Reducing CO_2 Emissions from Road Transport - Overview of the Main Initiatives and Technical Measures Proposed to Date in Europe

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Abstract

The demand for fossil fuel in the transport sector is constantly increasing and transportation is ranked amongst the highest greenhouse emitting sectors globally. Today, tackling CO_2 emissions from road transport a widely discussed topic and constitutes a milestone towards reaching a sustainable, carbon neutral economy. This challenge is being described in various initiatives adopted in the European Union and other parts of the world. So far several measures have been proposed and adopted for reversing the increasing greenhouse gas emissions trends. This paper attempts an overview of the existing policy framework in various countries focusing on European Union. In addition, the main technical measures proposed and promoted in this direction are presented and evaluated with respect to their greenhouse reduction potential. Special attention is paid to emerging technologies, such as hybrid vehicles and biofuels. The main factors differentiating the officially reported CO_2 emissions from actual real life emissions are discussed and a brief evaluation of the current European policy is presented.

Keywords: *CO_2 emissions, fuel consumption, road transport*

Introduction

The reduction of anthropogenic carbon dioxide (CO_2) emissions and the gases associated with global warming phenomenon is regarded as one of mankind's greatest challenges for the 21st century. CO_2 is emitted from almost all human activities and apart from its direct impact on climate, change it is indirectly linked with an older and perhaps more complex problem, namely the availability and utilisation of energy sources. Both influence and will continue to do so even more intensively in the future the daily life of people and the functions of human societies.

Transport is historically, one of the most important human activities while after the industrial revolution it has been amongst the fastest growing sectors of the global economy. Today, transport accounts for 20% of global primary energy consumption and for about 18% (~ 5.3 Gt) of the total anthropogenic greenhouse gas emissions. Transport industry is the third most energy demanding industries both of the final energy consumption and the second with respect to CO_2 emissions, outpacing both services and household activities. Based on the current GHG emissions inventorying regulation, transport was responsible for 27% of the total emissions in the U.S. in 2003. The calculations do not consider other transport related activities, such as refining and fuel production which raise the figure even higher. The corresponding percentage for the 15 European Union (EU) states is estimated at 21% of the total greenhouse gas emissions (2005) and the figure is increasing.

The energy consumed for transport is mainly consumed for road transport which includes passenger vehicles, light duty trucks, heavy duty trucks and buses, special vehicles and two or three-wheelers. Estimates for 2000 indicate that road transport accounts for 75% of total emissions in the sector with aviation and maritime transport coming second and third. A recent study issued by the International Energy Agency (IEA) reports even higher estimates for year 2005 with the share of road transport reaching 89%. Passenger cars and light duty trucks are responsible for the majority of CO_2 emissions and the energy consumed for road transport. Passenger cars and light duty trucks account for 65% of road transport greenhouse emissions and for about 45% of the total transport activity emissions.

The aforementioned increased energy consumption and greenhouse emissions would not cause so much concern if their evolution remained constant. On the contrary, the trend is steadily increasing worldwide. According to the IEA, between 1990 and 2005, the energy requirements for transport increased by 37% and reached 75 EJ (75 1018 J), making transport the fastest growing end-use sector. The growth rates of the developing countries' economies surpass those of industrially developed countries. This results in a sharp increase in transport activity both because of the rising demand for goods transportation and the increasing vehicle ownership. Table 1 presents the indicator vehicles per 1,000 inhabitants for India, China, USA and EU in

Table 1. Vehicle ownership and the estimated increase in vehicle population for the 2000-2030 period Sources:[1,2,3,4]

Year	India		China		USA		Europe	
	Vehicles /1000 inhabitants	Additional vehicles 2000-2030 ('1000)	Vehicles /1000 inhabitants	Additional vehicles 2000-2030 ('1000)	Vehicles /1000 inhabitants	Additional vehicles 2000-2030 ('1000)	Vehicles /1000 inhabitants	Additional vehicles 2000-2030 ('1000)
2000	5	155.000	12	375.790	779	43.354	375	56.100
2030	110		269		849		500	

Table 2. Regulatory initiatives to tackle CO_2 emissions in various countries

Country / Region	Standard	Unit	Classification	Driving cycle	Application
Japan	Fuel economy	km/l	Weight	JC08	Compulsory
EU	GHG emissions	g/km	Global standard/weight	NEDC	Voluntary / compulsory
China	Fuel consumption	l/100km	Weight	NEDC	Compulsory
Canada	GHG emissions	Reduction 5,3 Mt	Vehicle type	US CAFE	Voluntary
California	GHG emissions	g/mile	Vehicle footprint	US CAFE	Compulsory
USA	Fuel economy	mpg	Global standard / vehicle footprint	US CAFE	Compulsory
Australia	Fuel consumption	l/100km	Global standard	NEDC	Voluntary
South Korea	Fuel economy	km/l	Engine capacity	US EPA City	Compulsory

2000 and the corresponding forecast for the year 2030.

