Global Car Demand and Climate Change: A Regionalized Analysis into Growth Patterns of Vehicle Fleets, CO_2 Emissions, and Abatement Strategies

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Paper presented at the conference Transport – The Next 50 Years, 25-27 July 2007, Christchurch, New Zealand

ABSTRACT

The purpose of the study is to analyse and project global regionalized car stock demands and associated CO_2 emissions up to the year 2050. This is to quantify the evolvement of global passenger vehicle fleets and to assess the significance of the private car sector with respect to climate change in terms of CO_2 emissions. The study adopts an international approach describing in total 11 world regions thereby conceptualising regionally distinct growth patterns of average car stocks on a business-as-usual basis.

To facilitate the assessment we pursue a multi-model approach to car demand, applying two types of methodologies rooted in the economics of consumption, notably utility maximization and single equation income-consumption models. The first method is driven by the preferences of the representative consumers of each world region, i.e. by a Stone-Geary utility function that is being optimised within the constraints given by prices and income. This method is complemented by the application of income-consumption models, also known as Engel curves, based on logistical Gompertz functions and non-linear regression in order to allow for comparisons in model results. Both methods are calibrated to historical time series data of car stocks and income of the representative consumers of each region alike. Data have originally been collated and processed for this study. Model projections are driven by region specific income and population scenarios that are adopted from an aggregated economic growth model. Price scenarios are, in addition, defined and employed as input variables in the utility-based approach.

Associated reference CO_2 emissions scenarios of the world car fleet in use are computed on the basis of behavioral and technological assumptions about the distances driven per average unit of car and about the average fuel efficiency of the regional car fleets in use. Finally the impacts of CO_2 emissions abatement on the world passenger car fleet in use are demonstrated for 1) altered energy efficiencies of the car fleets in use and 2) scenarios of biofuel use up to the year 2030.

1. CARS AND CLIMATE CHANGE

Passenger car demand and use is a key sector of fossil fuel consumption and as such a contributor to anthropogenic greenhouse gas emissions (GHG) and a relevant driver of climate change. Passenger transport operates on oil as the fuel of choice; however, first signs of diversifying the fuel base are visible in road transportation in favor of natural gas, biofuels and synthetic fuels. Global transportation energy use accounts for roughly 23% of global carbon emissions from energy-use (21% in 2000). Recent trends in total aggregated GHG emissions of Annex I parties[1] state an overall decline from 1990 to 2004 in major energy consuming sectors except for the transport (+24.4%) and energy industry sector (+7.6%) (UNFCCC, 2007). So far, attempts to reduce the emissions from transportation have failed. And the share of emissions is projected to rise to about 25% if business-as-usual patterns of mobility are to prevail (OECD/IEA, 2004). This would constitute a dramatic increase in emissions of more than 85% from 2000 to 2030. On-road mobility contributes a majority share to transport related emissions, i.e. about 80% of total global transport energy demand and related CO_2 emissions are released on roads comprising passenger as well as freight transport (OECD/IEA, 2006). Improvements in energy efficiency and attemps to decarbonize the road sector therefore have a large impact on transport energy demand and CO_2 emissions. The present study focuses on the dynamics of passenger transport, i.e. on light-duty vehicles including cars, vans and light trucks that accounts for 65% of total road-fuel consumption.

An essential step to sectoral abatement strategies is to quantify long term sectoral and regionalized reference scenarios of CO_2 emissions. Scenarios are an essential tool to identify whether global CO_2 emissions from car use should be expected to be detrimental to the aim of climate protection. This question is of importance since other energy consuming sectors may not be able to bear the total burden of emissions reduction needed to stay within the 2°C target which the EU itself has comitted to, nor to compensate for substantial emissions growth in the transport sector. In addition, sectoral passenger car related emissions scenarios provide a framework of counterfactuals for quantifying avoided emissions when it comes to sector based mitigation projects. In particular, reference scenarios are needed to systematically discuss impacts of alternative futures in car use, for example the adoption of efficiency technologies, the use of alternative fuels or altered modal splits in the transport sector.

Recently, sectoral approaches to emissions abatement are receiving attention in international/national climate policy debate, i.e. in the design of a post-Kyoto agreement (Baron, 2006). A sector wide approach to emissions mitigation may - in certain cases - be more successful than national approaches such as binding reduction targets because competitiveness risks and carbon leakage can be overcome. A sectoral approach is particularly interesting for internationally oriented sectors and their businesses given a fairly limited number of actors, as for example the car manufacturing industry. The present analysis wants to contribute to this discussion.

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[1] Annex I parties are industrialised countries that are included in Annex I to the United Nation Framework Convention on Climate Change (UNFCCC). They have pledged to reduce their GHG emissions by the year 2000 to 1990 levels. Annex I parties consist of countries belonging to the OECD and countries designated Economies-in-Transition.

