



Critical Review of Trends in GHG Emissions from Global Automotive Sector

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ABSTRACT

Between 1906 and 2005, records show that global average air temperature near the earth's surface increased by $0.74 \pm 0.18^\circ\text{C}$. If emissions of greenhouse gases, and in particular CO_2 , continue unabated the enhanced greenhouse effect may alter the world's climate system irreversibly. Total emissions of greenhouse gases, across all sectors, were 42.4 gigatonnes (Gt) of CO_2 -eq in 2005. Energy sector, accounts for 84% of global CO_2 emissions and 64% of the world's greenhouse-gas emissions. Energy-related CO_2 emissions rise from 28.8 Gt in 2007 to 34.5 Gt in 2020 and 40.2 Gt in 2030. Global per-capita emissions of energy-related CO_2 in 2007 was 4.4 tonnes. Higher growth of automobiles and consumption of petroleum products is invariably attended by concerns of pollution and climate changes. Global fleet of passenger light-duty vehicles (PLDVs) is estimated to increase from 770 million in 2007 to 1.4 billion in 2030. Among all sectors that emit CO_2 , the transport sector is the fastest growing, representing from 22% to 24% of global GHG emissions from fossil fuel sources, second only to the industrial sector. World emissions of NO_x were 82 Mt in 2007, of which Road transport was responsible for about one-third of NO_x emissions. Only Road transport related CO_2 emission is estimated to increase from 4.8 Gt in 2007 to 6.9 Gt in 2030. The increase in CO_2 emissions is largely a result of increasing demand for individual mobility in developing countries. There are strong efforts and renewed investments by manufacturers and suppliers in providing solutions to the CO_2 reduction challenge. Low-carbon vehicles, such as hybrid cars, plug-in hybrids and electric cars, have received widespread public attention recently. It is estimated that share of hybrids in the global fleet will reach about 5% by 2020 and almost 8% by 2030, up from just 0.15% in 2007. Plug-in hybrids and electric cars will constitute only 0.2% of the global fleet in 2030. But increase in electricity consumption in road transport in future due to increased penetration of plug-in hybrids and electric vehicles, sees transport sector CO_2 savings partially offset by power generation emissions. An estimated increase of 880 TWh of

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electricity consumption in transport in 2030, of which 90% occurs in PLDVs, will result in about 250 Mt of additional CO₂ emissions. Authors forecasted that the use of environment-friendly and clean technologies is going to make all the difference between the winners and the losers of the industry. It is noted that current policies are insufficient to prevent a rapid increase in the concentration of greenhouse gases in the atmosphere. It is recommended that policy makers and researchers should give more emphasis on 'cost-effectiveness as most important factor to reduce automotive GHG emission reduction'. It is also concluded that CO₂ savings will be maximized if well-to-wheel impact is clearly addressed at all stages of the fuel and energy chain.

Keywords: Global warming, greenhouse gases, road transport, hybrid vehicle;

1. INTRODUCTION

Climate change, specifically global warming, is indicated by a rise in the average of the earth's surface temperature over the past decades. Between 1906 and 2005, records show that global average air temperature near the earth's surface increased by 0.74 ± 0.18 °C. Furthermore, 2005 was the warmest year in the last 100 years. According to the IPCC, 11 of the last 12 years (1995 to 2006) rank among the 12 warmest years on record when measuring global surface temperature since 1850. All these scientific readings provide incontrovertible signs of global warming (PWC, 2007).

