CO₂ benefit from the increasing percentage of diesel passenger cars: the case of Sweden

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Abstract

An efficient way to reduce CO₂ emissions is the replacement of gasoline passenger cars (PC) with diesel ones. Most of the member countries of the European Union have high percentages of new diesel PC registrations, however this percentage is only 7% in Sweden. In the present work, the benefit of CO₂ emitted from the new PC is studied in the case of an increased penetration of diesel PC in Sweden, for several scenarios using the current and estimated future PC sales and fuel consumption (FC). The results show that total future CO₂ emissions will increase significantly and can be partially controlled by the introduction of diesel PC or the replacement of heavy PC by lighter ones.

Keywords: CO₂ emissions, passenger cars, gasoline, diesel, Sweden, European Union.

1 Introduction

The transport sector is one important source of CO₂ in many countries [1, 2]. The authorities and policy makers look for a stabilization of these emissions following, for example, the Kyoto protocol [3]. However, even if the CO₂ emissions of each PC decrease, the total CO₂ emissions of the transport sector increases, mainly due to the increase of passenger car fleet. As for the same driving distance, Diesel PC emit less CO₂ than gasoline types, an efficient way of controlling the total CO₂ emissions is the replacement of a number of gasoline PC by Diesel ones.

The percentage of new Diesel PC sales is quite important in all European Union (EU) countries [4, 5], however, is less than 7% in Sweden [5, 6]. The
increase of the Diesel PC percentage in this country could be a very efficient way to decrease the CO₂ emissions from the transport sector, which is estimated to correspond to 37% of the total CO₂ emissions in Sweden at 1998 [7].

A particular point is that Diesel PC emits more particulate matter (PM) and NOx than gasoline ones. However, Diesel particulate filters (DPF) are already commercially used and will be necessary in the future. Diesel PC equipped with DPF emit similar or even less PM than gasoline ones [8]. We estimate that in the future the impact on local atmosphere quality will be independent of the vehicle type, because the difference between Diesel and gasoline PC NOx emissions will not be important in the future.

2 Assumptions and methodology used

The statistical data used here is a compilation of data presented in several sources. The Internet sites of Association of European Automobile Manufactures, ACEA, [4], Eurostat [5], Committee of French Automobile Manufactures, CCFA, [6], World Resources Institute [9], International Road Federation [10], and Swedish Statistics Net [11] are widely used. The German Federal Motoring Authority, KBA, [12] publishes some data, as inertia and CO₂ emissions of the PC certified in Germany. The current market of PC in Sweden is firstly analysed and compared with this of the European Union average (15 countries). Based on these data, the most probable scenarios for the Swedish market in 2010-1015 are established.

The CO₂ emissions changes due to the use of Diesel PC instead of gasoline ones are calculated at different percentages of Diesel penetration in the Swedish market. The comparison of CO₂ emissions is based on the emissions of the certification data on the NEDC using the KBA file. The same annual mileage is assumed for the current and future gasoline and Diesel PC. Firstly, the current CO₂ emissions are used; secondly, the future CO₂ emissions are estimated by applying factors taking into account the most probable future technologies [13]. This study is limited only to CO₂ emissions from new registered PC, without taking into account other alternatives as the use of hybrid or fuel cell vehicles or PC feed with other fuels, as natural gas or LPG, due to lack of data.

3 Results and discussion

3.1 Historical review, current situation and previsions of the Swedish and EU markets

In 2003, the Swedish population corresponds to 2.32% of the total EU population (figure 1); this percentage remains constant since 1970. However, the percentage of the passenger car fleet constantly decreases in this country: from 3.5% at the beginning of the 70’s, it reaches around 2.1% in 2000, which is lower than the population percentage. This percentage remains quite stable the last 6-7 years, but “Swedish Statistics” [14] predicts an increase in the future.

Another parameter is the number of PC per 1000 inhabitants (figure 1). The average EU number in 2001 is 488 PC per 1000 inhabitants, while this of
Sweden is 454, corresponding to 93% of the average EU value. This percentage decreases since 1970, but remains quite stable the last 6-7 years.