The paper starts with a historical snapshot of regional trends in car stock growth in section 2. It is demonstrated that regional car stock growth follows a stylized pattern known as Engel curve. Section 3 presents regionalized vehicle stock demands derived on the basis of partial equilibrium demand models from 11 world regions until 2050. It is complemented by a second set of regionalized scenarios modeled on the basis of an alternate method, notably single-equation models represented by S-shaped income-consumption curves. Applying different methodologies to model passenger car demands follows the idea of providing scenario ranges in order to quantify the scope of possible outcomes and thus bring to light uncertainty in modeling long term reference scenarios. The multi-model approach is commonly applied in integrated assessment of climate change; see for instance Nakicenovic and Swart (2000). Both methods are calibrated to the same historical data sets presented in section 2. Section 3 puts as well forward car related CO_2 emissions scenarios. The computation of associated CO_2 emissions scenarios involves behavioural and technological trend developments, i.e. distances driven per car (behavioral parameter) as well as average fuel economies of vehicle fleets in use (technological parameter). Section 4 embarks on quantified alternative emissions scenarios in passenger car use related CO_2 emissions that stem from 1) fuel efficiency improvements and 2) from substituting fossil fuels for biofuels according to the IEA reference and alternative policy scenarios. Given the model results, we conclude in section 5 that a portfolio of abatement strategies is needed in order to brake the current trend of ever rising CO_2 emissions form passenger car demand and use. This involves some systemized prospects for climate related approaches in the passenger car sector.

2. PATTERNS OF CAR STOCK GROWTH

Aiming at calculating global CO_2 emissions from passenger car use, the analysis considers eleven world regions representing clusters of regional proximity and comparable economic performance (see figure 1). The spatial resolution is widely used in the literature allowing for convenient comparisons. Historical trends of per capita car stocks and GDP (gross domestic product) for the elven world regions considered are shown in figure 2.

The data are collated from internationally renowened sources, e.g. the World Development Indicators published by the World Bank (2005, 2003) for population and GDP time series and the international source books by Mitchell (1995,1993,1992) and the International Road Federation (IRF, 2005, 1985-2001) for car stocks. Aggregated cluster specific time series of per capita car stock and per capita GDP are formed by weighted average according to population figures of the representative countries of each cluster.[2]

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[2] Countries that figure behind the regional clusters in terms of data are selected according to data availability and are listed in table 1 in the Appendix. Form the table it is apparent that the selected countries cannot fully reflect the geopgraphical scope in most cases. While som spatial clusters like NAM, WEU, PAO, CPA, and SAS are well represented by the data of the countries considered, other regions like AFR, LAM, MEA, EEU, FSU and PAS are under presented due to missing data.

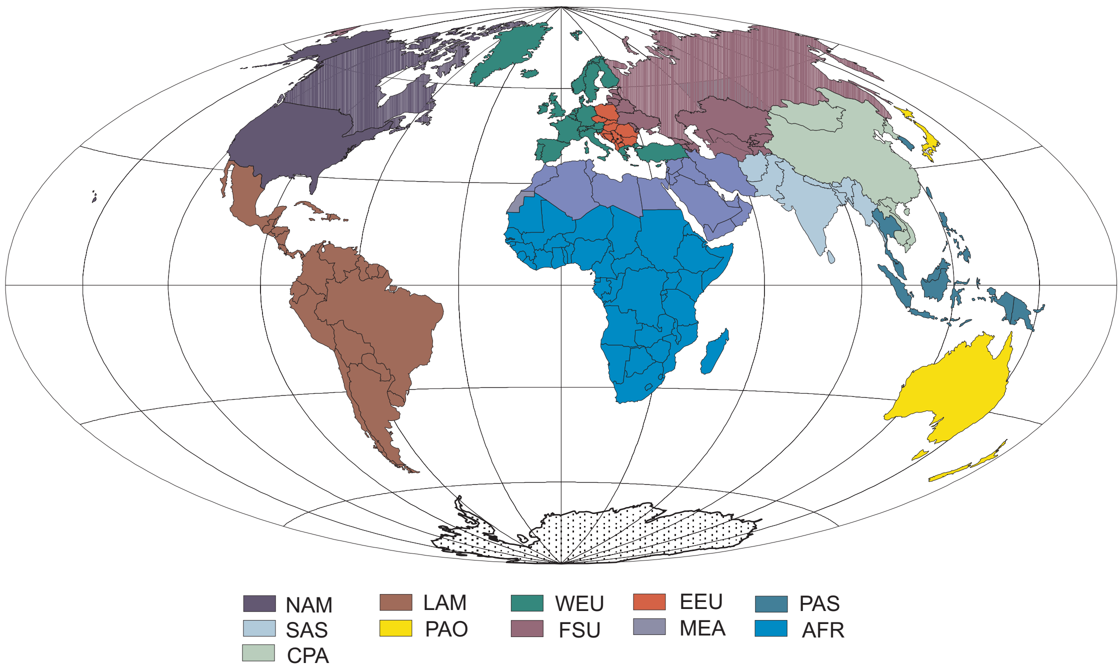

Figure 1: The eleven world regions considered

Figure 2 reveals NAM as the region with the worldwide highest per capita passenger car stock level of about 0.6, while WEU displays an average per capita car stock level of about 0.5 and PAO of 0.45 at the end of 20th century. These three clusters represent the most developed and industrialized regions with the highest statistical per capita GDP and the highest car stocks. PAO denotes the leader at an average income level of more than US$ 40,000 per capita.[3] The three regions are followed by EEU, FSU, LAM with per capita car stocks between 0.12 and 0.28, the regions PAS, MEA, AFR, ranging from 0.02 to 0.05 and CPA and SAS ranging from 0.006 to 0.008 cars per capita. The developing regions are thus clustered in the left bottom corner at very low levels in both car stock and income per capita.