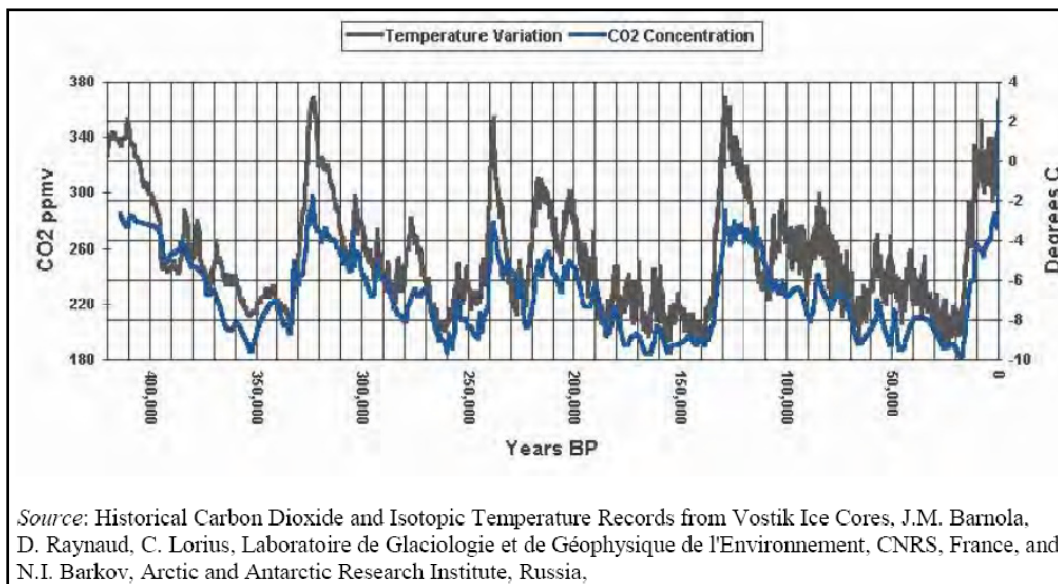


Fig. 1. Correlation of Temperature and Atmospheric CO₂ concentrations over last half million years (From Arctic Ice Core Data 1)

The latest scientific evidence indicates that human activities are leading to increased accumulations of greenhouse gases in the atmosphere, which are altering the Earth's climate patterns at unnatural rates (Austin et al., 2003). The monitored increase in the

concentration of anthropogenic greenhouse gases (GHG) is thought to be responsible for the recorded climate change, as the greenhouse effect is heating the earth's surface (Figure 1) (ECMT, 2007). CO₂ is the most important anthropogenic GHG, which has increased from a pre-industrial value of about 280 ppm (in 1750) to 379 ppm (absolute) in 2005 (PWC, 2007). If emissions of greenhouse gases, and in particular CO₂, continue unabated the enhanced greenhouse effect may alter the world's climate system irreversibly (ECMT, 2007).

The atmosphere currently contains long-lived greenhouse gases at a concentration of around 455 parts per million of carbon-dioxide equivalent (ppm CO₂-eq), which is roughly 60% above pre-industrial levels. Between 2000 and 2009, the world emitted 313 billion tonnes of CO₂. In order to limit the global increase of temperature within 2°C, CO₂ emissions over the period 2000-2049 must not exceed 1 trillion tonnes. Energy-related CO₂ emissions in the Reference Scenario rise from 28.8 Gt in 2007 to 34.5 Gt in 2020 and 40.2 Gt in 2030 (WEO, 2009). As a general rule, higher greenhouse-gas emissions lead to higher greenhouse-gas concentrations, leading to higher global temperatures and more severe climatic consequences. 1 ppm of atmospheric CO₂ concentration today equates to around 7.7 Gt CO₂. Consequently, at the present levels of atmospheric concentration, each additional 13.3 Gt of CO₂-eq gases released corresponds to an approximate increase in concentration of around 1 ppm, considering the present efficiencies of different CO₂ removing agents. However, the links between emissions of greenhouse gases and climate change are complex and factors such as carbon sinks, solar heat reflection, cloud cover, land-use change and aerosols might partially neutralize - or compound - these effects (IPCC, 2007). Nonetheless, it is clear that the rapid growth of green-house-gas (GHG) emissions projected in the Reference Scenario would lead to a substantial long-term increase in the concentration of greenhouse gases in the atmosphere, as well as a large increase in global temperatures.

Average global temperatures are currently around 0.76°C higher than pre-industrial levels and are rising at an increasing rate. The world is already experiencing the adverse effects of rising levels of greenhouse gases in the atmosphere. For example, the Greenland ice sheet has been losing mass at a rate of 179 billion tonnes per year since 2003 (Wouters et al., 2008), while global sea levels are on course to rise by around one metre over the remainder of the century. Developing countries and island states are particularly vulnerable to the impacts of global warming (WEO, 2009).

Virtually a global battle has been declared against climate change. Whether it is re-orientating our power generation mix away from fossil fuels and towards nuclear and renewables, maximising the efficiency of vehicles, appliances, homes and industries, or developing revolutionary technologies for the future, almost all potential sources of lower emissions will need to be tapped (WEO, 2009). Road transport sector is considered as one of the main contributing factor for global climate change. Higher growth of automobiles and consumption of petroleum products is invariably attended by concerns of pollution and climate changes. Climate change and CO₂ reduction have garnered enormous quantities of press coverage in both industry and general media. As a result, we are witnessing today a heightened public awareness which is in turn stimulating strong consumer expectations for regulators and the automotive industry to address this top priority issue.

Therefore, this paper aims to critically review global trend in GHG emissions from automotive sectors.

2. CONSEQUENCES OF GLOBAL WARMING

As per different studies of Intergovernmental Panel on Climate Change (IPCC), 2007 and classic analysis of World Energy Outlook report (WEO, 2009), the consequences of the world following the 1000 ppm CO₂-eq trajectory at Reference Scenario to 2030 and beyond, would, result in a global mean temperature rise of around 6°C. The impacts of climate change across world population will not be distributed evenly (Smith et al., 2001). With very high confidence, Schneider et al. (2007) concluded that regional temperature trends were already affecting species and ecosystems around the world. In a literature assessment, Rosenzweig et al. (2007) concluded that over the last three decades, human-induced warming had likely had a discernable influence on many physical and biological systems.

