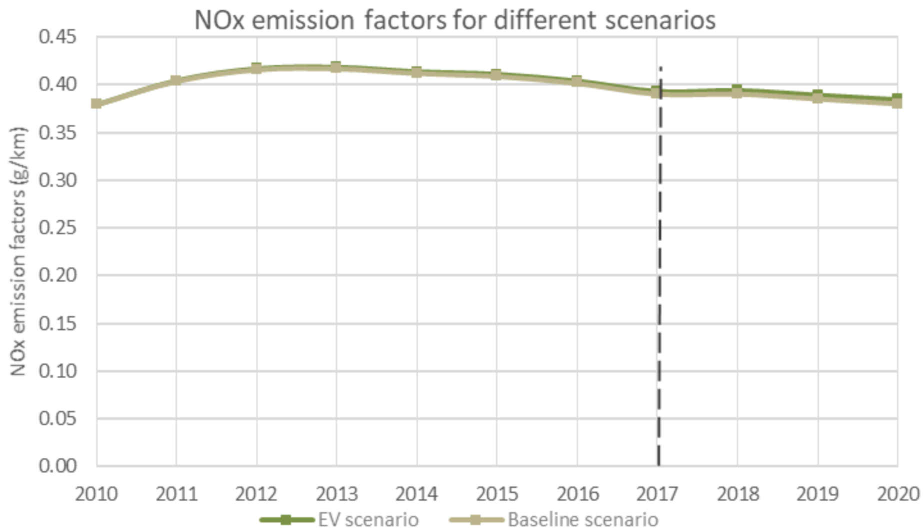
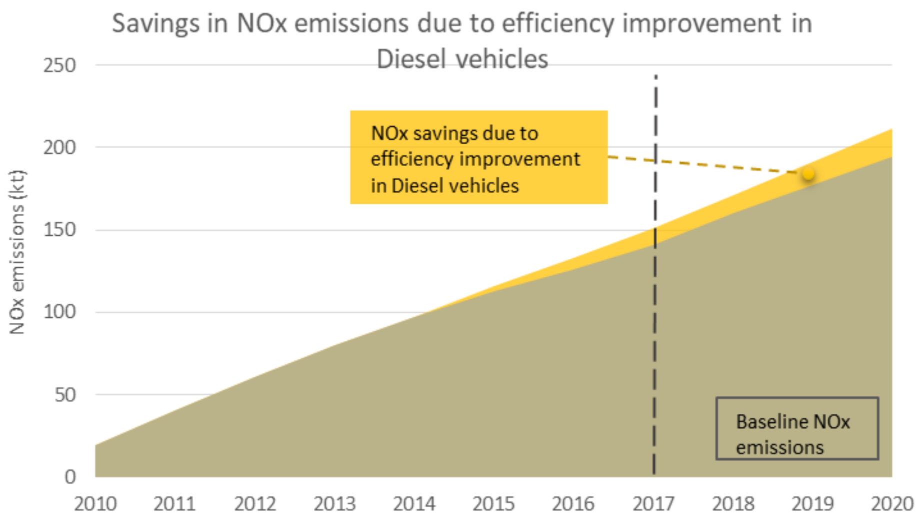


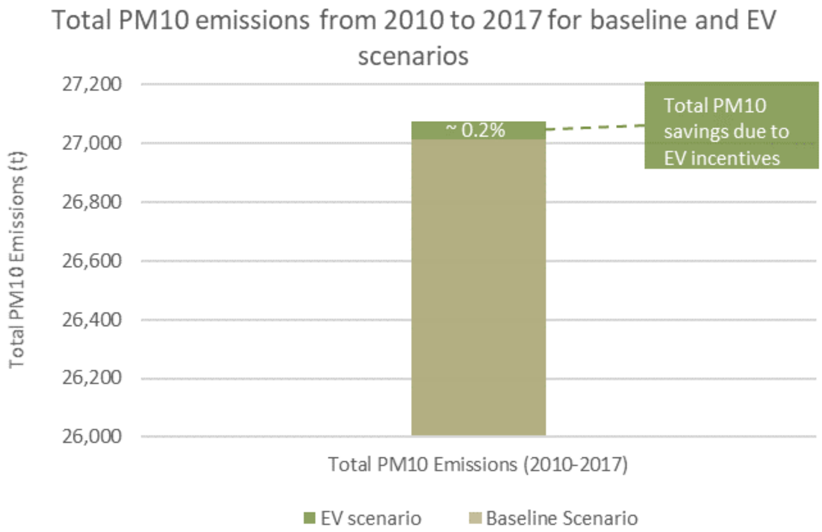
Figure 60: Savings in NOx emissions due to efficiency improvement in diesel vehicles.



