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What is the real-world CO_2 reduction benefit of the 95 g/km passenger car average emission target to be reached by 2020?

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Abstract

Road transport is responsible for roughly 20% of total Greenhouse gas (GHG) emissions in Europe with passenger cars being a significant fraction. To control this, emission limits for CO_2 have been set, with the target is to reach 130 g/km of CO_2 as an average for all new passenger cars in 2015. The medium-term target is to reach 95 g/km average in 2020. These average values refer to CO_2 emission over the New European Driving Cycle (NEDC). This cycle has been recently considered to be misrepresenting actual driving conditions. Hence, a vehicle may emit significantly higher CO_2 emissions in real-world than it does over the NEDC. This paper aims at quantifying the impact in real-world CO_2 emissions by selecting different technology pathways to reach the 95 g/km target. Along with a basecase scenario considering, three alternative scenarios were examined. The first scenario considers downsizing to smaller and more efficient diesel and gasoline cars. The second one assumes that hybrids will be the prime technology for emission reduction. The third scenario assumes that electrification will be the main technology pathway. The 95 g/km target is reached in all scenarios. Results show that despite the statutory target is fixed, actual reductions over the basecase scenario differ. Electrification, downsizing, and hybridization scenarios achieve 3 %, 4,1%, and 11% CO_2 reductions over the basecase new registrations in 2020, respectively. The average CO2 emission factor in the same order is 117, 116 and 108 g/km. These results show that actual CO_2 reductions to be reached not only depend on the average CO_2 value agreed but also on the technology pathway selected. Conclusions were obtained under certain boundary conditions and by studying a limited suite of scenarios and technology pathways. However, our intention has been to demonstrate that real-world performance differs than statutory targets by offering a few examples. Such an approach, when further developed and adjusted to national circumstances, may be used to inform policy regarding the expected benefits of vehicle GHG regulation in view of wider targets, such as the 20-20-20 initiative.

Keywords: climate change; greenhouse gases; emission targets; hybrid vehicle; electric vehicle

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1. Introduction

Combating global warming and climate change is one of the most important challenges facing mankind. As a result of its heavy dependence on fossil fuels the transport sector is a significant consumer of energy and a major source of greenhouse gas (GHG) emissions. The transport sector accounted for around 33% of total final energy consumption in the EU27 in 2007, and was responsible for around 20% of GHG emissions. Road transport is the dominant mode, emitting 71% of all transport-related GHG emissions (European Commission, 2010).

A major concern is that overall transport activity – and hence GHG emissions from the sector – has shown a continuous increase since 1990. Between 1995 and 2008 passenger transport by car increased by 21%, and passenger transport by bus or coach increased by 9%. There were large increases in both road freight transport (almost 50%) and passenger transport by air (62%) (European Commission, 2010). In the case of private motorised transport, the general trend of more or less continual growth during recent decades has been driven primarily by the association of personal mobility with quality of life and economic development (Uherek et al., 2010), and its consequence in terms of vehicle ownership and use.

For these reasons, there has been a significant effort at the technology front to decrease energy consumption and CO_2 emissions from vehicles. Passenger cars have been historically the first road sector for which emission reductions have been agreed. The voluntary agreement of the European Commission with the automotive industry (Commission Recommendation 1999/125/EC) was the first attempt to set CO_2 emission targets for new passenger cars. In this process, although significant emission reductions were achieved by the vehicle manufacturers in view of the 140 g/km target that had agreed by 2008/09, it was not made eventually possible to reach the reductions proposed. As a result, the European Parliament and the Council issued Regulation No. 443/2009 introducing mandatory CO_2 emissions limits for new passenger cars. The regulation specifies that each vehicle manufacturer must achieve a fleet-average CO_2 emission target of 130 g/km by 2015 for all new cars registered in the EU. A further reduction of 10 g/km is to be reached by additional measures, such as the use of biofuels. The regulation also defines a longer-term target of 95 g/km to be reached by 2020. These target limits are set taking into account emission levels produced over the type-approval driving cycle (the New European Driving Cycle – NEDC).