Figure 2 suggests that regional clusters together build a typical income-consumption curve - also known as Engel curve - of a stretched S-shape with each cluster representing a distinct development stage of car stock relative to per capita income within the temporal snapshot pictured. Thereafter a disproportionately high growth in car demand relative to income takes place when the market penetrations of the car and income levels are rather low. When car markets are ripe, notably when car endowments and income levels are gaining, growth in car demand slows below income growth. This is typically captured by income elasticities of greater or less than one. From the empirical data derives that firstly, every world region shows a particular income elasticity at a specific point in time and secondly, income elasticities vary with income growth following the pattern of a stylized S-shaped Engel curve. The conclusion from this analysis may be that preferences towards passenger cars are equal across time and space, i.e. across cultures, but they are restricted inter alia by income patterns.[4]

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[3] This high per capita income of PAO is due to Japan's high exchange rate measured in Purchasing Power Parity; the per capita income of PAO falls behind that of North America.

[4] For an early analysis of transport demand patterns across different countries and cultures, see for instance Zahavi and Talvitie (1980). See also Stigler and Becker (1977) on equal preferences.

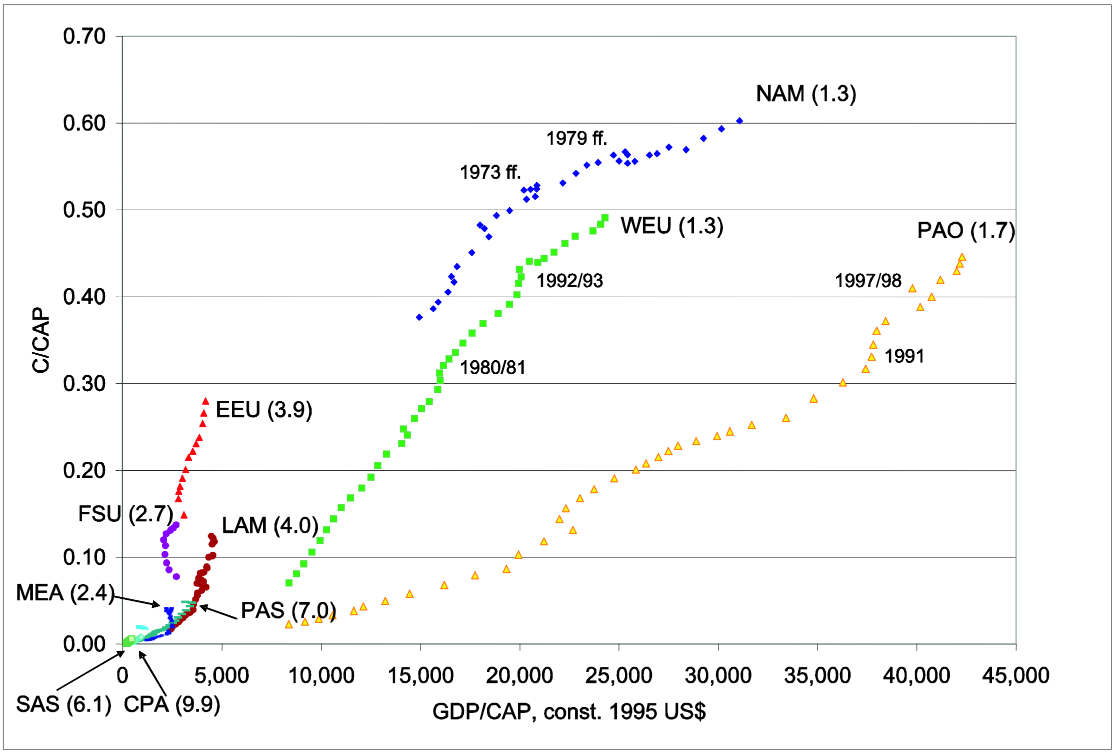

Figure 2: Income-consumption curves of car demand in eleven world regions 1960-2002

Also shown in the figure are average annual growth rates of average passenger car stocks during the last 5 years (figures in brackets). The Asian regions, among the lowest in car endowments, indeed show the highest growth rates of 9.94% in CPA, 6.14% in SAS and 6,95% in PAS. In contrast, industrialized countries exhibit growth rates of 1.3% (WEU, NAM) and 1.7% (PAO) only, indicating maturing passenger car markets.

3. REFERENCE SCENARIOS OF CAR FLEETS AND CO$_2$ EMISSIONS

Model results for reference scenarios on future regionalized car fleets and associated CO$_2$ emissions are presented in this section. The computation of model results is based on drivers of high growth, i.e. world population is growing to 10.1 bn people in 2050 and economic growth leads to a five-fold increase in the global gross product by the year 2050 compared to 1990.

The utility maximization approach to car demand is driven by region-specific preference functions of representative consumers, i.e. by Stone-Geary (SG) utility functions subject to income constraints. The demand for vehicle fleets is a function of expenditure and prices. Parameters values for preference functions are set for marginal budget shares concerning cars and generic goods demands. The latter good captures demand for the remaining of the consumer world. A further parameter represents a subsistence level of demand that has to be satisfied before demand for cars becomes viable. Regional models have been calibrated to empirical data as shown in figure 2. They are driven by region-specific income time series adopted from Leimbach and Tòth (2003) who have developed an optimal growth model that operates on the same regional specifications and generates income time series through capital and trade flows. Price trajectories are defined as input, notably we consider a one percent real price increase for car use; see Meyer et al. (2006) for further details on model specifications.