3.6.4 PM10 emissions

PM10 emission savings due to EV incentives can be considered as negligible, as for the whole period 2010- 2017 only 60 t of PM10 is gained which is about 0.2% reduction in the final emissions.

Figure 61: Total PM10 emissions (2010-2017) for different scenarios in Germany.



3.7 Poland

In February 2018, Poland formally adopted its first Electro-Mobility Act that aims for 1 million electric cars on Polish roads by 2025 [26, 27]. However, Poland until 2017 did not give any incentive for the uptake of EVs in its fleet. Therefore, we cannot calculate the emissions savings due to the vehicle tax system as no incentives have been given. The scenarios created for Poland are: Baseline scenario and Efficiency improvement scenario.

3.7.1 CO2 emissions

Average real-world CO2 emission factors for petrol and diesel conventional vehicles follow a slightly increasing trend and are shown in Figure 62. In 2017, average diesel vehicle emits 2% more CO2 and average petrol vehicle emit 1.5% more CO2, compared to 2010 values based on COPERT calculations.

Figure 62: Conventional vehicles CO2 EFs in Poland.

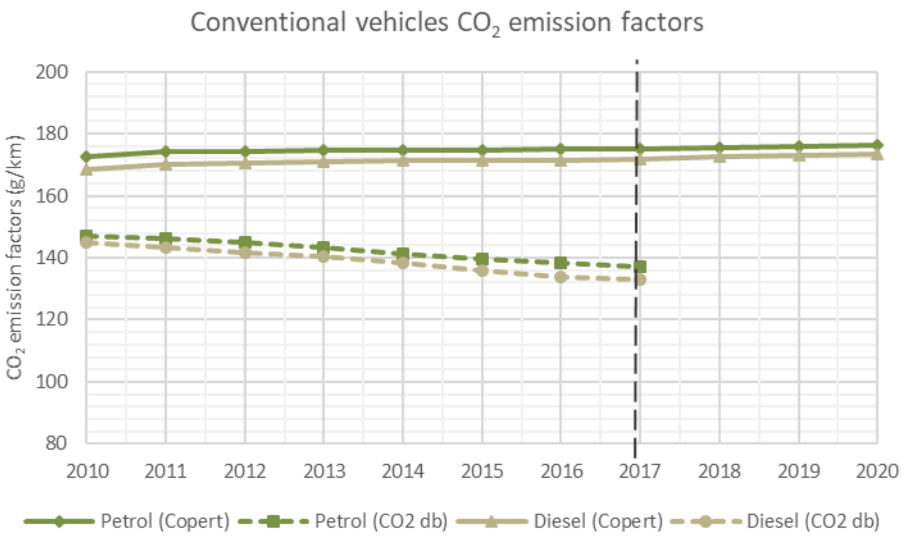


Figure 63: CO2 emissions for different scenarios in Poland.