Although targets have been agreed in the regulations, there are no recommendations or guidelines on how these targets have to be reached. That is, there are no prescriptions in the regulations as to which technologies or fuels have to be used or what vehicle sizes have to be introduced to reach the targets. In principle, every manufacturer is allowed to develop its own strategy, as long as the mean CO_2 target over the NEDC is reached for the vehicles sold. The different strategies introduced may have different real-world implications. A strategy which is based mainly in the introduction of hybrid vehicles may lead to different real-world emissions than, for example, introduction of small diesel vehicles, although the mean emissions over the NEDC may be the same. It is therefore interesting to explore the actual CO_2 emission reductions to be reached by the same emission target but using different strategies to achieve this.

2. Methodology

2.1. General approach

For the purposes of the present study, the CRUISE model, AVL's vehicle and powertrain level simulation tool (https://www.avl.com/cruise1), was used to simulate vehicle engine operation over certain driving cycles. In CRUISE, a vehicle is graphically setup, providing all kinds of powertrain details (wheel size, gearbox, differential, engine type, etc.). Then an engine map is given, where the engine characteristics (be it consumption, pollutants, noise, etc.) are provided as a function of the engine speed and power. Then the vehicle is allowed to operate over different speed profiles (driving cycles) and the software simulates the vehicle and engine operation by which it can produce total fuel consumed and total emissions produced. The success in the simulation depends on the quality of input data delivered both on the vehicle and engine fronts.

The main variables which were used as an input to the model were fuel consumption engine maps, rated engine power, frontal area and aerodynamic drag, vehicle mass, rolling resistance coefficient(s), gear and final drive ratios, wheel diameter and dimensions and weight of various components, for typical passenger cars of different technology. These data were retrieved from several sources such as measured coast down curves, measured engine maps, type approval data (VCA, 2010), literature (scientific papers, ordinary press, magazines, press releases) and specialized websites.

The following approach was generally implemented: First, some typical gasoline and diesel cars from the European stock were selected and mildly improved through simulation to meet the 95 g/km target over the NEDC. The mild improvements included reduction in the mass, improvements in the engine efficiency, reduction in the rolling resistance factors, further refinement of the aerodynamics of the vehicle, and optimization of the gear ratio to improve fuel economy. This is one path of achieving the 95 g/km requirement in 2020, i.e, by gradual improvements on existing widespread technologies. The second approach was to introduce two advanced technology vehicles which may achieve CO_2 emissions already below the 95 g/km requirement. The first advanced technology has been the well-known gasoline hybrid technology, where an electric motor is used to assist the engine during acceleration and high load conditions. Current hybrid vehicles can already achieve the 95 g/km target. The second advanced technology has been an electric car with a gasoline range extender. Such a configuration also consists by an internal combustion engine and electric motor but the power to the wheels is only provided by the electric motor. The engine is only used to power a generator that drives the electric motor. Compared to a hybrid vehicle, an electric vehicle with range extender offers a longer all-electric range.

Our approach was to introduce improved conventional and advanced vehicle technologies in different proportions along different scenarios and observe their impact in real-world CO_2 reductions, while achieving the same CO_2 target over the NEDC test in all scenarios.

2.2. Vehicle configuration

Two popular vehicle models, the Peugeot 107 1.0 and the Ford Ka 1.2 Duratec, were selected as representative types of the small gasoline car category to establish basecase emissions. The Peugeot has one of the lowest CO_2 emission values of conventional vehicles in the market today (108 g/km), while the Ford, mainly due to its size, emits some 30 g/km higher than the average 2020 target. This is however a very common vehicle in the European stock. The two small diesel cars selected included the Smart fortwo cdi, which is already below the 95 g/km limit, and the Fiat 500 1.3 MTJ, which is a typical small diesel vehicle with CO_2 emissions close to the 2020 target. Key technical specifications for these vehicles are presented in Table 1. The type approval (TA) CO_2 emissions reported by the manufacturer for each vehicle are also included in the table.