The application of income-consumption models to car stock demand is based on the functional relationship between car stock demand and income as depicted in figure 2. This can be represented in terms of Engel curves, notably by S-shaped or sigmoid functional forms. We use the Gompertz function as second method to estimate cluster specific car stock demands, see for instance Dargay and Gately (2001). The Gompertz model abstracts from marginal budget shares and price specifications. Hence relative prices are implicitly considered constant, or are assumed to not influence demand towards passenger cars. Parameters for saturation levels and starting levels are set equally across regions, i.e. 0.6 cars per capita for all regions. Regions-specific curvature parameters are estimated on the basis of empricial data shown in figure 2.

Results for the utility-maximisation demand scenarios show that the global car fleet in use rises from around 640 million to about 1.5 bn. in 2050 and thus is more than doubling within a 50 years time span (see fig. 3). While the industrialized regions NAM, WEU, PAO and EEU experience a slow absolute increase in car stock demand with an average annual growth rate of 0.8%, transition and developing regions together show a significant growth yielding an average annual growth rate of 3.3% in their vehicle fleet throughout the observation period. Average annual growth rates for these regions are slightly higher with respect to the year 2030, i.e. 0.9% for industrialized countries and 3.7% for transition and developing countries. The share of the industrialized countries vehicle fleet remains dominant throughout the observation period but is constantly decreasing from 77% in the year 2000 to 50% in mid 2040th.

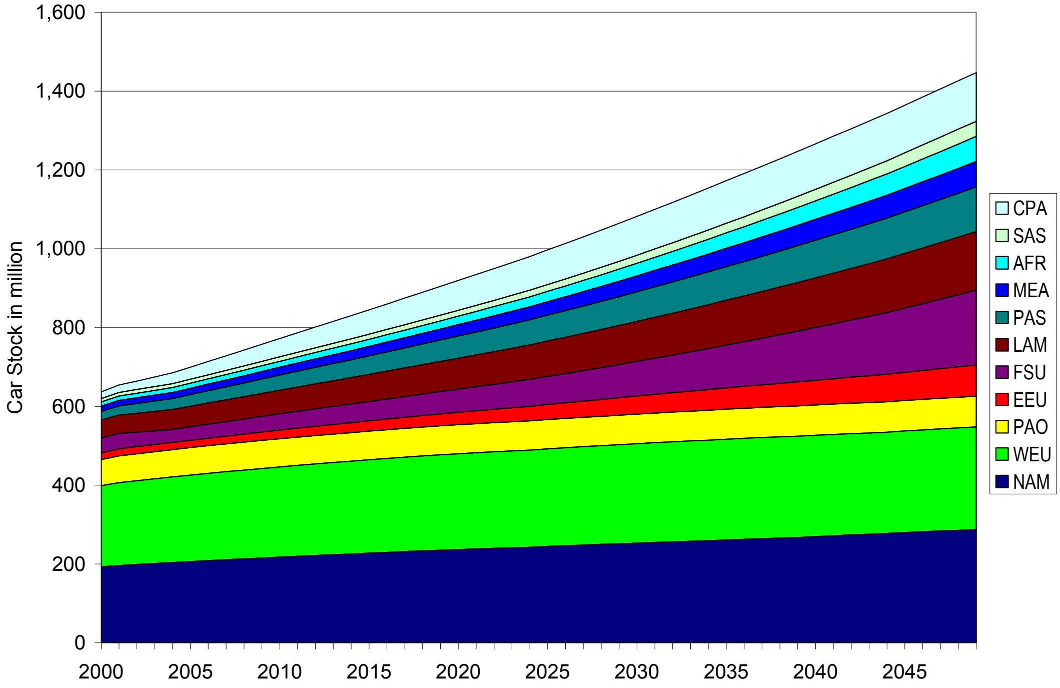

Figure 3: Car stock demand projections on the basis of utility-based approach to demand employing Stone-Geary utility functions 2000-2050

Results from Gompertz models (c.f. to fig. 4) show a more dynamic pattern of growth with the global vehicle fleet rising from around 600 million[5] to 2.7 bn. cars in 2050, thus the global vehicle fleet is more than quadrupling. Industrialized clusters yield average annual growth rates of 0.5%, i.e. lower than in Stone-Geary simulations, whereas transition and developing regions together show average annual growth rates of 6.4% within the simulated time span. Considering average annual growth rates until 2030, the vehicle fleet of the industrialised world is about to grow by 0.8% while the one of the transition and developing regions is at 8%. In the Gompertz case the share of industrialized car fleet falls from 83% to around 50% by 2022 already. Majorities in regional car fleet compositions are hence qickly shifting and car markets in Asia, Middle East, Latin America and Russia are rapidly gaining dynamics.

