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Cost and CO_2 aspects of future vehicle options in Europe under new energy policy scenarios

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ABSTRACT

New electrified vehicle concepts are about to enter the market in Europe. The expected gains in environmental performance for these new vehicle types are associated with higher technology costs. In parallel, the fuel efficiency of internal combustion engine vehicles and hybrids is continuously improved, which in turn advances their environmental performance but also leads to additional technology costs versus today's vehicles. The present study compares the well-to-wheel CO_2 emissions, costs and CO_2 abatement costs of generic European cars, including a gasoline vehicle, diesel vehicle, gasoline hybrid, diesel hybrid, plug in hybrid and battery electric vehicle. The predictive comparison is done for the snapshots 2010, 2020 and 2030 under a new energy policy scenario for Europe. The results of the study show clearly that the electrification of vehicles offer significant possibilities to reduce specific CO_2 emissions in road transport, when supported by adequate policies to decarbonise the electricity generation. Additional technology costs for electrified vehicle types are an issue in the beginning, but can go down to enable payback periods of less than 5 years and very competitive CO_2 abatement costs, provided that market barriers can be overcome through targeted policy support that mainly addresses their initial cost penalty.

1. Introduction

Transport related greenhouse gas (GHG) emissions have significantly grown over the past years and account for more than a quarter of today's global greenhouse gas emissions. Without significant technological innovation or policy intervention, it is expected that this development will continue and transport related GHG emissions may double by 2050 (Fulton et al., 2009). Road transport is the biggest contributor to these GHG emissions and their potential future growth (Meyer et al., 2007). A number of recent technological improvements and adoption of policy measures could potentially curb the expected future road transport related GHG emission growth. Several automotive manufacturers have announced the launch of battery electric vehicles (BEV) (Peugeot, 2009a; Nissan, 2009a) and plug-in hybrid vehicles (PHEV) (Opel, 2009a) for the coming years. A number of studies indicate that these vehicle types could have a large market potential in the future (Barkenbus, 2009; Becker, 2009). On the other hand, conventional vehicles that are powered by an internal combustion engine (ICE) are continuously improved (Taylor, 2008) in order to meet the market demand for more fuel efficient vehicles as well as to help in meeting future more stringent CO_2 targets as imposed by several governments in North America, Europe and Asia (ICCT, 2007). The market viability of BEVs and PHEVs will heavily depend on their total cost of ownership (TCO) versus the TCO of the vehicles that currently dominate the market (i.e. ICE powered vehicles). The TCO is greatly influenced by the purchase costs that will – in the beginning of their roll-out – certainly be significantly higher for BEVs and PHEVs when compared with similar ICE vehicles (Boston Consulting Group, 2009).

Most of the analyses done so far claim large environmental benefits associated to electric driving versus driving with combustion engines (McKinsey, 2009; Boston Consulting Group, 2009). Since BEVs drive exclusively and PHEVs can drive a significant portion in purely electric driving mode without any tailpipe emissions, it is important to consider emissions from well-to-wheel (WtW) for any comparison with ICE propelled vehicles. The potential environmental impact of electrified road transport is very much linked to the electricity generation mix that is used to fulfil this transport demand. The electricity generation mix is subject to policy measures in various regions and countries with the clear goal to reduce the specific CO_2 emissions per unit of generated electricity (DG TREN, 2008; Holt

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and Whitney, 2009). Furthermore, many governments have put policies in place to increase the share of renewable road fuels (Directive 2009/28/EC). While there are many case studies available for North American vehicle options and energy supply, there exist only limited studies with a specific European focus (Nemry et al., 2009). However, since the European and North American automotive market, energy mix and policies are different in many aspects, it is important to better understand the European situation.

This paper compares the cost and CO_2 aspects of BEVs and PHEVs with ICE vehicles in Europe for the years 2010, 2020 and 2030. It focuses on passenger light-duty vehicles. The comparison considers assumptions of (i) further technical improvements for conventional vehicles, (ii) future evolution of well-to-tank (WtT) CO_2 emissions of energy used for road transport as a result of policies both for the electricity mix and liquid road fuels, (iii) future volume and technology market share scenarios in the automotive market and resulting technology cost reductions through learning effects, (iv) future energy prices. As a result of the analysis, CO_2 WtW emissions, the payback period for the initial additional investment costs from a car owner's perspective as well as the societal CO_2 abatement costs are shown for 2010, 2020 and 2030 for the compared vehicle types under the above listed assumptions. A number of sensitivity analyses are performed in order to assess the validity of the results under varied assumptions.