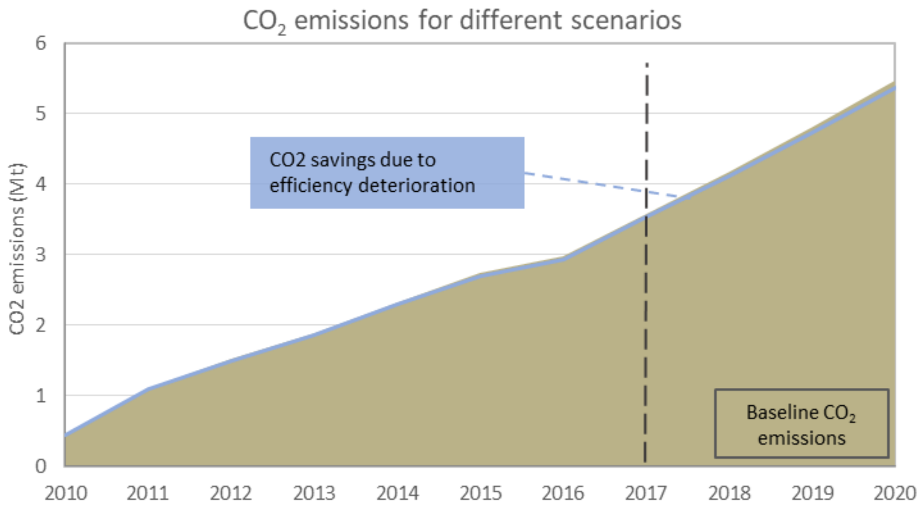


Figure 64: CO2 emission factors for different scenarios in Poland.

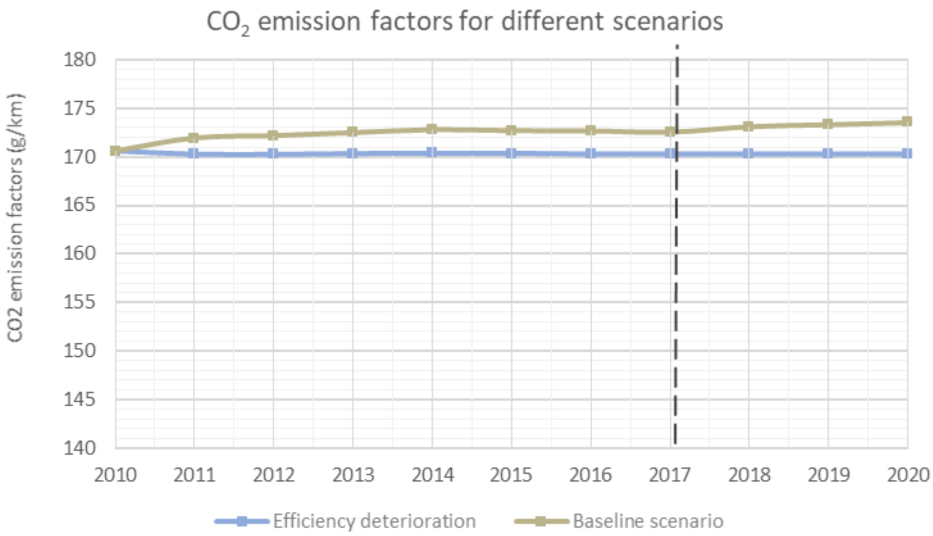


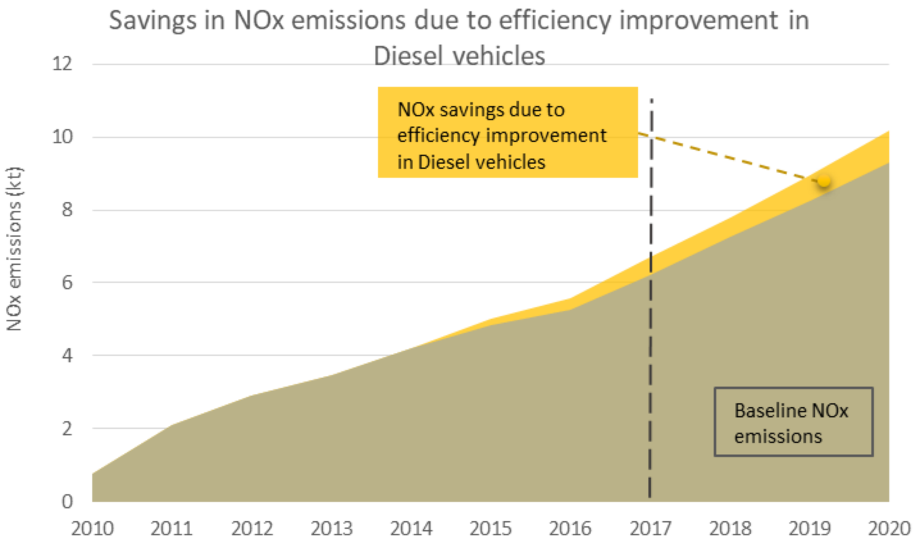
Figure 63 displays the baseline CO2 emissions calculated with COPERT. The blue line represents the emissions that Poland would have if the emission factors remain the same for all years and equal to their 2010 values.