![Figure 1: Comparison of the Swedish and EU PC markets.](image)

The Swedish PC fleet increases from new PC registrations and from the increase of the average age of the already registered vehicles. In both parameters, an important difference exists between Swedish and average EU market. In 2003, 27.3 new PC/1000 inhabitants are registered in Sweden, against 34 PC registered in EU (figure 1). The Swedish fleet is older than the average EU age (in 1999, this age is around 9.2 years in Sweden against 7.6 in UE [15]).

The other significant difference between the Swedish and EU market is the number and percentage of Diesel PC registrations. In most of the EU countries, this percentage was only around 10% in 1980, but increases sharply to reach almost 60% in 2002 in several countries, as France and Spain [4, 6]. With an average of about 40% in the 15 countries of the EU, this percentage is at least 30% in every country, but remains only 7% in Sweden.

Another important parameter taken into account in this work is the car segment. The majority of the EU average and Swedish market corresponds to four classes: economic, small car, lower medium and upper medium. The Swedish market is composed from bigger and heavier PC than the EU average: in 2003, the average inertia is 1348 kg and 1607 kg respectively for gasoline and Diesel PC in Sweden, against 1126 kg and 1366 kg for the EU average. This
statement indicates that for the same number of PC and the same annual mileage, the CO₂ emissions are higher in Sweden.

3.2 Comparison of gasoline versus diesel current CO₂ emissions

Figure 2 shows the CO₂ emission of gasoline and Diesel PC as a function of vehicle inertia. For every car type, no distinction is made between manual and automatic transmission, because the percentage of manual gearboxes in Sweden is more than 79% in 2003 and this parameter has a relatively small influence [13]. No differentiation is made in the case of direct or indirect injection of gasoline and diesel engines, even if this parameter has a strong influence on FC and consequently on CO₂ emissions, because the percentage of gasoline direct injection is still very low in Sweden. Moreover, the inclusion of this parameter enhances the benefits of the use of Diesel PC [13]. Figure 2 shows that CO₂ emissions are correlated with the PC inertia. The equations: \( \text{CO}_2 = 0.1479 \times \text{Inertia} - 7.9 \) and \( \text{CO}_2 = 0.1133 \times \text{Inertia} - 8.2 \) are valid in the case of gasoline and Diesel PC. The relative standard deviation values of CO₂ emissions are generally similar for gasoline and Diesel PC and they increase with the vehicle inertia to reach a plateau at about 10%.

We believe that an eventual replacement of gasoline PC by Diesel versions will occur within the same segment than the same inertia. Upper curves of figure 2 present the same data as the lower ones, but using the average inertia of each segment. Two new lines are now obtained: \( \text{CO}_2 = 0.1521 \times \text{Inertia} - 11.1 \) and \( \text{CO}_2 = 0.1167 \times \text{Inertia} - 8.9 \) for gasoline and Diesel PC respectively. The RSD values are now higher: around 15% instead of 10% in the previous case. Two gasoline segments (4x4<4m50 and Prestige) present high error bars. However, as their registration percentage is less than 2%, their contribution to the final results remains very low. The average difference between the estimated CO₂ emissions using the 2003 KBA file and the average inertia of each segment is quite low: not more than 1.8% in the case of gasoline PC and 2.8% in the case of Diesel PC. The last two equations are used in this work.