The Smart fortwo is already below the 2020 target of 95 g/km, hence no additional improvements were brought to this vehicle. All other conventional vehicles were above the limit. A number of improvements were introduced in order to bring them along the 2020 CO_2 targets and introduce them as characteristic vehicles to the scenarios. These improvements are summarized in Table 2 and are rather mild ones, expected to be easily obtained by technology improvement. The values in Table 2 are not a unique combination to reach the 95 g/km target but they represent a feasible approach based on observed current trends and expected future developments. Several other options exist; identifying all these options is not expected to fundamentally change the conclusions of this study. Hence, the improved specs conventional vehicles can be considered typical of small gasoline and diesel cars in 2020.

Table 1. Main technical data for the selected small gasoline and diesel cars

Input parameter	Peugeot 107	Ford Ka	Smart fortwo	Fiat 500
Mass empty (kg)	790	940	650	960
Drag coefficient	0.30	0.34	0.34	0.32
Frontal area (m^2)	2.20	2.11	2.10	2.42
Engine capacity (l)	1.0	1.2	0.8	1.25
Fuel type	Gasoline	Gasoline	Diesel	Diesel
Max torque (Nm)	100	102	110	145
Max power (kW)	50	51	45	55
CO_2 (g/km)	108	125	88	110

Table 2. Improvements introduced to conventional vehicles to meet the 2020 targets

Parameter	Peugeot 107	Ford Ka	Fiat 500
Vehicle mass	- 10 %	- 25 %	- 10 %
Drag coefficient	- 10 %	- 20 %	- 20 %
Gear ratios	0 %	+ 15 %	0 %
Engine efficiency	+5 %	+ 5 %	+ 5 %
TA CO_2 emissions	- 11 %	- 22 %	- 11 %

A full hybrid electric mid-size car (Toyota Prius) and an electric vehicle with range extender (Opel Ampera) were also selected as representative of the advanced vehicle technologies. The CO_2 emissions of the third generation Toyota Prius (2010 model year) are as low as 89 g/km, significantly reduced compared to the 104 g/km of the previous (2nd) generation Prius. The Opel Ampera uses electricity (provided through the grid) as its primary power source and gasoline as a secondary power source to generate electricity through an internal combustion engine. In contrary to a hybrid or plug-in hybrid, that use both the internal combustion engine and the electrical motor to directly power the wheels, an electric vehicle with a range extender is only propelled by the electric drive unit and the engine is only used to power a generator and produce electricity to recharge the batteries. This is why it is equipped with a stronger electrical motor and larger batteries than hybrid vehicles. The Opel Ampera is the first vehicle introducing this technology and, according to the manufacturer, has an all-electric range of 60 km. Within this range, it emits no tailpipe CO_2, as it is practically driven as an electric vehicle. Key technical specifications for these two vehicles are presented in Table 3.

Type-approval CO_2 emissions for the Opel Ampera are determined by the test procedure described in UN-ECE (2005). According to this, two tests are carried out, one with a fully charged battery and one with a battery at minimum state of charge. Weighted values of CO_2 emissions are then calculated with the following formula:

$$MHEV = (De \times M1 + Dav \times M2) / (De + Dav) \qquad (1)$$

Where MHEV is the mass emission of CO_2 (in g/km), *M1* is the mass emission of CO_2 (in g/km) with a fully charged electrical energy/power storage device, *M2* is the mass emission of CO_2 (in g/km) with an electrical energy/power storage device at minimum state of charge (maximum discharge of capacity), *De* is vehicle's electric range and *Dav* = 25 km is the assumed average distance between two battery recharges).

Table 3. Main technical data for the hybrid and the electric vehicle

Input parameter	Toyota Prius	Opel Ampera
Empty vehicle mass (kg)	1379	1660
Drag coefficient	0.25	0.26
Frontal area (m^2)	2.61	2.30
Max engine torque (Nm)	142	125
Max engine power (kW)	73	66
Max electric motor torque (Nm)	207	370
Max electric motor power (kW)	60	111
Max battery capacity (Ah)	6.5	45
CO_2 emissions (g/km)	89	< 40

2.3. Scenario simulations

The specifications of these vehicles were introduced in the CRUISE model and their emissions were calculated over the NEDC and over real-world driving cycles. The latter were derived from the ARTEMIS project (André, 2004) and have been widely considered to represent actual driving conditions in urban, rural, and highway conditions, respectively. This made possible to predict the real-world behaviour of the vehicles in terms of their actual CO_2 emission levels.