Different studies indicate different level of severity at different levels of temperature rises. According to the studies summarised by the IPCC (2007) and WEO (2009), a 6°C increase in global temperature could lead to:

- Damage to ecosystems, with extinction of over 40% of the world's species and widespread coral mortality.
- Sea level rise of up to 3.7 metres, with 50% loss of coastal wetlands, the loss of several islands and millions of people experiencing flooding each year.
- Water droughts in mid-to-low latitudes and disappearance of glaciers. Food shortages and decreased productivity of all cereal crops. With high confidence, Confalonieri et al. (2007) projected that malnutrition would increase due to climate change. Increased cardio-respiratory and infectious diseases, and increased mortality from heat-waves, droughts and floods.

Even long before this stage is reached, there is a risk that the world would reach significant tipping points that could propel the climate into a vicious cycle of deterioration. For example, melting ice caps could reduce the earth's reflection of solar energy, leading to higher temperatures. In turn, rising Arctic temperatures could precipitate the melting of permafrost across northern regions, leading to a massive release of methane and further temperature increases. Studies published since the IPCC report suggest that the risks associated with global warming are even more severe than previously thought (WEO, 2009). A study by Smith et al. (2009) shows that deleterious climate change impacts now appear at significantly lower levels of global average temperature rise and that, even for a temperature rise of 2°C, there are very high risks of extreme weather events and destruction of many ecosystems. Even at 2°C, there is now considered to be a moderate likelihood of a major tipping point having been reached. The impacts of climate change can already be seen to be increasing. For example, current surveys (such as Church et al., 2009) suggest that ocean warming is about 50% greater than had previously been reported by the IPCC. The recent research merely increases the importance of taking urgent action to reduce greenhouse-gas emissions. Low-latitude and less-developed areas are probably at the greatest risk from climate change (Schneider et al., 2007).

3. TRENDS IN GLOBAL GHG EMISSIONS

Total emissions of greenhouse gases, across all sectors, were 42.4 Gt of CO₂-eq in 2005. In the Reference Scenario, they reach 50.7 Gt in 2020 and 56.5 Gt in 2030. Energy sector, accounts for 84% of global CO₂ emissions and 64% of the world's greenhouse-gas emissions. Having already increased from 20.9 Gt in 1990 to 28.8 Gt in 2007, emissions are projected to rise further to 34.5 Gt in 2020 and 40.2 Gt in 2030, an average rate of growth of

1.5% per year over the projection period. Global per-capita emissions of energy-related CO₂ in the Reference Scenario show a steady increase over the period, from 4.4 tonnes in 2007 to 4.8 tonnes in 2030 (Figure 2) (WEO, 2009). Per-capita emissions in OECD countries currently outstrip those in non-OECD countries by a factor of four, but this gap is closing rapidly. Of the world's largest countries, the United States is the biggest per-capita emitter (18.7 tonnes in 2007). Figure 3 shows the present status and future trends of GHG emissions from energy sector (WEO, 2009).