3.3 Prediction of the future fuel consumption

After 2005, the European PC will fulfil Euro4 emission standards, but in the future, more severe standards will require advanced emission control technologies which will increase the FC. On the other hand, fuel efficiency will be improved by enhanced vehicle aerodynamics, better combustion, decreased frictions, etc. The work of Sullivan et al [13], provides a list of technologies that are expected to increase or decrease future FC. According to this work, in 2015, a decrease of about 11% in FC is expected in the case of gasoline engines and a decrease of 0-3% in the case of the Diesel ones. Other works estimate some penalties or benefits in FC due to future technologies: a 3% penalty from the use of a Diesel Particulate filter [16-18], a 5% penalty for the use of NOx trap technology [18, 19], and a 1% penalty for the use of urea SCR [19]. Some changes in FC of advanced gasoline engines and transmissions are given in CAFE [20].
Taking into account the above estimations, two assumptions are used in this work for gasoline and Diesel PC:
- the Diesel optimistic assumption (DO) presumes no FC change, because the FC increase from heavier after-treatment devices is considered as equal to FC decrease from frictions and engine or vehicle design improvements,
- the Diesel pessimistic assumption (DP) presumes an increase of 5% of FC,
- the gasoline optimistic assumption (GO) presumes a 10% decrease of FC,
- the gasoline pessimistic assumption (GP) presumes a 5% decrease of FC.

![Graph showing CO2 emissions vs weight for gasoline and Diesel vehicles.](image)

Figure 2: CO2 emission on the NEDC.

After the incorporation of these corrections, the lines linking the CO2 emissions with the inertia of PC are now: GO: CO$_2$=0.1369*Inertia-11.1, GP: CO$_2$=0.1445*Inertia-11.1, DO: CO$_2$=0.1167*Inertia-8.9 and DP: CO$_2$=0.1225*Inertia-8.9.

### 3.4 CO2 changes from the increased penetration of diesel PC in Sweden

Several scenarios are constructed to calculate the changes on CO2 emissions for different percentages of Diesel penetration. These percentages vary from 7 to 97% total penetration, taking into account the actual new Diesel passenger sales which correspond to 7% of total PC sales. These scenarios take into account two parameters:
- the differences between the Swedish and EU market and,
- the FC of gasoline and Diesel PC (scenarios CFC, for current FC and scenarios corresponding to the four previous FC assumptions).

The combination of all these situations gives 20 scenarios. These scenarios can be divided in four main groups:
1. The scenarios using the current Swedish new PC sales (named CURRENT).
2. The scenarios using the average number of current Swedish and EU new PC sales (corresponding to 31 new PC per 1000 inhabitants per year). The percentage of each segment corresponds to the average value of the current Swedish and EU percentages (named AVERAGE).
3. The scenarios using the average number of current Swedish and EU new PC sales, but keeping the current Swedish segment distribution (named AVERAGE1).
4. The scenarios using the current EU new PC sales in terms of number (corresponding to 34 new PC per 1000 inhabitants per year) and segment distribution (named EU).

3.4.1 CO$_2$ change as a function of scenario using the actual diesel penetration

The first comparison is made in the case of actual Diesel penetration (figure 3, lower bars). The first remark is that all scenarios using DO and DP FC give quite similar results, because the Diesel penetration is very low: only 7%. The DO and GO scenarios give always a little lower values than the DP and GP ones, because the FC is lower in the first case.

Comparison of CURRENT scenarios: Comparing the four CURRENT scenarios, a decrease of the global CO$_2$ emitted from new PC will occur in the future. This decrease will be about 5% in the case of a small gasoline FC decrease (the two GP assumptions), but will reach about 10% in the case of more important decrease (the two GO assumptions).

Comparison of CFC scenarios: The global CO$_2$ emissions will practically remain constant in the case of scenario AVERAGE-CFC. This statement indicates that even if the total new PC sales increase, the total CO$_2$ emissions will not change because these sales will correspond to lighter cars. If the new PC sales increase with the actual Swedish segment distribution (AVERAGE1-CFC), the CO$_2$ emissions will increase by 8%, indicating the high importance of vehicle inertia and segment distribution. This increase will be even higher (20%) in the case of the EU-CFC scenario.

Comparison of GO scenarios: If the future optimistic gasoline FC is taken into consideration, the total CO$_2$ emissions will decrease about 10.5% in the case of the two AVERAGE-GO scenarios, or decrease about 2.5% in the case the two AVERAGE1-GO ones, or increase 8-9% in the case of the two EU-GO ones.