The different vehicles simulated were then introduced in the stock at various rates. The German vehicle fleer was selected as a test case, because this is a dynamic stock with fast vehicle replacement rates and generally short lifetime of the vehicles in operation. This allows a fast technological replacement and allows any impacts of the technology change to be maximized. The projection of the total stock growth in Germany was delivered by the LIFE+ EC4MACS project (www.ec4macs.eu). Data from this project have served as input to high level projections in Europe, such as the one used in the White Paper on Transport and the Thematic Strategy on Air Pollution, hence are consistent with the long-term planning in EU.

3. Results

3.1. Estimated vehicle performance

Table 4 shows the emission level of the improved gasoline and diesel vehicles, expected to be in operation in 2020. These have been calculated by the CRUISE model, starting from the gasoline and diesel vehicles in Table 1 and introducing the incremental changes of Table 2. Emissions have been calculated both for the type-approval driving cycle (NEDC) and the three real-world driving cycles. The mean emission performance, also taking into account the duration of the three real-world driving cycles, is shown in the last row of the table. The real-world performance results to higher CO_2 emissions than over the type-approval test. The reason for this is the more transient character and the stronger accelerations encountered in the real-world than in type-approval. The relative difference between the real-world and type-approval tests depends on the vehicle considered and ranges from 9% to 15%. Table 4 also shows the CO_2 emissions of the hybrid vehicle, without introducing any additional improvements, as this is already below the 2020 target.

Table 4. CO_2 (g/km) emissions of 2020 specs vehicles in type approval and real-world cycles

Driving cycle	Gasoline 1	Gasoline 2	Diesel 1	Diesel 2	Gasoline Hybrid
NEDC	97.0	89.1	96.5	97.5	89.9
Artemis urban	154.7	141.6	144.2	160.1	89.9
Artemis road	90.7	76.0	94.9	90.9	72.3
Artemis motorway	111.4	104.9	107.2	107.2	105.2
Artemis (all)	110.4	97.0	111.4	108.6	81.1

An alternative approach had to be followed for the electric vehicle with range extender. Tailpipe emissions from such vehicles are a function of the distance of the trip, the initial battery charge level, and the speed. Short trips (up to ~50 km) can be conducted only with the electric motor running, hence they do not result to the production of any CO_2 emissions. A typical behaviour of these vehicles is shown in Figure 1. This graph has been produced by simulating with CRUISE the full suite of Artemis cycles (Urban, Rural, Motorway) and then continuing by executing a number of consecutive Motorway cycles. The reason of choosing Motorway to extend the trip distance is based on the assumption that trips >50 km should in principle be executed in highways. The performance in Figure 1 would be slightly different had the simulation been conducted with consecutive urban or rural cycles.

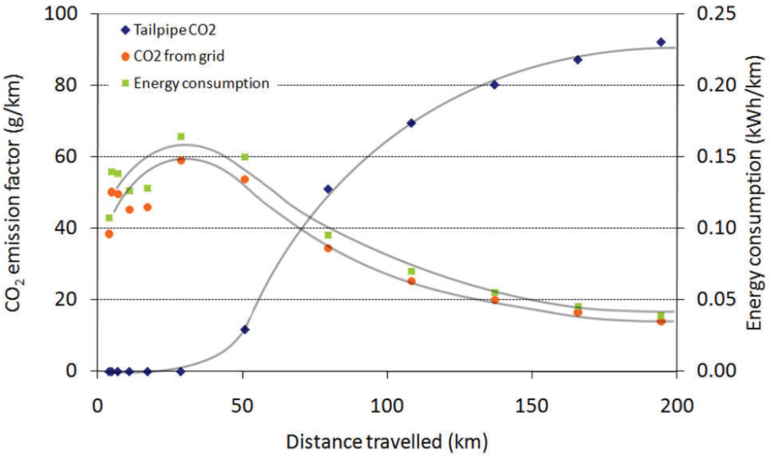

Fig. 1. Energy and CO_2 emissions of an electric car with range extender as a function of the distance travelled.