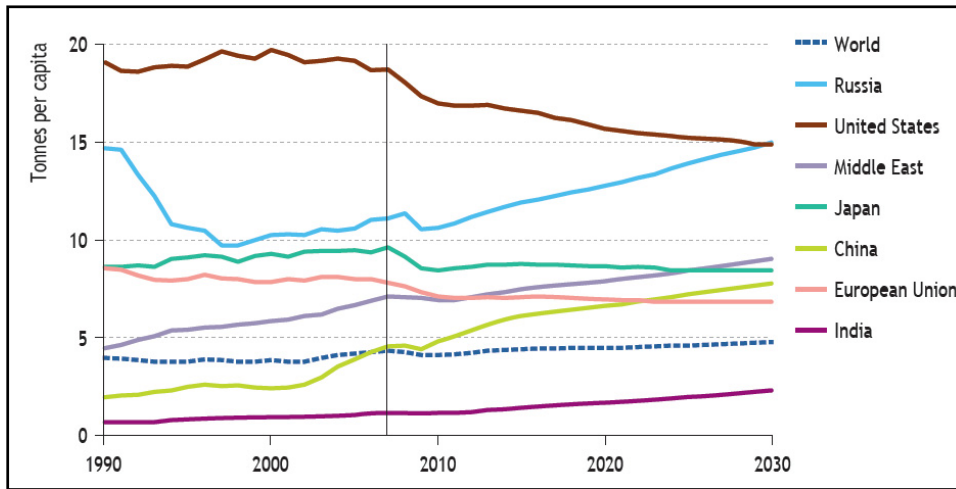


Fig. 2. Trend in per-capita energy related CO₂ emission under Reference scenario

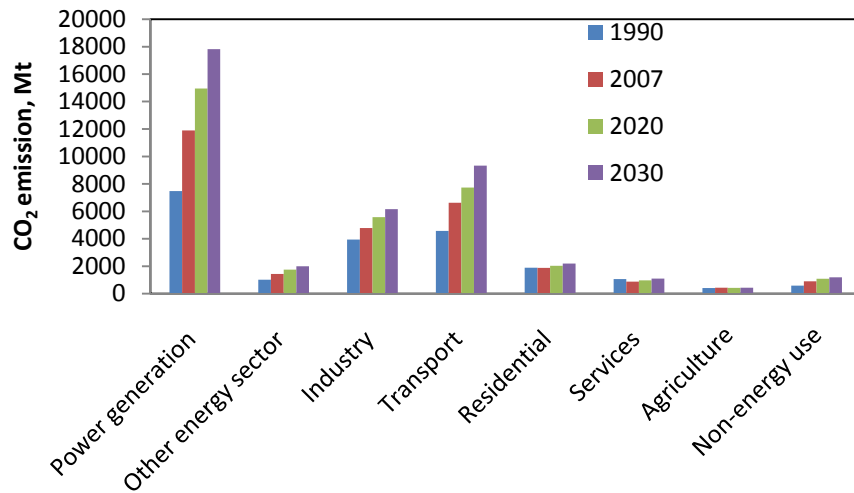


Fig. 3. Present status and future trends of GHG emissions from energy sector

4. PRESENT STATUS AND FUTURE TREND IN GLOBAL AUTOMOTIVE INDUSTRY

Continued increases in vehicle ownership in non-OECD regions push up the global fleet of passenger light-duty vehicles (PLDVs) from an estimated 770 million in 2007 to 1.4 billion in 2030. Most of this growth occurs in Other Major Economies and Other Countries. The Chinese fleet is anticipated to approach that of the United States by around 2030, at which time the Chinese market is projected to represent 24% of global sales (Figure 4) (WEO, 2009).

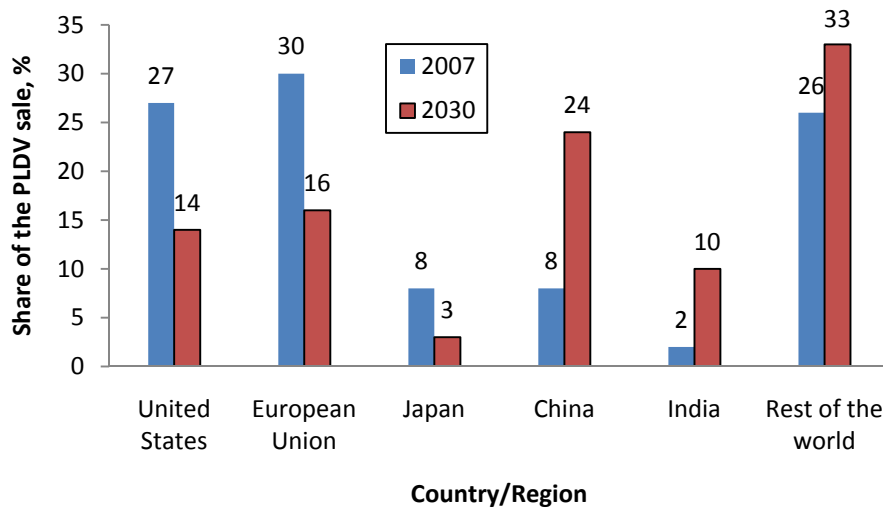


Fig. 4. Percentage share of PLDV sales in 2007 and 2030 (WEO, 2009)