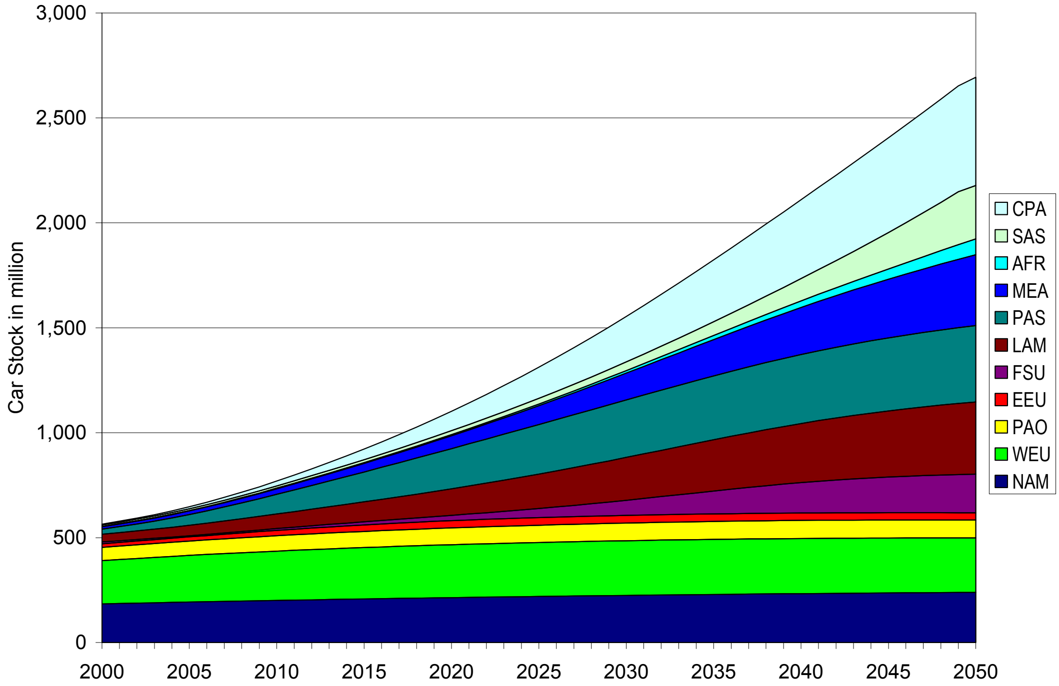

Figure 4: Car stock demand projections on the basis of income-consumption models employing Gompertz functions 2000-2050

The variance in global passenger car fleets of the two scenario projections based on equal driving forces in population and income is widening over time. Main reasons are the assumptions behind the models that shall be briefly discussed, for details see Meyer et al. (2006). Modeling car stock demand by utility-maximization models incorporates the common economical-modelling assumption that people's behaviour ramains the same (constant preference assumption). So in each country people will continue to spend the same proportion of their salary on a car (constant marginal budget share). But as a rule and according to the historical example of industrialised countries, people start to spent a larger proportion of their earnings on a car (rising marginal budget shares) as they get richer. So projections of the utility-based approach are probably an underestimate, in particular with respect to transition and developing regions that experience high per capita income growth and thus have not reached their prefered share of budget spending on cars. Projections on the basis of Gompertz income-consumption functions, on the other hand, may overestimate car demands as contingencies from price developments and income restrictions are not incorporated in the model. Additionally, assuming the same saturation level of 0.6

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[5] Differing starting values are due to the deviation of Gompertz regression models from empirical data.

cars per capita as in the USA (NAM) for all regions may not be achievable for every region since most countries don't have the wide-open spaces of North America but face high densities of cars on restricted road networks. Bearing the above in mind, we calculate associated CO_2 emissions scenarios on the basis of behavioral and technological assumptions following the two passenger vehicle fleet projections.

Behavioral scenarios encompass the total volume of transport activity from private car stock in use, measured in kilometers as average annual distance driven per car. Converting activity volumes of the global car fleet in use into CO_2 emissions, we extrapolate the state-of-the-art fuel economcy improvements using the example of Germany. Here, the average fuel economy of the vehicle fleet in use improved by one liter gasoline per 100 kilometers driven within two decades (OECD, 2001). This development is applied uniformly to all regional vehicle fleets starting from regionally differentiated initial fuel use standards, however. In line with empricial data, NAM is modeled on the basis of 12 liters per 100 kilometers while in WEU this level is at 9 liters per 100 kilometers driven, for further details refer to Meyer et al. (2006). CO_2 reference emissions scenarios are depicted in figure 5.

As demand for cars is increasing, so does the related fuel demand and the associated CO_2 emissions. Compared with today's annual 2 gigatonnes of CO_2, the global passenger car fleet may yield between 4 to 8 gigatonnes CO_2 within the next 50 years. Demand for passenger road transport is, thus, expected to increase strongly in the coming decades, especially in transition and developing regions. By 2030 CO_2 emissions from the global passenger car fleet in use are expected to be 45% to 140% higher than in the beginning of the century.