2. Vehicle comparison

The analysis was limited to vehicle options that have the potential to enter the European market in the near term with significant market shares and without regional limitations. In today's market, there are vehicle types available in certain niches and with limited regional dispersion like vehicles with LPG, CNG and E85 capable or dedicated engines. The authors assessed as unlikely that these vehicle types could overcome their regional limitations and reach a broader European roll-out in the near term. A limited number of hydrogen powered vehicle demonstrators, fuel cell and ICE based, are currently operated in various field tests. Also here, the authors assessed that market maturity for these technologies will not be reached in the near term as the technology challenges for these vehicle types are still high and the required infrastructure set-up is large. Gasoline and diesel vehicles as well as their corresponding fuel stations are abundant in today's European market. Gasoline hybrid vehicles are available in the market and the launch of a diesel hybrid vehicle is announced for 2011 (Peugeot, 2009b). The launch of PHEVs is announced for 2011 in Europe (Opel, 2009a). The launch of BEVs is announced for 2010 (Peugeot, 2009a; Nissan, 2009a). Looking at the numerous announcements of the automotive manufacturers, a broader roll-out of BEVs and PHEVs seems imminent. Both, BEVs and PHEVs need a charging infrastructure, but simple private and public charge points can be installed with short leadtime and relatively small costs.

The following vehicle technologies were chosen for the comparison:

- advanced gasoline vehicle that features a downsized turbocharged gasoline direct injection engine with 70 kW power output and a starter based stop–start system,
- advanced diesel vehicle that features a downsized common rail direct injection engine with 74 kW power output and a starter based stop–start system,
- advanced gasoline hybrid vehicle that has a downsized turbocharged gasoline direct injection engine with 62 kW power output, hybridized with a 14 kW electric motor and a 2 kWh lithium-ion battery in order to perform limited pure electric driving (a few hundred meters up to a speed of 50 km/h),
- advanced diesel hybrid vehicle that has a downsized common rail direct injection engine with 63 kW power output, hybridized with a 14 kW electric motor and a 2 kWh lithium-ion battery in order to perform limited pure electric driving (a few hundred meters up to a speed of 50 km/h),
- plug-in hybrid electric vehicle with a 11.5 kWh lithium-ion battery, a 95 kW electric motor and a 56 kW gasoline engine in a series hybrid set-up,
- battery electric vehicle with a 24 kWh lithium-ion battery and a 80 kW electric motor.

To compare the key parameters of these technology options, the technologies were applied to a hypothetical generic 2010 European compact class vehicle. Table 1 summarises the key assumptions for the vehicles as well as the main resulting performance, cost and tailpipe CO_2 figures. The technology assumptions, performance and cost values for the ICE vehicles and hybrids were derived from JRC et al. (2008). The technology assumptions and most of the performance values for the PHEV were derived from the preliminary Opel Ampera specifications (Opel, 2009b). However, a number of modifications were made. The battery capacity for the hypothetical PHEV was decreased from 16 kWh in the Ampera to 11.5 kWh and the power output of the electric drive motor was decreased from 111 kW in the Ampera to 95 kW as this power output is more in line with the other vehicle types that are analyzed here. The Opel Ampera needs roughly 8 kWh electricity for its stated 60 km electric range (Eberle, 2009) giving a specific electric power consumption of ca 135 Wh/km in pure electric drive mode. Hence, the charge swing of the Ampera battery is approximately 50% of the rated capacity. For the hypothetical PHEV, a charge swing of 70% was assumed, resulting in an 11.5 kWh battery. The combined energy consumption of the PHEV was calculated with the use of Opel (2009b) and UN ECE (2005). The calculation per UN ECE (2005) leads to an electric driving share of roughly 70% for this PHEV over the entire driving cycle. The weight of the vehicle was calculated based on the technical specifications and the use of JRC et al. (2008) and Eberle (2009). The costs were estimated based on the technical specifications and the use of JRC et al. (2008). The technology assumptions and most of the performance values for the BEV were derived from the preliminary Nissan Leaf specifications (Nissan, 2009b). However, a number of additional assumptions needed to be made. The battery capacity for the hypothetical BEV was estimated to be 24 kWh. As for the hypothetical PHEV, a charge swing of 70% was assumed, resulting in 125 km pure electric range for the BEV at an assumed electric power consumption of 135 Wh/km. The weight of the vehicle was calculated based on the technical specifications and the use of JRC et al. (2008) and by up-scaling the battery and its weight from the PHEV. The costs were calculated based on the technical specifications and the use of JRC et al. (2008).

The combined power output of the ICE engines and electric motors for the hypothetical vehicles are chosen so that they can guarantee similar driving performances across the different vehicle types and their related vehicle weight. The weight data show that the PHEV is with more than 1500 kg the heaviest vehicle type because it carries the additional weight of all components required for electric driving and it still needs the ICE engine as a range extender. The BEV has a larger battery compared to the PHEV but this is overcompensated by the weight loss due to the missing ICE and tank, resulting in roughly 70 kg less weight than the PHEV. The gasoline vehicle is about 185 kg