These figures attest to the need for immediate action to be taken for tackling transport greenhouse gas emissions and energy consumption at the international level. Addressing such an issue requires initiatives to be adopted on various levels, such as technology, policy, and economy. It also implies the willingness to share responsibility between developed and developing countries in a fair manner that will not restrain the growth prospects of the latter. Worldwide many different measures and approaches to the problem have been proposed. The core of them is related to CO_2 emissions reduction from new vehicles entering the circulation. This is expected to be achieved through the application of new technologies at vehicle level.

The main objective of this paper is to study and evaluate theoretically and experimentally some of the technologies proposed for reducing CO_2 emissions from vehicles (eg. hybrid electric vehicles, biofuels, etc.) and recognise possible routes for achieving future European targets.

Regulatory framework

Measures to reduce CO_2 emissions and increase energy efficiency of road transport have been adopted or announced by most developed countries. Amongst these initiatives, one can distinguish EU measures, which have achieved low levels of CO_2 emissions, the United States policy with the US being the first to apply systematically limits for fuel consumption, the state of California regulations which are also heading towards implementing innovative measures, Canada, Australia, Japan, China and South Korea [5]. The overall policy measures are based on the following pillars:

- Many countries aim at improving passenger car fuel consumption while Japan has introduced regulations for heavy duty vehicles and Germany attaches great importance to energy efficient equipment of vehicles
- The majority of countries resort to policies promoting biofuels to reduce greenhouse gas emissions while several bodies support the introduction of strict criteria ensuring sustainability during their production.
- Many countries have adopted measures to promote public transport and certain infrastructure use, aiming to limit emissions and tackle congestion.
- A large number of implementing policies are aimed at changing the means (modal shift), but have a small chance of success compared with other policies.

In this framework and according to what has been recorded during the study, the basic policies related to passenger cars are presented in Table 2.

Regarding the introduction of emission-fuel consumption limits, three alternative approaches are found: i) the approach of the single limit value which provides a limit value based on weighted average emissions from new vehicles, ii) the approach that is based on the value of a vehicle’s characteristics (most commonly weight) and iii) the approach which is based on a vehicle’s utility parameter (such as the footprint) which foresees various limits depending on the value of the parameter.

In Europe, until recently, the burden for reducing vehicle fuel consumption was a responsibility of vehicle manufacturers[6]. Manufacturers signed a voluntary commitment to cut average emissions from new vehicles down to 140 g / km by 2008-2009. The new EU policy which is in the process of public consultation sets a pan-European target for 2015 to 120 g / km (130g/km should be achieved on weighted average emissions over the type approval procedure and an additional 10g from other measures, such as biofuels and eco innovations). Special attention should be paid to the Integrated Approach on which the new EU policy is based. This approach immerged after extensive dialogue between the European Commission and various stakeholders and partners. This approach foresees the introduction of measures to address vehicle GHG emissions at several levels along with the upcoming emission standard CO_2 adoption. This will help maximize the efficiency of measures and mobilize all stakeholders.

Methodology

The use of experimental, theoretical, and computational tools is essential to fully understand the phenomena associated with CO_2 emissions and assess the reduction potential of various technology options. The basic evaluation methods which were used in the context of this work were experimental measurements on chassis dynamometer and engine test bench, computer models and theoretical calculations. The target of both experiments and simulations was to quantify the CO_2 reduction potential of improvements in major vehicle characteristics defining fuel consumption over the New European Driving Cycle (NEDC) which is the cycle employed for type approval in Europe.

Emission measurements were conducted on three diesel passenger cars (Euro 2-DI of 1900cc, Euro 3-DI common rail, 1900cc and Euro 4-DI common rail of 2200 cc all equipped with oxidation catalysts) following the European regulations (Directive 70/220/EEC and amendments). The exhaust gas was sampled in a dilution tunnel following the constant volume sampling (CVS) technique. The exhaust gas was primarily diluted and conditioned by means of Constant Volume Sampler (CVS). A 6 m long corrugated stainless steel tube transferred the exhaust from the tailpipe to the CVS tunnel inlet. A flowrate of 500 Nm3/h was maintained in the CVS tunnel by a positive displacement pump. The dilution air was filtered through a HEPA class H13/EN1822 filter at the inlet of the dilution tunnel.

