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GHG Mitigation Strategy in the European Transport Sector

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Abstract

Transport accounts for roughly one quarter of all greenhouse gas emissions (GHG) in Europe. Transport is the only sector that did not reduce its GHG in recent years. To meet the European and global targets to reduce GHG in industrialized countries by -80 to -95% until 2050 compared with 1990 requires that also the transport sector is put on a pathway to drastically reduce its emissions. The paper demonstrates that with a combined R&D and transport policy strategy reductions of -60 to -70% of GHG until 2050 will be achievable for the European transport sector.
The analysis to develop the transport strategy combines an analysis of the innovation system of the transport sector with respect to developing GHG reduction technologies of all modes and a model-based quantitative scenario exercise to assess the transport impacts, economic and environmental impacts of the scenarios.
We suppose to support R&D for biofuels for air transport and R&D for cross-modal transport. The policy strategy suggests in early years to focus on road transport (i.e. efficiency of ICE) and in medium time horizon on alternative energy technologies (i.e. electricity and hydrogen both from renewables). Additionally the transport strategy must include pricing measures and ambitious regulations (e.g. ban of fossil fuel cars in 2035).

Keywords: greenhouse gas emissions; GHG reduction targets; research strategy; transport policy strategy; all modes; European transport.

Résumé

Le transport est aujourd'hui à l'origine d'environ un quart des émissions de gaz à effet de serre (GES) en Europe. Il est le seul secteur à ne pas avoir réduit ses émissions de GES au cours des dernières années. Pour atteindre les objectif européen et mondiaux que les pays industrialisés se sont fixés (de -80 à -95% en 2050 par rapport aux niveaux de 1990) le secteur des transports devra lui aussi réduire drastiquement ses émissions.
L'analyse du développement d'une stratégie pour les transports requiert d'une part une analyse du système d'innovation (développement de technologies réduisant les émissions de GES pour l'ensemble des modes) dans le secteur du transport et d'autre part un exercice de modélisant visant à quantifier les impacts économiques et environnementaux associés à différents scénarios.
Nous supposons de soutenir la R&D pour les biocarburants pour le transport aérien ainsi que la R&D pour le transport multimodal. La stratégie de politique suggère, au cours des premières années, de se concentrer sur le transport routier (c'est-à-dire l'efficacité des automobiles) et, à moyen terme, de développer des technologies utilisant des énergies de substitution (c'est-à-dire l'électricité et l'hydrogène issus de sources d'énergie renouvelables). En outre la stratégie des transports doit inclure des mesures de tarifaires et réglementaires ambitieuses (p. ex. interdiction de voitures consommant des carburants issus de combustibles fossiles en 2035).

Mots-clé: Émissions de gaz à effet de serre; objectifs de réduction des émissions de GES; stratégie de recherche; stratégie en matière de politique des transports; tous les modes de transport; transport européen.

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1. Introduction

Transport accounts for roughly one quarter of all greenhouse gas emissions (GHG) in Europe. Transport is the only sector that did not reduce its GHG in recent years. However, European and global targets to reduce GHG in industrialized countries by -80 to -95% until 2050 compared with 1990 requires that also the transport sector is put on a pathway to drastically reduce its emissions. To achieve such reductions will be a challenge for industry and policy-makers. This challenge can only be tackled by a consistent strategy that considers both R&D for transport innovations and transport policy, taking also into account potential changes of behaviour and production patterns.

Such a transport strategy is the outcome of the European FP7 co-funded research project GHG-TransPoRD (http://www.ghg-transpord.eu). The development of the GHG reduction strategy of transport consisted of five main steps undertaken by GHG-TransPoRD and explained in the following sections of this paper:

- Analysis of R&D funding and the innovation systems in all transport modes and for alternative fuels.
- Scoping of GHG reduction measures and technical reduction potentials.
- Techno-economic assessment of cost of GHG reduction measures.
- Stepwise scenario building and model-based assessment of scenarios and their GHG reduction pathways.
- Synthesis and conclusions on suitable GHG reduction strategy for transport.

First it is important to understand the status quo i.e. today's structure of GHG emissions of the transport sector in Europe (see Fig. 1). On the left hand side the distribution of CO_2 emissions for transport originating in EU27 is presented. This includes international bunkers for planes and ships leaving Europe, which then can be named the comprehensive figure. Looking at the comprehensive numbers it is obvious that in particular three modes must contribute to the significant GHG reductions: road, air and maritime shipping. Together these modes account for 96% of all EU transport GHG emissions stemming from transport activities.

On the right hand side, only the domestic transport emissions are presented, i.e. those GHG emissions stemming from transport activities within European countries (see Fig. 1 right hand side). Domestic road transport accounts for 94% of EU27 domestic emissions, which is roughly split into one third stemming from road freight transport (29% of total domestic) and two thirds coming from road passenger transport (65% of total domestic). This analysis of status quo reveals that priorities for GHG mitigation of transport should have the following order: (1) passenger road transport, (2) freight road transport, and (3) maritime and air transport. Concerning the latter it should be mentioned that these two modes over the last years, except the crises years 2008/2009, revealed by far the highest growth rates of transport demand and thus emissions.