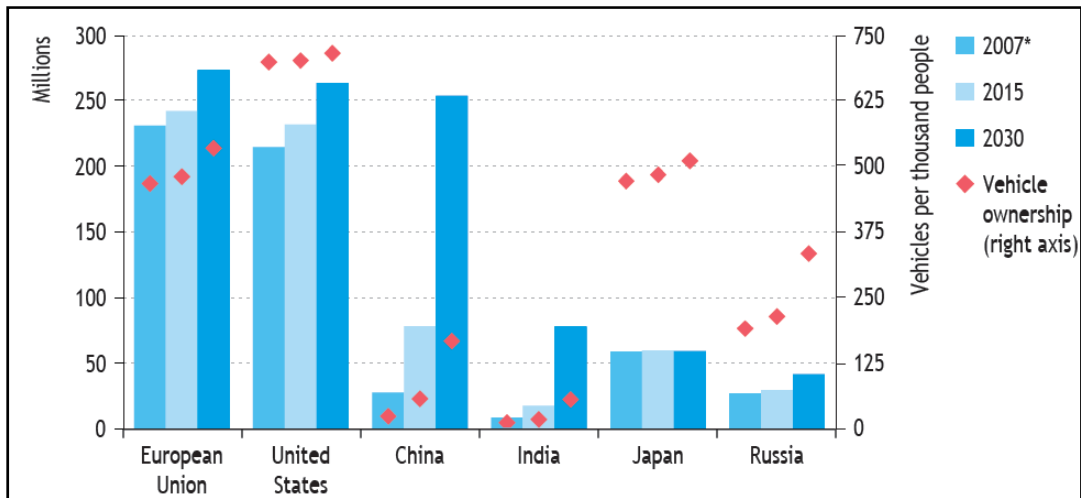


Fig. 5. Present status of total number of vehicle and vehicles per thousand people

By the year 2030, the US and Chinese PLDV fleets combined make up 37% of the global total: in the Reference Scenario in 2030, these fleets are responsible for 36% of global road

CO₂ emissions, despite recent policy efforts in both countries to encourage the mass uptake of fuel-efficient vehicles. Figure 5 shows present status of total number of vehicle and vehicles per thousand people in different countries/regions.

4. TRENDS OF GHG EMISSIONS FROM ROAD TRANSPORT SECTOR

While CO₂ emissions arise at nearly every stage of a motor vehicle's life—including extraction of raw materials and manufacturing of component parts—it is the combustion of gasoline and diesel fuels during vehicle use that accounts for the greatest share (approx. 75%) of vehicle-related CO₂ emissions (Figure 6) (Weiss et al., 2000). Among all sectors that emit CO₂, the transport sector is the fastest growing, representing from 22% to 24% of global GHG emissions from fossil fuel sources, second only to the industrial sector (Wright, 2004). Road transport is an important source of greenhouse gas emissions (primarily carbon dioxide and nitrous oxide). Unlike CO₂ emissions from fuel combustion, CH₄ and N₂O emissions from road transport are less easily estimated. In addition to activity data, CH₄ emissions are a function of a number of factors that can vary considerably, such as combustion conditions, post-combustion emission controls, fuel composition, and driving practices. Similarly, N₂O emission rates can vary dramatically and have been found to be primarily functions of the type and operating temperature of catalytic emission control equipment, which can be affected by several variables (UNFCCC, 2004).

Within the transport sector, private and commercial road transport has accounted for the great majority of CO₂ emissions in most countries. World emissions of NO_x were 82 Mt in 2007, of which Road transport was responsible for about one-third of NO_x emissions. Road transport emissions are split two thirds to passenger transport one third to freight at present in OECD countries as a whole. The same pattern holds for the European Union countries. Freight emissions have been growing somewhat faster than passenger emissions for some time and the trend is expected to continue.

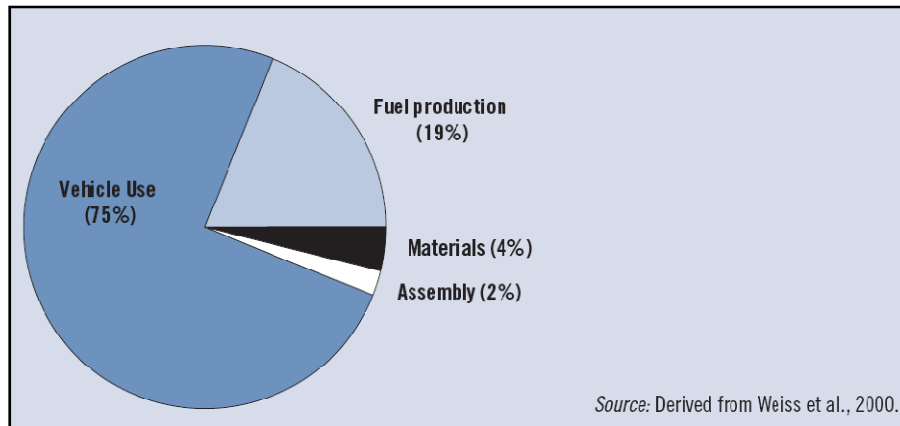


Fig. 6. Share of emission from Life Cycle of a typical vehicle

Transport-related CO₂ emissions is estimated to increase by 41% from 2007 to 9.3 Gt in 2030. Only Road transport related CO₂ emission is estimated to increase from 4.8 Gt in 2007 to 6.9 Gt in 2030 (Figure 7) (WEO, 2009). The increase in CO₂ emissions is largely a result of increasing demand for individual mobility in developing countries, where increases in

vehicle ownership are expected to increase substantially the global fleet of passenger light-duty vehicles (PLDVs) (WEO, 2009).