Regarding the simulations performed, data from the vehicles measured and additional ones were used. A pool of vehicles representative of those typically found in the European passenger car fleet was selected. Six vehicles, 3 gasoline and 3 diesel, with different weight and engine capacity characteristics were chosen and modelled. Data were collected in order to model vehicle operation including:

- vehicle weight
- coast down times or aerodynamic characteristics
- tyre rolling resistance values
- gear – final drive ratios
- wheel characteristics (dimensions – weight)
- specific fuel consumption engine operation maps

In certain cases when actual data for particular vehicle components were not available, qualified assumptions were made based on previous experience and values representative of the European passenger car fleet were used. Such assumptions were made especially for gearbox efficiency (which was not possible to determine), idle fuel consumption, and in a few cases for aerodynamic drag coefficient. The models created were validated against manufacturer reported data for fuel consumption over NEDC.

After reaching an optimal convergence between reported and simulated fuel consumption over both UDC and EUDC (subcycles composing NEDC), simulations were conducted for estimating how each vehicle's characteristics affects vehicle efficiency over NEDC. All simulations were conducted using Advanced Vehicle Simulator 2002 (Advisor 2002) tool which is based on Simulink simulation software. A similar modelling exercise had been performed previously for light duty trucks (N1 vehicles) and was validated by chassis dynamometer measurements which proved the accuracy of the modelling technique. [7,8,9,10].

Technology options at vehicle level

The key technological options considered at vehicle level in this work were:

1. vehicle weight reduction
2. aerodynamic resistance reduction through aerodynamic optimization of the design characteristics
3. low rolling resistance tyres
4. In addition an increase of the overall Powertrain efficiency was studied and evaluated.

For the analysis of the CO_2 emissions reduction potential , experimental measurements over NEDC were performed and their results were used for modelling passenger and N1 vehicles. The accuracy of the simulations reached satisfactory levels and ranged between ± 2.5% (See Table 3). Both the experimental and the computer results showed that changes of key vehicle characteristics, such as weight, aerodynamic resistance, rolling resistance and the cargo mass are associated with changes in CO_2 emissions through linear relationships (see Figure 1 subfigures a,b,c,d).

The improvement in the overall powertrain efficiency offers the same CO_2 emissions reduction potential regardless of vehicle and driving profile and does not follow a linear trend. Increasing the total efficiency by 10% will lead to reduction of CO_2 emissions by almost 8%.

The results indicate that combining technological op-

Table 3. Simulation results and deviation from reported data

Driving Cycle	UDC (Cold)			EUDC			NEDC		
Model:	Simulated. [l/100km]	Reported [l/100 km]	Deviation [%]	Simulated. [l/100km]	Reported [l/100 km]	Deviation [%]	Simulated. [l/100km]	Reported [l/100 km]	Deviation [%]
Gasoline small	8.38	8.65	3.1%	5.45	5.25	-3.8%	7.31	7.41	1.3%
Gasoline medium	9	8.8	-2.3%	5.73	5.6	-2.3%	7.81	7.64	-2.3%
Gasoline large	10.5	10.35	-1.4%	6.25	6.1	-2.5%	8.95	8.80	-1.7%
Diesel small	4.49	4.5	0.2%	3.5	3.6	2.8%	4.13	4.17	1.0%
Diesel medium	6.85	6.54	-4.7%	4.05	4.15	2.4%	5.83	5.67	-2.8%
Diesel large	8.84	8.9	0.7%	5.57	5.5	-1.3%	7.65	7.66	0.2%

tions at vehicle level leads to a reduced improvement compared to the sum of their individual reduction potential. The gain in emissions achieved by improving vehicle characteristics in the near future is expected to be around 6-7%. In 2006, emission levels, such as gain corresponds to approximately 10 g CO_2 / km. At the same time, possible increases in the total average efficiency of 10% will lead to further reductions in emissions of about 12 g CO_2 / km. It is understood that a parallel implementation of the two will lead to average emissions around 138 g CO_2 / km.

Particularly in terms of individual measures, it should be noted that while the changes in weight and aerodynamic resistances are directly reflected in the type approval results, those related to rolling resistance are most likely to be incorporated in the type approval results due to a legislative provision which allows manufacturer to use different sets of tyres during the test compared with those with which vehicles are sold. The resistance caused by higher rolling resistance tires ultimately leads to increased CO_2 emissions especially in during city traffic conditions. Finally, a key factor that affects rolling resistance and, hence, CO_2 emissions is tyre pressure. The implementation of tyre pressure control systems will promote the reduction of fuel consumption over real world operating conditions.