Figure 1 shows two different sets of CO_2 emission factors. One set refers to the "tailpipe CO_2" emission factors, i.e. those produced by the internal combustion engine and delivered at the exhaust of the vehicle. The emission factor (expressed in g/km) is zero up to a trip distance of approximately 50 km and then gradually increases as the battery charge is depleted and the engine has to be powered up to recharge the batteries. The "CO_2 from grid" emission factor refers to the CO_2 emissions which are not produced on board the vehicle but are equivalent to the CO_2 emissions produced to generate the electric energy stored in the batteries. The CO_2/MJ generated will depend on the energy intensity of the power mix in the particular region. In our calculations, we took into account the average European energy mix of 2020 considered in the PRIMES 2009 baseline scenario (European Commission, 2010b), consisting of 1.8% liquid fuels, 24.9 % solid fuels, 22.8% gaseous fuels, 24.5% nuclear, and 26% renewables. This results to an average upstream CO_2 production factor of 359 g/kWh.

3.2. Scenario results

Three scenarios for the penetration of different technologies in the European vehicle stock were designed, in order to demonstrate how the same average CO_2 target over the NEDC may be reached with varying actual effects on real-world emissions. These scenarios are only meant to demonstrate the sensitivity of real-world CO_2 emissions to engine technology and they do not attempt to dictate a particular path that has to be followed to reach a target.

The options to meet the future target of 95 g/km (tailpipe only) include shift to smaller cars/engines (downsizing scenario) and penetration of hybrid (hybridization scenario) and electric (electrification scenario) vehicles. Full electric vehicles (i.e. without a range extender) may be introduced but we still consider that their numbers will be relatively small to have a substantial impact on mean CO_2 emissions. Plug-in hybrids are the other option for an advanced technology. However, it is considered that their performance is similar to the electric with a range extender so they were not introduced not to unnecessarily complicate the calculations. Between the four available technologies, downsized gasoline, downsized diesel, hybrid and electric with range extender, any mix is considered possible as long as the average CO_2 target of the new registrations is met.

The basecase new registration development considered in Germany is shown in Figure 2. Total registrations per year are in the order of 4.4 million vehicles, with more than half being small petrol and diesel ones. A number of structural changes were introduced in these new registrations in order to build the three alternative scenarios but the total number always remained the same.

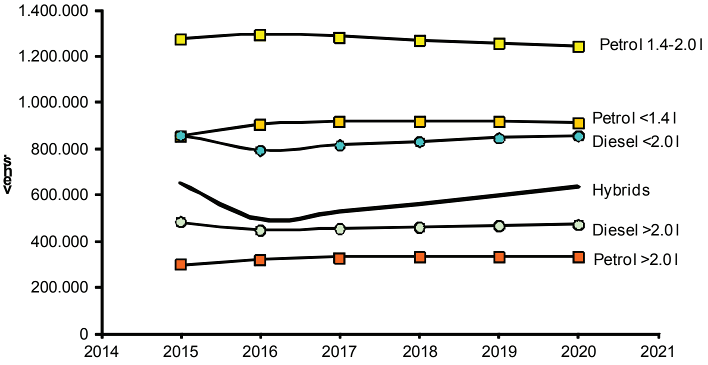

Fig. 2. New vehicle registrations in Germany, considered in the basecase scenario.

- Scenario 1 (downsizing) assumes a shift towards small vehicles at the expense of bigger cars. According to this scenario, 70 % of medium-size gasoline cars are substituted by small ones, whereas large gasoline and diesel cars are completely phased-out by 2020. In order to achieve the 2020 target, 6% of hybrids are substituted by electric vehicles. This results in the vehicle market being dominated by small cars with a 77 % share in new registrations by 2020.