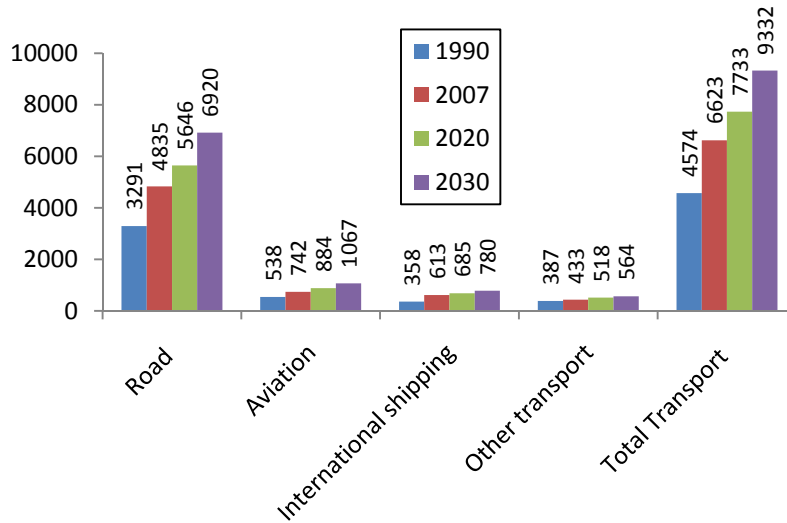


Fig. 7. Sector wise CO₂ emission in reference scenario in Mt (Million Metric ton) (WEO, 2009)

In US, CO₂ emissions from road transport fall by 7.8% between 2007 and 2020, in large part due to strengthened CAFE standards to ensure improved vehicle efficiency and the adoption by a number of states of California's more stringent efficiency standards (WEO, 2009). With rapidly expanding car ownership, China's road-transport emissions increase more than four-fold between 2007 and 2030.

By 2030, Heavy Duty Vehicles (HDVs) account for almost 40% of road-transport emission savings. The global average HDV fleet is 20% more efficient by 2020, achieving a CO₂ emissions reduction from an estimated 340 gCO₂/km in 2007 to 270 gCO₂/km in 2020, and 227 gCO₂/km in 2030 (reaching a 34% improvement in efficiency from today). Savings come from both engine and non-engine vehicle efficiency improvements, increased biofuels consumption, modal shift to rail and more efficient logistics. The latter, e.g. increased load factors, reduction of empty runs and better driver training, come at low or negative costs.

5. TRENDS IN THE LOW CARBON TECHNOLOGIES AND THE GLOBAL OEMS

Due to mounting public debate and regulatory pressures, there are strong efforts and renewed investments by manufacturers and suppliers in providing solutions to the CO₂ reduction challenge (Anonymous, 2011). As opposed to other environmental regulations affecting the auto industry, this time the solutions and strategies available are more complex and go far beyond the simple question of which is the most suitable engine technology (PWC, 2007). A perspective of different short term and long term CO₂ reduction technologies like advanced gasoline ICE, advanced diesel, gasoline hybrid, diesel hybrid, and different

fuel cell technologies and their respective GHG reduction potential has been shown in figure 8 (Weiss et al., 2003).