Comparison of GP scenarios: In the case of the gasoline pessimistic FC (GP), the CO$_2$ benefits are lower. The corresponding values for the CURRENT-GP, AVERAGE-GP, AVERAGE1-GP and EU-GP scenarios are -4%, -5.5%, 2-3% and 14%, indicating the high importance of future FC on the total CO$_2$ emissions from new PC.

3.4.2 CO$_2$ change as a function of diesel penetration, using the actual FC

Figure 4 presents, for all scenarios studied, the change on CO$_2$ emitted from new PC as a function of Diesel penetration. The dashed area of this figure shows a decrease of the total CO$_2$ emissions, while the white one shows an increase. For zero Diesel penetration, the scenarios using the GO or GP assumptions converge to the same point, because the Diesel FC is not taken into account in these cases.
At 100% Diesel penetration, the scenarios using the DO or DP assumptions converge to the same point, because gasoline FC is not taken into account in these cases. This figure shows that the four scenarios groups form four almost parallel groups of lines. Of course, the total CO\textsubscript{2} emissions generally increase with the number of PC sales (scenarios \textit{EU>AVERAGE1>CURRENT>AVERAGE}), but the change of segments to lower ones can be benefit of about 0.5%, even in the case of increased PC sales (scenarios \textit{CURRENT>AVERAGE}). The scenarios using the \textit{AVERAGE1} sales are about 7 percentage units lower than the current sales scenarios, while the \textit{EU} sales are even much higher: about 17-20 percentage units.

![Figure 3: Relative change of total CO\textsubscript{2} emissions emitted from new PC.](image)

\textbf{30\% and 50\% Diesel penetration}: The percentage of Diesel penetration strongly influences the total CO\textsubscript{2} emissions change. Two cases will be particularly examined: a 30\% and a 50\% Diesel penetration. The total CO\textsubscript{2} emitted from new PC decreases by 4.1\% and 7.6\% respectively when the 1st scenario is used (\textit{CURRENT-CFC}). The corresponding values for the \textit{AVERAGE-CFC} scenario are quite similar: a 4.9\% and 8.4\% decrease, indicating again that even if the number of new PC increases, the use of lighter cars and the higher penetration of Diesel PC can be benefit for the CO\textsubscript{2} emissions. The \textit{AVERAGE1-CFC} scenario changes respectively the total CO\textsubscript{2} emissions by +3.5\% and -0.3\%. This statement indicates that a 50\% Diesel penetration can balance the increase of the number of passenger car sales of this scenario. The values of \textit{EU-CFC} scenario are even higher: an increase of 15.1\% and 10.9\% respectively for a 30\% and 50\% Diesel penetration. It must be noticed that all the above values are lower than those obtained in the case of a 0\% Diesel penetration: - 0.5\%, +8\% +20.1\% for the \textit{AVERAGE-CFC}, \textit{AVERAGE1-CFC}
and EU-CFC scenarios respectively. The EU-CFC scenario reaches the current total CO$_2$ emissions in the case of a 100% penetration of Diesel passenger car, while the AVERAGE1-CFC one in the case of a 50% penetration. These results show that, if the Swedish new PC sales approach the EU average ones, a quite important increase of total CO$_2$ emissions will occur, even for very high Diesel penetration.

**10% supplementary Diesel penetration:** In all cases studied, a supplementary penetration of 10% gives the same change of the total CO$_2$ emitted from new PC. Upper bars of figure 3 present the supplementary benefit on CO$_2$ emissions for a 10% supplementary penetration of Diesel new PC registrations. This benefit can reach 2.1% in the case of scenario EU-CFC. Comparing the four CFC scenarios (CURRENT, AVERAGE, AVERAGE1 and EU), this benefit follows the order EU>AVERAGE1>CURRENT>AVERAGE, because of the increased number of future PC sales. This last remark is not valid in the case of CURRENT and AVERAGE scenarios, because the replacement of heavy vehicles by lighter ones gives more benefit than the increased number of vehicles.