This line is a bit inside the brown area because the CO2 emission factors for conventional vehicles increased slightly over the seven-years period.

3.7.2 NOx emissions

Figure 65 demonstrates the savings due to the transition from Euro 5 standard vehicles to Euro 6.

Figure 65: Savings in NOx emissions due to efficiency improvement in diesel vehicles.



4 Discussion and Conclusions

The purpose of this study has been to investigate the quantitative effect of vehicle taxation and incentives offered in seven different countries on CO_2, NO_x and PM10 emissions.

The countries examined in our study vary considerably in the vehicle tax system that have followed. There are some countries that implemented an aggressive policy and gave robust incentives to introduce many EVs into the fleet but there are also those that followed a more moderate policy regarding the incentives they offered for EVs. In a brief summary, the major facts of each country's vehicle tax policy have been presented.

For the calculation process two scenarios have been evaluated, one scenario that simulates the observed situation in the EVs market (baseline) and one scenario in which the market was not influenced by the introduction of vehicle-related taxes (EV scenario). The emissions difference between these two scenarios can be considered as the quantitative effect of vehicle taxation and measures taken from each country on CO_2, NO_x and PM10 emissions. The effectiveness of the policy and measures applied by a Member State can be determined in terms of total reduction of CO_2 emissions. At this point, we should emphasize that the results of our calculations are real-world emissions as COPERT was used for the computational process.

The major outcome of our analysis is that the countries that promoted the EVs market managed to avoid a significant amount of emissions. The leading country in terms of emission savings is Norway. One likely reason for this relatively high performance is strong incentives for promoting purchase and ownership of PHEVs and BEVs. To fully understand the value of Norway's incentives, it can be said that the purchase price for a BEV is more or less equal to the price of a similar ICEV.

Follow-up country is the Netherlands which has also implemented policies favoring EVs and penalizing high- emitting ICEVs

It is important to stress that a lot of BEVs and PHEVs were introduced into the fleets of these countries because policies were more targeted to these two technologies. These vehicle categories can bring the most benefits.

Conversely, countries that did not offer special incentives to close the cost competitiveness gap between EVs and equivalent ICE vehicles failed to achieve high reductions in emissions. Examples of countries in this category are Greece and Poland.

Exception of the above rule is Ireland where, despite the financial incentives to support EVs, their sales have not taken off. The Irish government should explore and find out the reasons holding back the expected surge in adoption of these cars (e.g. due to insufficient charging stations) and make the necessary modifications in its vehicle taxation system.

For Greece, we also examined the effect of lifting the ban on diesel cars (that took place in 2012), as it brought a dieselization of the fleet which produced very large CO_2 emission savings but had adverse effects on air quality, as much more NO_x emissions were emitted.

Another fact that should be underlined is the consumer's sensitivity to modifications in the tax system. An example that confirmed this conclusion, is sales of PHEVs in the Netherlands in 2017. Due to withdrawal of some incentives, PHEV sales dropped dramatically. That is why Member states should be very careful when developing long-term vehicle taxation policies.

This study has focused only on exhaust tailpipe emissions and has shown that electric vehicles have a great potential to reduce GHG emissions and air pollution during the use-phase. From a life cycle analysis perspective, an electric car in Europe already produces on average less greenhouse gases and air pollutants than its petrol or diesel equivalent, according to the EEA's report 'Electric vehicles from the life cycle and circular economy perspectives' [28]. However, it should be emphasized that the country's electricity generation mix plays a key role in the final emissions of electric vehicles. This should be thoroughly considered when developing long-term vehicle taxation schemes. Generally, there is a wide range in electricity carbon intensity values among Member States.

Finally, it should be emphasized that the present study takes into account the increasing divergence between real-world and type-approval CO2 emission values. Indeed, for some countries although the official average CO2 emission factors have fallen sufficiently over the years, the average real-world emission factor have increased slightly. This is a problem that is imperative to be solved for many reasons. More importantly, it undermines national vehicle tax policies, and this results in fewer low-emitting vehicles to be imported into the country's fleet and also financial losses to state funds. It also undermines the European Union's effort to mitigate climate change.

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