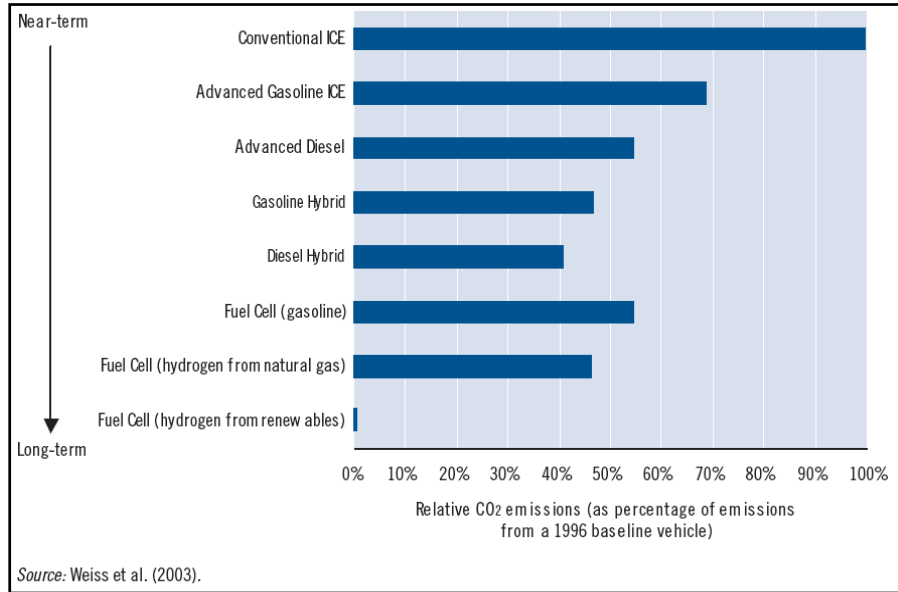


Fig. 8. Development of Low Carbon Technologies (World), 2005-15

Low-carbon vehicles, such as hybrid cars, plug-in hybrids and electric cars, have received widespread public attention recently. However, this has so far led to only limited policy support: examples include subsidies for hybrids, electric cars and fuel cell vehicles in China, the United States and some European countries, all of which are taken into account in the Reference Scenario.

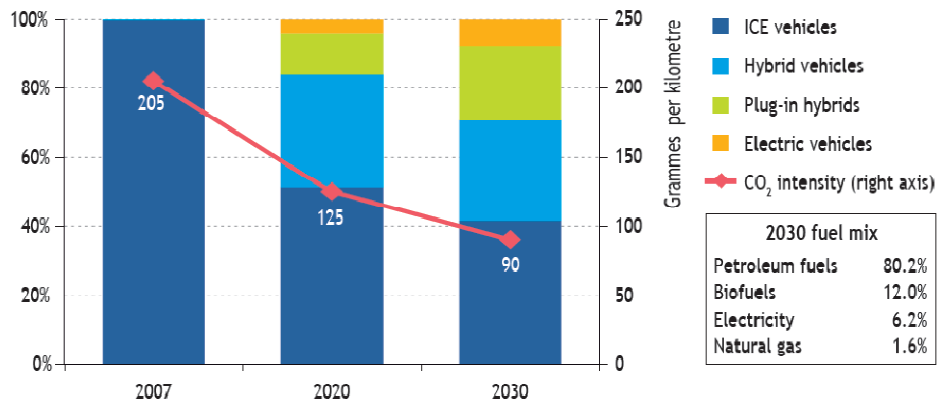


Fig. 9. Future world trends of Auto-technologies and correspondig GHG emissions (WEO, 2009)

In the absence of more direct policy support, the combination of high costs and the slow rate of vehicle stock turnover sees the share of hybrids in the global fleet reach about 5% by

2020 and almost 8% by 2030, up from just 0.15% in 2007. Plug-in hybrids and electric cars remain marginal in the Reference Scenario, accounting for only 0.2% of the global fleet in 2030. Future world trends of Auto-technologies and corresponding GHG emissions are presented in figure 9 (WEO, 2009). It has been also felt that current policies are insufficient to prevent a rapid increase in the concentration of greenhouse gases in the atmosphere, with very serious consequences for climate change (Venkatakrisnan, 2005).

5.1 EMISSION TRADEOFF BETWEEN VEHICLE AND ELECTRIC ENERGY REQUIRED FOR VEHICLE

Increases in electricity consumption in road transport due to rapid penetration of plug-in hybrids and electric vehicles, and to a lesser extent increased electricity powered rail transportation, sees transport sector CO₂ savings partially offset by power generation emissions. An increase of 880 TWh of electricity consumption in transport in 2030 compared with the Reference Scenario, of which 90% occurs in PLDVs, results in about 250 Mt of additional CO₂ emissions (WEO, 2009). Higher market shares for electric vehicles and plug-in hybrids are desirable for reaching climate policy targets, but are insufficient if they are not accompanied by the decarbonisation of the power sector. Well-to-wheel CO₂ emissions per kilometre from future hybrid vehicles are lower than those of plug-in hybrids and electric cars if the electricity consumed is produced using the global power generation mix from the Reference Scenario (WEO, 2009).

6. CONCLUSIONS

- Vehicle makers are integral to modern society. They have embraced the challenge, delivering significant environmental progress to date. Manufacturers will continue to play a pivotal role within the context of sustainable growth. The automakers are currently facing greater uncertainty than ever. Changing regulations and proliferation of technology upgradation have redrawn the realms of the automotive industry. The drivers of the automotive industry are changing fast. There seems to be a greater nexus between the automotive industry's objectives and the social goals. Use of environment-friendly and clean technologies is going to make all the difference between the winners and the losers of the industry. The automakers have to make some strategic choices in selecting, developing, and commercializing those technology platforms that best portrays their brand and marketing strategies.
- Current policies are insufficient to prevent a rapid increase in the concentration of greenhouse gases in the atmosphere, with very serious consequences for climate change (Venkatakrisnan, 2005). While the transport sector accounts for around a quarter of total CO₂ emissions from fuel combustion, size is not the primary basis for selecting abatement measures in an economy. Cost-effectiveness is the most important factor. Some of the measures already adopted in the transport sector are expensive per tonne of CO₂ abated, costing upwards from Euros 100 per tonne. Some of the lowest cost opportunities for emission reductions in transport have not been exploited so far (ECMT, 2007).
- Innovation is driving forward cleaner, 'greener' and affordable transport. Further progress on CO₂ reduction will come from improved powertrains and the development of more renewable energy sources. Low-emission vehicles offer the most convincing solution on the road to sustainable mobility. A commitment to