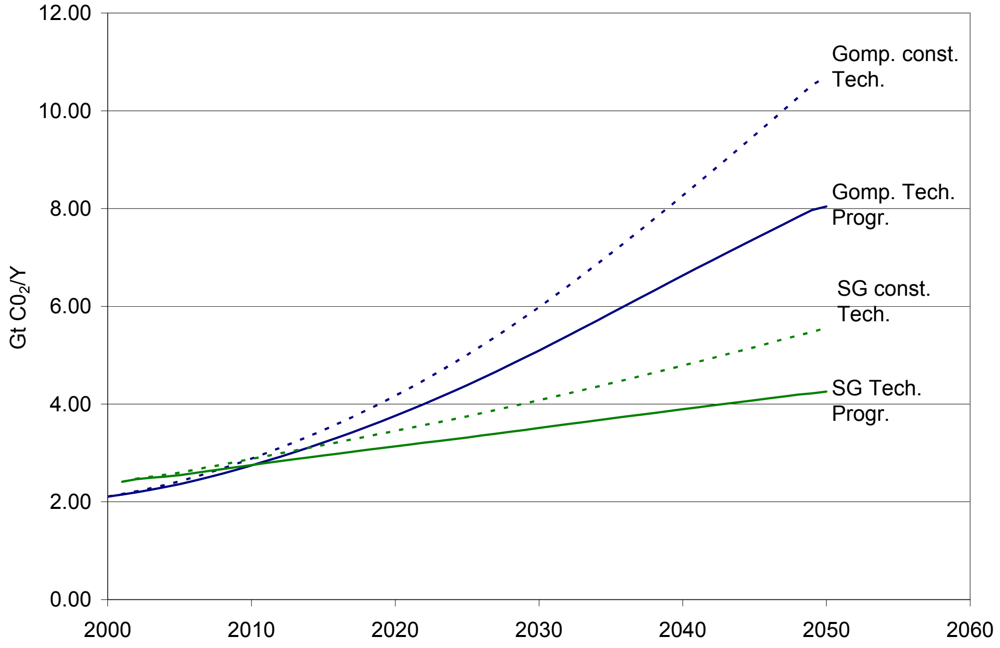

Figure 5: CO_2 emissions scenarios from global car fleet in use with and without fuel economy improvements

4. ALTERNATIVE EMISSIONS SCENARIOS – THE CASE FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY

This section presents two alternative scenarios of CO_2 emissions based on the above reference scenarios of passenger car fleets in use. Hence, we assume vehicle ownership to remain unchanged and employ reference scenarios as counterfactuals to compute the impacts of 1) vehicle fuel efficiency improvements and 2) of rising biofuel use. This implies that we consider measures that alter parameters of fuel consumption and associated CO_2 emissions but neither vehicle use nor vehicle demand.

4.1 SCENARIOS OF VEHICLE FUEL EFFICIENCY IMPROVEMENTS

The volume of CO_2 emissions released by the world car fleet in use reflects the combined influences of consumer car stock demand and use behavior as well as technological applications. The fuel efficiency is measured in liters fuel per hundred kilometers driven, or, in non-metric terms, in miles per gallon fuel use of passenger cars. Car manufacturers may dedicate technological advances in vehicle design to increase the power and performance of the vehicle or to increase its fuel efficiency. Generally, these aims conflict, with power improvements damaging fuel efficiency and vice versa. Furthermore, market forces often favour increased power as manifested in the growing demand for all-terrain vehicles (sports utility vehicles – SUV). This is because the car is not only a means of transport but a consumer good that satisfies other demands like status, individuality and comfort. These attributes go hand in hand with a high willingsness to pay. Although a trend towards more heavier and powerfull cars realized, the efficiency of the whole vehicle stock in most OECD countries nevertheless improved since the fuel economy of new cars was better than that of the cars replaced. Take, as an example, the fuel economy of the combined car and light truck fleet since 1975 in the USA, there was a rapid increase from 1975 to the mid 1980s, a slow increase into the late 1980s, a decline until the mid 1990s, and from there a period of relatively constant overall fleet fuel economy (EPA, 2006).

The impacts of technological progress in vehicle fuel economies on CO_2 emissions is depicted by the two scenarios plotted in dashed lines in figure 5. The graphs show emissions projections that arise when technological characteristics in fuel efficiency remain constant, while the counterfactuals show an extrapolation of historical fuel efficiency improvements into the future. An improvement in the vehicle fleet fuel consumption of one liter fuel per 100 kilometers driven within 20 years translates into a reduction in CO_2 emissions of about 5% (5%) in 2010, 11% (10%) in 2020 and 33% (31%) in 2050 for higher (lower) CO_2 emissions scenarios. These observations show that a moderate increase in the fuel economy of the vehicle fleet in use may result in substantial fuel and CO_2 emissions savings in the medium to long term. The higher the assumed reference growth of emissions, the higher is the potential of fuel efficiency improvements to mitigate emissions from passenger on-road activities. But the projections also show that in total increased car use outweighs efficiency gains achieved as emissions are rising. In order to compensate for growing car demand and use, vehicle fleet fuel efficiency improvements have to be enhanced significantly above historical rates.

4.2 SCENARIOS OF BIOFUELS IN PASSENGER TRANSPORT

Recently, much attention has been directed to biofuels as a blend or substitute for conventional fuels, see for instance EEA (2006) and OECD/IEA (2004a). Biofuels can help curb GHG emissions, depending on how they are produced, and contribute to rural development. Higher oil prices have made biofules more competitive with conventional oil-based fuels, but further cost reductions are needed for most biofuels to be able to compete effectively without subsidy (IEA 2006). There is considerable interest in the promotion of biofuels on both sides of the Atlantic for reasons of security in energy supply and agricultural support but also for reasons of CO_2 abatement and sustainable development in rural areas.[6]

There are several types of biofuels and many different ways of producing them. At present, almost all biofuels produced around the world are either ethanol or esters, referred to as biodiesel. Ethanol is usually produced from sugar and starchy crops, such as cereals, while biodiesel is produced mainly from oil-seed crops, including rapeseed, palm and sunflowers. Other crops and organic wastes can also be used (IEA 2006). Second-generation biofuels are made from any plant material such as waste from agriculture and forestry. They could significantly reduce CO_2 production, and do not compete with food crops. Second generation fuels are based on lignocellulose applying processing technologies such as gasification and Fischer-Tropsch technology, i.e. biomass-to-liquids (BTL). Producing ethanol made from trees, grasses and other types of biomass which contain a lot of cellulose, the energy balance could be much higher than from ethanol made from maize (The Economist, 2007).