Friction reduction – low viscosity lubricants

Engine friction reduction is a technological option to reduce fuel consumption through improving powertrain efficiency. Fuel economy lubricants (alternatively referred to as low viscosity lubricants or energy efficient lubricants)

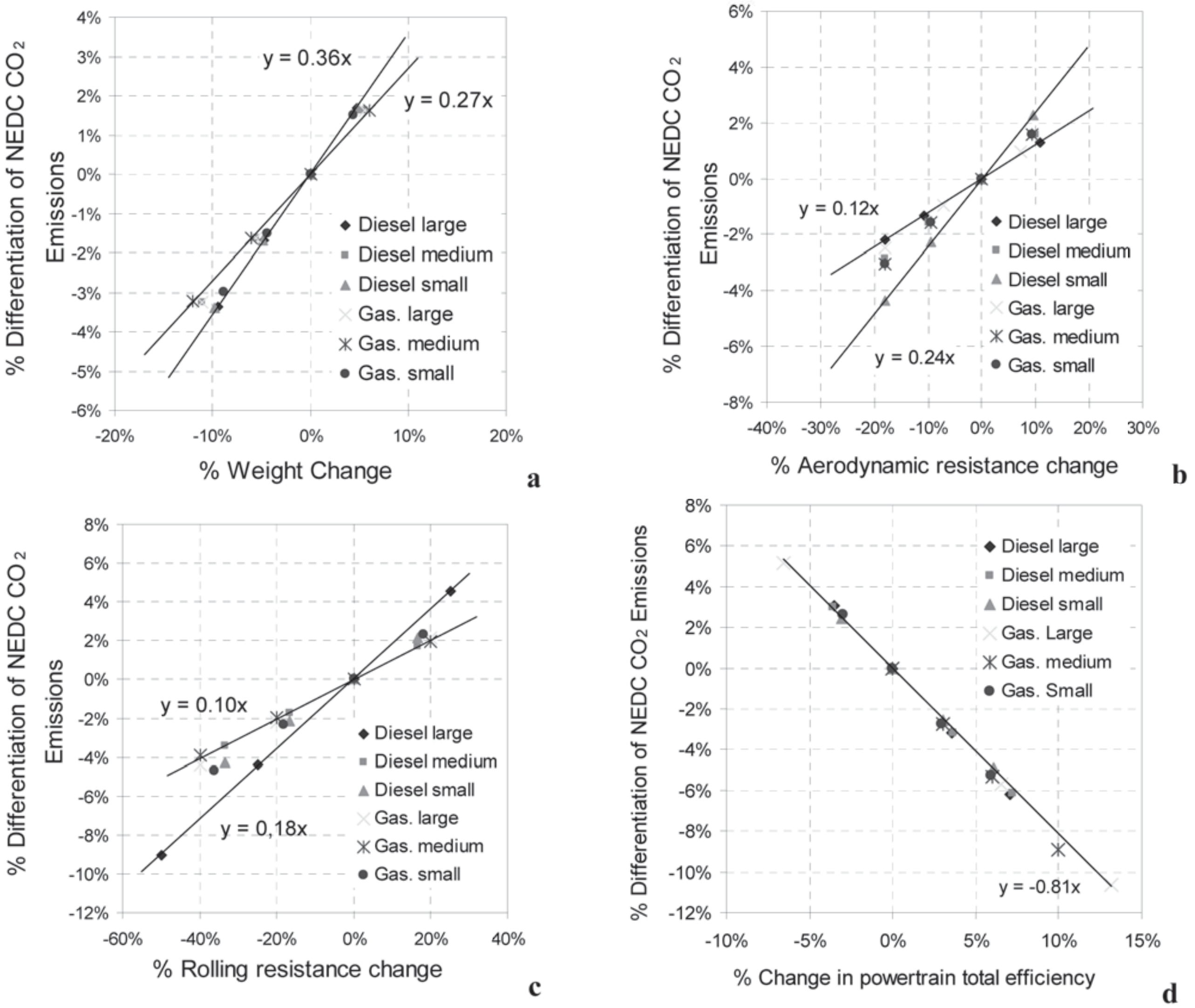


Fig 1. Change in CO_2 emissions with respect to change in vehicle weight (a), aerodynamic resistance (b), rolling resistance (c) and total efficiency (d)

can reduce vehicle CO_2 emissions from 0.5-3%. As part of this study, low viscosity lubricants were implemented and measured in actual vehicles and engine test bench in order to quantify their CO_2 reduction potential (See Table 4).