robust RandD, infrastructure improvements, energy use and market demand will be needed to accelerate progress (Anonymous, 2009). CO₂ savings will be maximized if well-to-wheel impact is clearly addressed at all stages of the fuel and energy chain.

REFERENCES

- Anonymous. (2011). The automotive industry and climate change. <http://www.pwc.com/be/en/publications/the-automotive-industry-and-climate-change.jhtml> (Last accessed on 5th April, 2011)
- Anonymous. (2009). The automobile industry and climate change - a long-term perspective. <http://www.acea.be/index.php> (Last accessed on 5th April, 2011)
- Austin, D., Rosinski, N., Sauer, A., Duc C.L. (2003). CHANGING DRIVERS: The Impact of Climate Change on Competitiveness and Value Creation in the Automotive Industry. SAM and World Resource Institute, 1-84.
- Confalonieri, U., Menne, B., Akhtar, R., Ebi, K.L., Hauengue, M., Kovats, R.S., Revich, B., Woodward, A. (2007). Executive summary. In (book chapter): Human health. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds.). Print version: Cambridge University Press, Cambridge, UK. This version: IPCC website. ISBN 9780521880107. Retrieved 2010-05-27.
- ECMT (European Conference of Transport ministers). (2007). Cutting transport CO₂ emissions: what progress? - ISBN 92-821-0382-X.
- IPCC (Intergovernmental Panel on Climate Change) (2007). "Synthesis Report", contribution of Working Groups I, II and III to the *Fourth Assessment Report of the IPCC*, Core Writing Team, R.K. Pachauri and A. Reisinger (eds.), IPCC, Geneva.
- PWC (Price WaterHouse Coopers). (2007). The automotive industry and climate change Framework and dynamics of the CO₂ (r)evolution. 1-127.
- Rosenzweig, C.G., Casassa, D.J. Karoly, A. Imeson, C. Liu, A. Menzel, S. Rawlins, T.L. Root, B. Seguin, P. Tryjanowski, (2007).: Assessment of observed changes and responses in natural and managed systems. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 79-131.
- Schneider, S.H., et al. (2007). Assessing key vulnerabilities and the risk from climate change. In Parry 2007, p. 781.
- Smith, B., Schneider, H., Oppenheimer, M., Yohe, W., Hare, W., Mastrandrea, D., Patwardhan, A., Burton, I. et al. (2009). Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC) reasons for concern. Proc.: Nat. Academy of Sci. of the United States of America, 106(11), 4133–4137.
- Smith, J.B., et al. (2001). Vulnerability to Climate Change and Reasons for Concern: A Synthesis.. In McCarthy, J.J., et al. Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Retrieved 2010-01-10.
- UNFCCC. (2004). Estimation of emissions from road transport. FCCC/SBSTA/2004/INF.3. pp. 1-27.

- Venkatakrishnan, K. (2005). Climate Change Policies and Global Automotive Industry Frost and Sullivan. <http://www.frost.com/prod/servlet/cif-econ-insight.pag?docid=49415398>. (Last accessed on 5th April, 2011).
- Wouters, B., D. Chambers and E.J.O. Schrama (2008), "GRACE Observes Small-scale Mass Loss in Greenland", *Geophys. Res. Lett.*, Vol. 35, L20501, doi:10.1029/2008GL034816.
- Weiss, M.A., Heywood, J.B., Schafer, A., Natarajan, V.K. (2003). Comparative Assessment of Fuel Cell Cars (Cambridge, MA: MIT, 2003 p. 29).
- Weiss, M.A., Heywood, J.B., Drake, E.M., Schafer, A., AuYeung, F.F. (2000). On the Road in 2020: A Lifecycle Analysis of New Automobile Technologies (Cambridge MA: MIT, October 2000).
- WEO (World Energy Outlook). (2009). International Energy Agency. ISBN: 978 92 64 06130 9 pp. 1-698.
- Wright L. (2004). The limits of technology: achieving transport efficiency in developing nations, UK. <http://eprints.ucl.ac.uk/archive/00000108/01/Lloyd_Wright,_Bonn,_Germany,_Transport_and_climate_change.pdf>; 2004.

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