- Scenario 2 (hybridization) assumes an aggressive penetration of hybrid vehicles. According to this scenario, 50 % of medium-size gasoline cars and 80 % of large gasoline and diesel cars are substituted by hybrid gasoline and diesel cars respectively by 2020. Again, 6 % of the basecase hybrids are substituted by electric vehicles. As a result, the penetration of hybrid vehicles increases from 15 to 42% from 2015 to 2020, whereas it is in the order of 13 to 15 % in the basecase over the same period.
- Scenario 3 (electrification) assumes an aggressive penetration of electric vehicles with a range extender. Compared to the previous scenarios, a smaller fraction of medium and large cars (20 % of medium-size gasoline cars and 30 % of large gasoline and diesel cars) is substituted by electric vehicles. This results in an 11 % share of E-REV in the total new registrations by 2020.

In all these scenarios, an average value of 95 g/km is achieved for the emission level of new registrations over the type-approval test. The replacement patterns assumed were based on assumptions. Alternative replacements would lead to a different net CO_2 benefit, than the one calculated in this study.

Based on these assumptions on stock evolution, the share of new registrations and using the emission factors developed with the simulations in the previous section, Figure 3 shows how the average real-world CO_2 emission factor of new passenger cars in Germany will evolve according to the three scenarios, compared to the basecase. The graph shows that the basecase emission factor will drop in any case due to the existing trends of downsizing and technology improvement. Also the graph shows the “Regulation” line which corresponds to the average emission factor if the type-approval emission level was representative of the actual one.

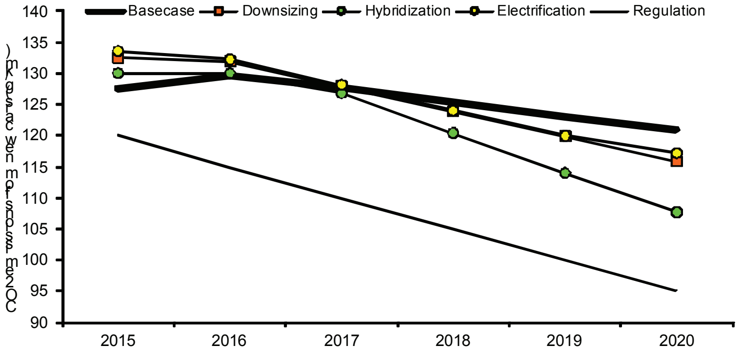

Fig. 3. Average real-world CO_2 emission factor of new passenger car registrations in Germany according to three scenarios, compared to the statutory (“Regulation”) mean emission factor.

All scenarios result to emission factors higher than the basecase one before 2017. The reason for this is that the introduction of new technologies produces an emission margin over the fixed annual target. For example, hybrid and electric vehicles are already much below the 95 g/km target, which allows the registration of a significant number of high CO_2 emitters (large and powerful vehicles). Such vehicles tend to have much higher real-world over type-approval emission ratio and as a result, the average real-world emission factor tends to be higher even than the basecase one. This trend also explains why the electrification scenario results to higher emissions than the hybridization one in the years to come. The emission benefit that the introduction of electric vehicles produces in type approval is so high that several high emitters can be accommodated while still meeting the average target. Based on these considerations, the emission reductions over the basecase achieved in 2020 range from 7% for the electrification scenario, to 12% for the downsizing scenario and 17% for the hybridization scenario. Moreover, if one takes upstream CO_2 emissions into consideration, total CO_2 emission benefits drop to 1.6% for the electrification scenario.

The actual CO_2 emission benefits that can be introduced at a fleet level by the three scenarios are a combined effect of the performance of the new vehicles registered and the performance of the vehicles they replace. This is shown in Figure 4. The benefit increases with time over the basecase, as an increasing number of improved vehicles is introduced in the stock. In this case, the downsizing and the electrification scenarios result to more or less similar reductions. This is because downsizing is mostly used to replace larger cars with smaller ones while cars of the same more or less specifications are replaced in the electrification scenario. Highest emission reductions (4%) overall over the basecase are achieved for the hybridization scenario.