A general conclusion derived from the measurements is that the tested lubricants confirmed the fuel saving potential mentioned in the literature[11,12,13] for low viscosity lubricants over NEDC (see Figure 2). In terms of pollutant emissions, no substantive differences were identified which could create problems when employing this technology. Each vehicle and engine presented a different behaviour and there is a general

trend to maximize fuel consumption gains at high -speed operation and medium loads. In further detail,

Table 4. Lubricants tested

Vehicle / Engine	High Viscosity Lubricants		Low Viscosity Lubricants	
	Base Stock	SAE Visc. Grade, ACEA Class	Base Stock	SAE Visc. Grade, ACEA Class
Vehicle b 1.9cTDi	Semi-synthetic (E3HV)	10W-40, B3	Synthetic (E3LV)	5W-30, B3/B5
Vehicle c 2.2 i-CTDi	Synthetic (E4HV)	0W-40, B3	Synthetic (E4LV)	0W-30, B3/B5
Vehicle c 2.2 i-CTDi	Mineral (E4MHV)	15W-40, B2	Synthetic (E4MHV)	0W-30, B3/B5
Test Cell engine	Mineral (ENRF)	20W-50, B2	Synthetic (ENLV)	5W-30, B3/B5

- The use of low-viscosity synthetic lubricants had a positive effect on CO_2 emissions on vehicles. The common rail vehicle showed reductions of around 4% while fuel economy increases with increasing speed of the vehicle
- Emissions with low-friction lubricants remained at usual levels over most driving cycles
- Engine test bench measurements indicated small reductions in fuel consumption and certain emissions variations. The analysis of in cylinder pressure did not reveal significant changes in the combustion process when using a synthetic lubricant.

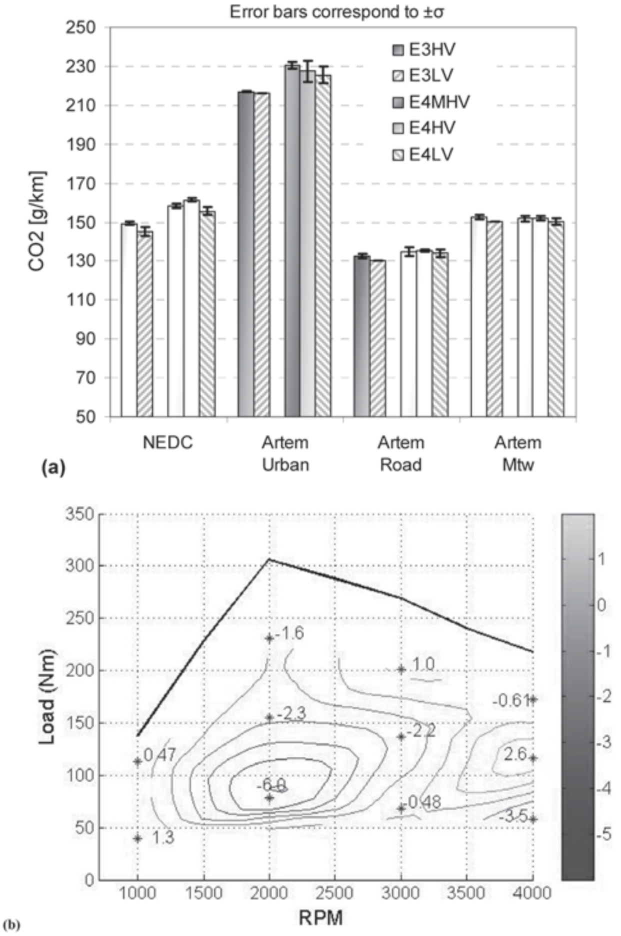


Fig 2. CO_2 emissions results over the various driving cycles tested (a) and differences in CO 2 emissions (%) for the test cell engine results (b)

Hybrid vehicles

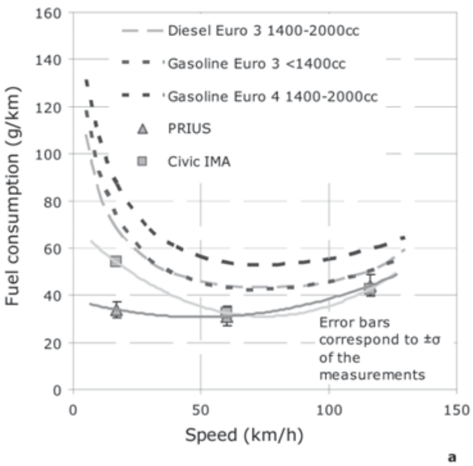
The introduction of massively produced hybrid electric vehicles (HEV) in the global automotive market over the last decade was essential for spreading the concept of the hybrid vehicle and helped to obtain a better understanding of their benefits and their weaknesses.