Biofuels	**Well-to-wheels GHG emissions, compared to base gasoline/diesel vehicle**
Ethanol from starchy grains (corn/wheat)	-20% to -40%
Ethanol from sugar beets (European studies)	-35% to -56%
Ethanol from Sugar Cane (Brazil)	up to -92%
Ethanol from Cellulosic Feedstock (poplar trees, switchgrass) - enzymatic hydrolysis	-70% to -90 %
Biodiesel from FAME[7] or RME[8]	-40% to -60%
CNG[9] from local eucalyptus	-80%

Table 2: GHG impacts of alternative biofuels

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[6] See for instance the EU Biofuel directive (Directive 2003/30/EC) for a legally binding target on biofuel use.

[7] Fatty Acid Methyl Esters

[8] Papeseed Methyl Ester, i.e. biodiesel from oil-seed rape. In North America studies additionally look at soy-based biodiesel.

[9] Compressed natural gas from gasification

The net impact on GHG emissions reduction from the substitution of conventional fuels through biofuels depends on several factors: These include the type of crop, the amount of energy that is embedded in the fertilizer used to grow the crop, emissions from fertilizer production, the resulting crop yield, the energy used in gathering and transporting the feedstock to the biorefinery, alternative land uses[10] and land use changes, the energy intensity of the conversion process, emissions credits that can be attributed to the various by-products. CO_2 emissions from the point of use are assumed to be zero based on the fact that biomass feedstock is a renewable resource emitting as much carbon as was absorbed by the biomass (OECD/IEA 2006). But from the point of the full "fuel cycle", from biomass feedstock production to final fuel consumption, GHG emissions may vary substantially. In some cases, emissions may be as high as or even higher than the net GHG emissions from gasoline vehicles. On the other hand, some biofuel feedstock and conversion processes, such as enzymatic hydrolysis of cellulose to produce ethanol and increasing the use of biomass as the process fuel, can reduce well-to-wheels CO_2-equivalent emissions to near zero (OECD/IEA, 2004a). Estimating the net impacts of using biofuels on oil use and GHG emissions is, thus, a complex issue. A survey of studies conducted by the OECD/IEA (2004a) indicates a range of GHG emissions savings of specific biofuels as summarized in table 2.

However, the absolute potential of biofuels to abate CO_2 emissions is limited. Producing biofuels on a large scale requires large areas of land. At present about 1% of global road-transport fuels are derived from biomass. Increasing this share to a complete substitution is impossible unless fuel demand is reduced substantially, land productivity is increased dramatically, and large areas are converted to arable land, or biofules are made from ligno-cellulosic biomass that requires less arable land.

	CO_2 Emissions Reduction from Biofuel Use with respect to [in %]			
	Stone-Geary Reference Sc.		Gompertz Reference Sc.	
	ABSI	ABSII	ABSI	ABSII
2010	-0.72	-0.73	-0.41	-0.42
2020	-0.71	-0.73	-0.43	-0.44
2030	-0.71	-0.73	-0.44	-0.47

Table 3: Impacts on GHG emissions from biofuel use in passenger transport

Impacts of biofuel use on CO_2 emissions from passenger transport are depitcted in table 3 in terms of alternative emissons scenarios until the year 2030. The scenarios are computed on the basis of global biofuel use scenarios that the IEA's latest World Energy Outlook (OECD/IEA, 2006) has established. In both scenarios only first-generation biofuels are assumed to be economically viable before 2030. The first alternative biofuel scenario (ABSI) assumes an average annual growth in global biofuel use of 6.3% starting with a biofuel use of 1% of road fuel demand in 2005.

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[10] For example, if crops are planted on land that would otherwise become a forest, then there is a significant emission of GHG associated with the loss of carbon sequestration.

This is considered a reference scenario of biofuel use. The second alternative biofuel scenario (ABSII) presumes an average annual growth of 8.3% for biofuel use. We apply these rates to our reference fuel demand scenarios on the basis of the two car fleet projections. One assumption made for the calculation is that we assume the same energy efficiency for gasoline as for biofuel use, i.e. one liter of gasoline and one liter of biofuel translates into the same distance driven. We calculate resulting CO_2 emissions from the two alternative biofuel scenarios with -40% CO_2 emissions from biofuel use, considering the above ranges of GHG reduction impacts (see tab. 2). In particular row one to three and five are considered from where we simply built an average reduction parameter. In addition, we do not incorporate technological progress in terms of rising GHG reductions from biofuel use as technology progresses.