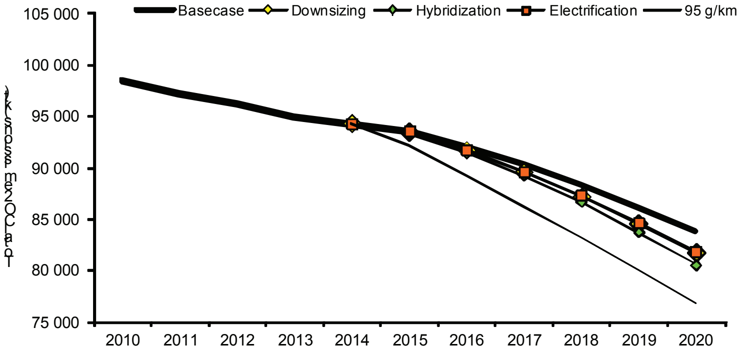

Fig. 4. Total CO_2 emission evolution from passenger cars according to the three scenarios and the statutory reductions “95 g/km).

4. Conclusions

A number of conclusions can be drawn from this work, with regard to the real-world development of CO_2 emissions from passenger cars. Three scenarios were designed, following a basecase one, to simulate three directions in reducing emissions, i.e. downsizing, electrification, and hybridization. A range of assumptions was used in formulating each scenario, so that the average of 95 g/km over the NEDC was met in each of them. For simulating the real-world performance of vehicles, the suite of three Artemis cycles (Urban, Road, Motorway) was used. We have selected the German stock for the simulations. Somehow differentiated conclusions may be reached when applying the same scenarios in other countries, for example in countries with a high diesel share (e.g. France, Belgium, …). Based on the simulations under the conditions explored, the following conclusions may be drawn:

- Different approaches are possible to bring the NEDC-average CO_2 emission of new cars down to 95 g/km. As three distinct alternative approaches, we demonstrated that the target can be reached by downsizing of conventional vehicles, by hybridization, and by electrification of the new vehicle stock.
- The actual emission benefit varies with scenario when a 95 g/km average CO_2 emission target is fixed. Compared to a basecase development, the scenarios we examined result to real-world CO_2 emission benefit from new registrations in 2020 that range from 3% for the electrification scenario, 4,1% for the downsizing scenario and 11% for the hybridization scenario.
- The average real-world CO2 emission factor exceeded the agreed 95 g/km value in all scenarios (13% in hybridization, 16,6% in downsizing and 17% in the electrification scenarios).

- The actual emission benefit from the stock also depends on the vehicles being replaced. Since downsizing can be applied to larger vehicles, while electrification is more relevant for smaller vehicles, it appears that downsizing and electrification result to similar overall emission benefits.
- The calculation uncertainty is highest for the electrification scenario. Optimization of the electric vehicle usage pattern (e.g. use only in urban driving) can greatly increase the benefit. On the other hand, the very low CO_2 emissions achieved by electric vehicles over type approval provide the margin for the introduction of large conventional cars in the fleet. This counterbalances the benefits.
- If one takes into account the CO_2 emissions for electricity generation and a projected energy mix in 2020, the benefits of the electrification scenario over the basecase further diminish.
- The hybridization scenario achieves the best overall result because hybrids seem to perform well under all driving conditions. In addition, they have a type-approval CO_2 emission very close to the target which means that provide limited margin for the introduction of vehicle types with higher emissions.

These conclusions show that the effectiveness of Regulation 443/2009 in achieving real-world CO_2 emission reductions will greatly depend on the technology pathway that will be used to achieve the targets, as well as the vehicles being replaced by new technology. This has been an exploratory study only, and does not aim at recommending a particular technology pathway. However, it has been demonstrated that the difference between the best and the worst scenario examined is 13%, i.e. as if the actual target was 107 g/km instead of 95 g/km in one of the scenarios. Moreover, the analysis has shown that the combination of electrification with a fixed average CO_2 emission target might only lead to marginal overall benefits, much lower even than downsizing. The latter is much easier to achieve both from a technical and infrastructural point of view. In other words, the deployment of electrification requires close monitoring and guidance in order to achieve its expected benefits.

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