Today, the market for hybrid vehicles varies significantly between Europe and America. In 2007, 459,788 HEVs entered the circulation globally, 73% of which were sold in the U.S. (70%) and Canada (3%), 14% in Japan while the remaining 13% in other countries with Britain and Germany accounting for approximately 6.5%. Being oriented to the diesel engine as a key technology for reducing CO_2 emissions, the introduction of hybrid vehicles in the European market remains weak. European manufacturers have invested heavily in improving the efficiency of conventional engines with an emphasis on diesel engines. In EU the share of HEVs in the new registrations for 2007 ranged around 0.5%.

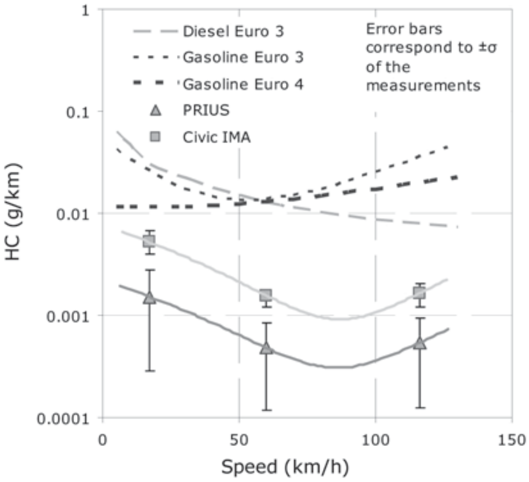
Hybrid vehicles are classified according to the degree of electric power penetration in the hybrid system in mild, full, and plug in hybrids. As part of this study, tailpipe emissions and fuel consumption measurements were performed on two production hybrid vehicles[14], which presented different levels of hybridisation (mild and full hybrid).

The results showed (see Figure 3) that the higher the degree of hybridisation, the higher fuel economy is achieved over urban driving conditions. Over 60km / h both HEVs presented similar consumption which over 100km / h became more or less equal to that of a conventional vehicle. In urban conditions, the fuel consumption was found to be 40-60% lower than that of the average conventional petrol vehicle. This advantage is maximized when operating at a very low average speed with continuous stops. Therefore , it is likely that vehicle hybridisation will be extended to models which are mainly found in urban environments.

For mean velocities lower than 90km/h HEV fuel economy is also better than that of the conventional diesel. The main difference between the two HEVs becomes clear in the low speeds range. For urban driving conditions (20km/h), full hybrid fuel consumption compared to the mild hybrid fuel consumption is 40% less. Compared to the conventional diesel and gasoline cars, the full hybrid fuel economy is improved by 50% and 60%, respectively. As the mean speed increases the differentiation between the two HEV decreases and, above 60km/h both present similar fuel consumption. The mild hybrid fuel consumption becomes similar to that of a gasoline Euro 3 passenger car with engine



a



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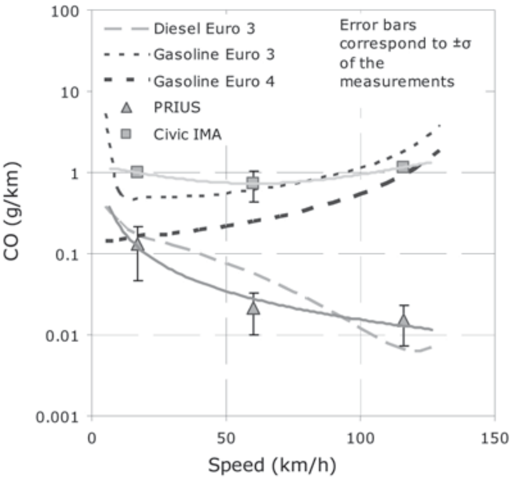