Model results indicate that starting from 1% biofuel use in 2005 average annual growth rates in biofuel use of 6.3% (ABSI) and 8.3% (ABSII) do create only a very minor share of CO_2 emissions savings of less than 1% with respect to both reference scenarios. With respect to Stone-Geary reference scenario, biofuels would achieve a share of 3.33% for ABSI and 5.31% for ABSII in 2030. With respect to Gompertz reference scenarios the share of biofuel use based on ABSI would be 2.14% and 3.4% for ABSII. In order to achieve a significant share of biofuel use, e.g. 30% in 2030, growth rates of biofuel production must be considerably higher. With respect to Stone-Geary projections the average annual growth of biofuel use must reach about 16% and for Gompertz projections about 18% in order to realize a biofuel share of 30% on fuel demands. This would contribute reductions in passenger car related emissions of around 12% in 2030 with respect to both reference scenarios. Whether growth rates in biofuel production of annually 16% to18% can be achieved in a sustainable manner needs to be assessed within an integrated framework of e.g. land-use and land-use modelling.

5. PROSPECTS FOR ABATEMENT STRATEGIES IN THE PASSENGER CAR SECTOR

The above analysis illustrates that a displacement of oil by moderate growth trajectories of biofuel use in the order of magnitude of 6% to 8% does not yield substantial reductions in CO_2 emissions if reference trends in the growth of passenger car demand and use are going to prevail. The modelling excercise put as well forward that a moderate improvement in fuel economy standards does not solve the problem of rising global CO_2 emission because gains from efficiency improvements are compensated by growing passenger car use. This leads us to the conclusion that 1) energy efficiency improvements and biofuel use must be enhanced and 2) there is no silver bullet, no single technology to drive the scale of emissions reductions needed to break the trend of ever growing passenger car related emissons. Therefore, we must prepare to rely on a portfolio of abatement strategies for the passenger transport sector in order to achieve CO_2 emissions savings. One of the main targets should be to ease growth in car demand and use because this could multiply the impacts from efficiency improvements and biofuel use.

As a final point we give an overview of strategic approaches that should be addressed in order to strive for a transformation of private mobility towards climate friendly mobility in the passenger car sector, see figure 6. From the technological point of view a more ambitious approach to technically reducing the energy intensity of passenger cars is essential. This is considered to be a measure that can be implemented in the short to medium term. On the one hand, this addresses the motivation and responsibility of private car manufacturers around the world to act as innovators in decarbonizing passenger transport systems. On the other hand, public incentives for stimulating research and market deployment are necessary. Establishing price signals that pull new technologies at a sufficient rate and scale seems to be essential in order to make new technologies competitive with conventional ones. As vehicle manufacturing is highly concentrated - the world's 20 largest vehicle manufacturers account for 92% of global production (2003) - establishing a common technology standard would be a very effective way of realizing technically viable energy efficiency gains.

Behavioral Approach	**Technological Approach**
⇩	⇩
consumer choice towards efficient/advanced technology cars	enhance fuel efficiency of vehicles
shift in modal split	develop/deploy technological innovations of decarbonization
reduce transport activities and needs	alternative fuels/biofuels alternative propulsion systems (hybrid, electro, gas, hydrogen)
change preferences regarding spatial patterns of housing, working and leisure to prevent urban sprawl	optimize intermodality enhance quality of public transport

Set coherent political framework conditions (taxes, subsidies and standards)

Figure 6: Approaches to decarbonize passenger car transport

The behavioral approach mainly addresses questions on how to shift individual preferences for passenger car demand and use towards efficient/advanced technology cars and/or how to consolidate passenger car demand in general. Preferences for cars as a mode of transport are manifold and range from the utility derived from using cars as a fast and comfortable way of being mobile, from the freedom from dependence on schedules and availability of public transport, to the car as being a luxury item with status-symbol significance. The choice of passenger transport is, hence, not only the result of individual preferences but is explained by socio-political preferences as well. Often, alternative public transport schemes and incentives to the car are lacking or public transport schemes are less attractive. For example, the length of road networks has been increasing constantly while the railway systems have been cut back. Thus preferences towards automobility and certain technological performance parameters are subject to a variety of boundary conditions of which price incentives, legislation, spatial planning and the quality and availability of public transport systems are among the most important factos. Besides setting the boundary conditions towards more efficient passenger transport it will be necessary to enhance the public understanding of the adverse environmental impacts from passenger transport on climate stability.

APPENDIX

Region & Time Span of Series (Fig. 1)	Countries Considered due to Data Availability
AFR – Subsaharan Africa 1979-1996	Cameroon, Congo (GDP), Ethiopia (cars), Kenya, Nigeria, South Africa
CPA – Centrally Planned Asia 1985-2002	China
EEU – Eastern Europe 1990-2002	Hungary, Poland
FSU – Former Soviet Union 1993-2002	Russian Federation, Ukraine
LAM – Latin America 1964-2002	Argentina, Brazil, Chili, Mexico, Peru
MEA – Middle East, North Africa 1961-1995	Algeria, Egypt, Iran, Israel, Saudi Arabia
NAM – North America 1965-2000	Canada, United States
PAS – Pacific Asia 1960-1995	Indonesia, Malaysia, Singapore, South Korea, Thailand
PAO – Pacific OECD 1960-2002	Australia, Japan
SAS – South Asia 1961-2000	India
WEU – Wetstern Europe 1960-2002	France, Germany (cars), Italy, Netherlands, Spain, Switzerland, United Kingdom

Table 1: Regions, countries, and time horizons of data considered

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