![Figure 4: Change of the total CO$_2$ emitted from new PC.](image)

**3.4.3 CO$_2$ change as a function of scenario, using the future FC**

Comparing the future FC scenarios, the order GPDO>GPDP>GODO>GODP is observed in all cases. The reasons are that the two first scenarios consider a pessimistic gasoline FC which increases the difference between gasoline and Diesel CO$_2$ emissions, while the last two scenarios consider an optimistic gasoline FC, which reduces this difference. The cases GPDO and GODO are respectively more benefit that the GPDP and GODP, because they take into consideration an optimistic Diesel FC, which increases the difference between gasoline and Diesel CO$_2$ emissions, contrary to the last two ones which decrease it.
Comparison of actual and future FC in the case of DO scenarios: The comparison between the scenarios using the current and future FC shows that, for each group of sales (CURRENT, AVERAGE, AVERAGE1 and EU), the total CO₂ emissions are lower than the CFC scenarios in the case of the DO assumption (figure 4). This difference is higher in the case of actual Diesel penetration: 10 and 5 percentage units lower for the scenarios CURRENT-GODO and CURRENT-GPDO compared to CURRENT-CFC one. About the same differences are observed in the case of AVERAGE-GODO and AVERAGE-GPDO scenarios compared to the AVERAGE-CFC one, but they reach 10-11 units lower in the case of AVERAGE1-GODO and AVERAGE1-GPDO, compared to the AVERAGE1-CFC one. The decrease in the EU-GODO and EU-GPDO scenarios compared to the EU-CFC one is a little lower: 11 and 6 percentage units. The AV1-GODO and AV1-GPDO scenarios decrease the CO₂ emissions by 10-11 percentage units comparing to the AV1-CFC one. These differences are slightly more important at increased sales, showing the relative importance of the future FC on the future CO₂ emissions control. The GO scenarios give higher differences than the GP ones, due to the higher relative difference of gasoline/Diesel FC.

Comparison of actual and future FC in the case of DO scenarios: The previous remarks are not always valuable in the case of DP scenarios. These last scenarios give lower CO₂ emissions than the four CFC ones (CURRENT-CFC, AVERAGE-CFC, AVERAGE1-CFC and EU-CFC), only for a Diesel penetration lower than about 60% and 75% respectively for the GP and GO assumptions. For higher Diesel penetrations, the total CO₂ emissions are higher than those of the CFC scenarios. This last result indicates that Diesel PC FC control is an important factor for future total CO₂ emissions in the case of an increased Diesel penetration and can even be negative in the case of a pessimistic future Diesel FC.

4 Conclusions

The aim of this work is to determine the CO₂ benefit from the increasing percentage of Diesel PC in Sweden. The main conclusions of this work are the following:

- On NEDC, there are two quite good relationships between CO₂ emissions and PC inertia, one for gasoline and one for Diesel PC. Two other quite similar relationships are found between CO₂ emissions and the average inertia of each segment.

- The global CO₂ emissions in Sweden from new PC will decrease 5-10% in the future, if the future PC registrations remain as the current ones and the FC of future PC decreases.

- The total CO₂ emissions increase with the number of PC sales, but the change of segments to lower ones can be benefit, even in the case of increased PC sales. If the new registrations become the same as the average current Swedish and the average EU ones (in terms of new PC number and segment distribution), the total global CO₂ emissions will practically remain constant,
because the increase of PC number is balanced by the PC lower inertia. If the new PC registrations increase with the current Swedish segment distribution, the CO$_2$ emissions will increase by 8%, indicating the high importance of vehicle segment distribution.

- A supplementary penetration of Diesel PC of 10% gives a CO$_2$ benefit which can reach 2.1%.

- The introduction of Diesel PC and the decrease of vehicle inertia will help to reduce the total CO$_2$ emitted from new PC. The future FC is the other key parameter for this control. If FC of future Diesel PC increases, an increased Diesel penetration can be negative for the total CO$_2$ emissions control.

References

[5] Internet site of Eurostat (europa.eu.int/comm/eurostat/)