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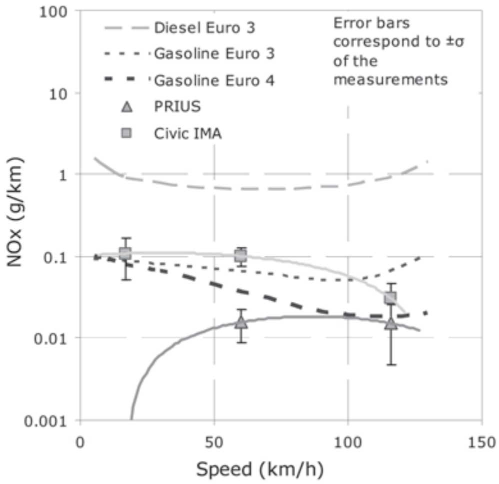

d

Fig 3. Emissions results comparison with Artemis emission factors for conventional passenger car for fuel consumption (a), HC (b), CO (c) and NOx (d) [14] capacity less than 1400cc at 95km/h. Full hybrid vehicle's fuel consumption reaches that of a conventional Euro 4 gasoline car (1400-2000cc category) at 120km/h. Battery condition plays an important role in HEV fuel economy.

As the level of hybridisation increases, the influence of environmental temperature on fuel consumption becomes significant. According to Yaegashi [15], ambient temperature affects the battery of the Prius II with colder weather reducing its capacity and, hence, reducing fuel economy. Similar observations were made in this study with 7C increase in ambient temperature leading to measurable differences in fuel consumption. When calculating fuel consumption from HEV, seasonal variations in ambient temperature must be included since they may lead to increases in fuel consumption up to 12%

Overall, HEVs can play an important role in limiting CO_2 emissions from road transport and perhaps are a necessary option to achieve the 130 g CO_2 / km by 2015. The introduction of hybridisation on diesel vehicles will further help to reduce consumption by making vehicles more efficient under both urban and rural driving conditions.

Biofuels

Biofuels are currently the most widespread technological option for reducing transport generated CO_2 emissions. Especially over the last decade, the use of biofuels worldwide has grown at a remarkable rate for reasons not related solely to environmental issues.

Table 5. Summary of the impacts of different biodiesel blends application on vehicle emissions

Driving cycle	UDC	EUDC	NEDC	UDC	Artem	Artem	Artem	Conclusions
Fuel	**cold**			**hot**	**Urban**	**Road**	**Mtw**	
CO2								
B10 soya	-	-	-	-	-	-	↓	-
B10 UFO	↓	-	-	-	-	-	-	
B10 Plam oil	-	↓	↓	-	-	↓	-	
B10 Sunflower	-	↑	↑	↑	↑	↑	↑	
B10 Repeseed	-	-	-	-	↓	-	-	
CO								
B10 soya	↑	↑	↑	↑	-	-	-	-
B10 UFO	-	↑	-	↑	-	-	-	
B10 Plam oil	-	-	-	-	-	-	-	
B10 Sunflower	-	-	-	-	-	-	-	
B10 Repeseed	-	-	-	↑	↑	-	-	
HC								
B10 soya	↑	-	↑	↑	-	-	↓	↑
B10 UFO	↑	-	-	-	-	-	-	
B10 Plam oil	↑	↑	↑	-	↑	-	-	
B10 Sunflower	-	-	-	-	↑	-	↑	
B10 Repeseed	-	-	-	↓	↑	-	-	
NO_x								
B10 soya	-	↓	-	↓	↓	-	↓	Fluctuations ↑↓
B10 UFO	-	↓	-	↓	-	-	↓	
B10 Plam oil	-	-	-	-	↑	↑	↑	
B10 Sunflower	-	↑	-	-	↑	↑	↑	
B10 Repeseed	-	-	-	↓	↓	-	-	
PM								
B10 soya	↓	-	↓	↓	-	↓	↓	↓
B10 UFO	↓	↓	↓	↓	↓	↓	↓	
B10 Plam oil	↓	↓	↓	-	↓	↓	↓	
B10 Sunflower	↓	↓	↓	↓	↓	↓	-	
B10 Repeseed	↓	↓	↓	↓	↓	↓	↑	

Biofuels under certain conditions offer an important CO_2 reduction potential [16]. However, their benefits should not be taken for granted. The conditions that must be satisfied in order for biofuels to be considered as sustainable fuel in the future are related to key socio-economic factors. Main criterion that should be covered by any future biofuel is non-competitiveness with edible products. In addition, the use of biofuels must be accompanied by reduced greenhouse gas emissions throughout the product's life cycle and neutral or positive impact on other pollutant emissions.

The measurements carried in this analysis on a Euro 3 commonrail diesel passenger car showed that the introduction of biodiesel or straight vegetable oils in European automotive fuels up to 10% v/v will have no significant impact on operation and pollutant emissions of existing vehicles. Table 5 summarizes the results of these measurements. Similar conclusions are reported in other studies [17,18,19]. The presence of biofuels in the fuel leads to limited fluctuations in engine operation which largely depend on the engine operating point. The use of high biofuel concentrations, however, requires appropriate adjustment of the engine and exhaust aftertreatment system. In a different case, it might lead to high pollutant emissions and reduced engine performance. Further targeted study is considered necessary before any large-scale implementation of biofuels at higher concentrations. Higher biofuel concentration should be considered for captive fleets and constitutes an interesting option for further promoting biofuels.

In Greece and other Mediterranean countries with similar geographical characteristics, there is a considerable potential for biofuel production. However, the lack of regulatory framework for use and marketing is preventing their expansion. According to the analysis conducted, Greece can produce biofuels which meet the sustainability criteria, but in order to do so biofuel production should be introduced in a broader policy context and in a national plan which will systematically promote biomass and energy crops in the country. In this direction, it is recommended that the biofuels which are to be introduced in the national energy balance are carefully evaluated with respect to sustainability and effectiveness criteria of the forthcoming EU legislation.

Conclusions

In view of the need for more sustainable transport, new regulatory measures are being introduced throughout the world. The new European framework foresees a binding CO_2 emissions limit of 130 g CO_2/ km for the year 2015. All manufacturers must comply to their targets or face fines. This fact is expected to affect passenger cars and fleet composition in the forthcoming years. Several vehicle characteristics must be improved in order to reach the average targets set. A potential route described below is summarised in Figure 4.

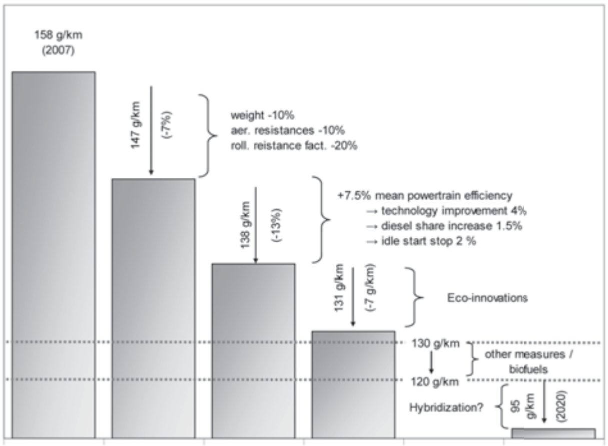

Fig4. Possible route to the European target of 120g CO_2 / km and beyond [20]

The experiments and analyses performed showed that over NEDC, improvements in vehicle weight, aerodynamic, and rolling resistance usually lead to a rather uniform impact on emissions. Particularly, the improvement of total powertrain efficiency presents the same CO_2 emissions reduction potential over NEDC regardless of the vehicle. Simulations run with combination of various technological options led to the conclusion that the improvement achieved through their parallel implementation is lower than the sum of their individual reduction potential which is an important observation that should be considered when developing future policy scenarios and strategies. It is concluded that a realistic estimation of the emissions benefits achievable in the near future through vehicle characteristics, improvement is 6-7%. In terms of the 2007 average emissions, this benefit translates in to about 11 g CO_2 / km. An increase of the powertrain efficiency by 7.5% at the same time will lead to further reductions in emissions by 9 g CO_2 / km. It is understood that their combination will lead to average CO_2 emissions levels of 137-139 g CO_2 /

km which are just below the previous CO_2 emissions target for the year 2008. At this point it should be noted that eco-innovations to be implemented in the future may result in important benefits in actual CO_2 emissions. However, a specific methodology is still needed for accounting the benefit of such technologies into the type approval test.

Additional emission reductions of 7-9 g CO_2 / km which are necessary to reach the 2015 130 gCO_2/km target will be more difficult to realise. According to the new regulation, eco-innovations can bridge the distance towards the 2015 target. In this sense, accurate and unbiased assessment of their real world reduction potential becomes of great importance. In view of a 2020 95 g/km limit, the potential of mild and full hybrid systems goes beyond the 130 g/km but cost effectiveness is still a major issue that needs to be addressed.

Judging from the former evolution of the European fleet performance, the aforementioned improvements appear difficult to achieve. Vehicle mass has been constantly increasing throughout the near past and the analysis has showed that improvements in the efficiency of conventional powertrains may advance at a slower pace than what they have done so far. However, non-technological factors, such as policy measures, incentives, and consumer awareness may play an important role in accelerating the necessary development.

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