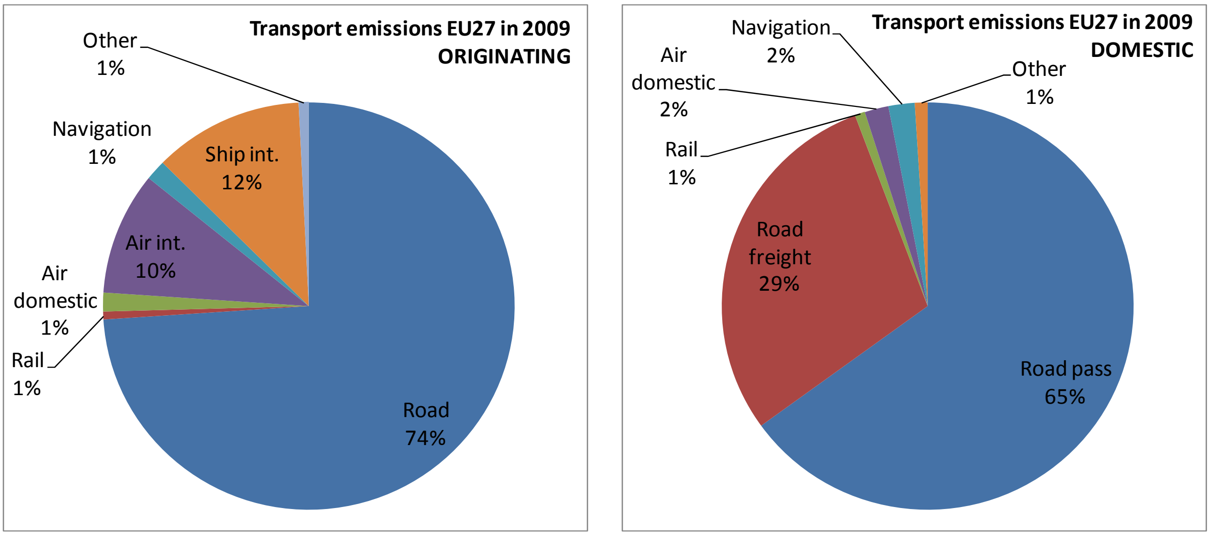

Fig. 1. Structure of GHG emissions of transport in EU27 in 2009 (Schade/Krail 2012 using own estimates and EEA 2011)

2. Analysis of R&D funding and the innovation systems of the transport modes.

Three different approaches have been combined by GHG-TransPoRD for the analysis of how innovations are emerging in the transport sector and how well positioned would be the European transport industry to develop GHG reduction technologies: (1) a quantitative assessment of R&D investments; (2) the analysis of patents; and (3) the qualitative description of the innovation system transport (ISyT). Each of these activities would be worth a paper on its own (see also Leduc et al. 2010, Wiesenthal et al. 2012). This section provides a summary of findings to show the strength of the European transport industry in terms of global R&D and innovation efforts.

Table 1 reveals the strength of the European R&D in the transport sector. The transport sector is the largest industrial R&D investor in the EU. In terms of global sales the share of European transport industry accounted in 2008 for roughly one third 774 €bn (34.2%). However, 40.3 €bn spent on R&D represents more than two fifth (42.4%) of global transport R&D by EU transport industry. So, the EU industry spends over-proportional on R&D compared to other world regions. The main other innovative actors in the past have been companies with headquarters in Japan and the USA (Leduc et al. 2010). In recent years significant R&D capacity in the automotive sector has been built-up in China, and this trend is expected to be continued (Oliver Wyman 2012).

Table 1. R&D investments, sales and total number of employees related to the 'Transport' sector (2008) (Source: EU Scoreboard 2009, European Commission DG RTD, 2009)

	R&D investment (€bn)		**Sales (€bn)**		**Number of employees (million)**	
	World	EU27	World	EU27	World	EU27
Automotive manufacturers	53.0	20.9	1,213	423	2.76	1.26
Automotive suppliers	19.6	9.5	437	156	2.33	0.98
Commercial vehicles and trucks	6.9	2.4	233	66	0.62	0.22
Aerospace & defence	15.6	7.5	379	129	1.74	0.55
'Transport' sector	95.1	40.3	2,262	774	7.50	3.00
All industries	431.0	130.0	13,897	5,712	45.10	21.00

Herewithin, research efforts of the automotive industry are clearly dominating, followed by those of the aviation sector. R&D investments of the automotive sector have been further disaggregated into road passenger and road freight transport and supplier components. We found significantly higher levels of R&D investment volumes and a higher R&D intensity of car manufacturers compared to manufacturers of commercial vehicles. This can be explained by the very distinct nature of road passenger and road freight transport. In road freight transport, the high competition means that transport companies focus largely on reducing their costs. Given the significant share of fuel costs out of the total operating cost for commercial vehicles, fuel efficiency is an important purchase criterion. Nevertheless, transport companies were following a strict economic calculus when buying new trucks and in the past periods of low oil prices they have not been ready to pay for 'innovative technologies' as such. The situation is different in cars, where consumers' choice is influenced by a variety of factors. Cars are more exposed to a 'differentiation and branding pressure', and innovative technologies can be one selling factor.

R&D investments in rail and maritime are more limited in 2008, comparing the absolute values with road and air. However, when setting the R&D investments in relation to the net sales of the sectors – i.e. estimating the R&D intensity – this heterogeneity becomes less pronounced. In 2008, R&D intensities in the road sector are around 5% (passenger cars: 5.3% and commercial vehicles: 3.5%; suppliers: 6%), while aviation (civil aeronautics) shows significantly higher (7.8%) and rail (3.9%) and waterborne (3.2%) slightly lower values.

Industrial R&D investments have been highly concentrated in a few players in 2008, with 15 companies accounting for 80% of the total transport-related R&D investments. EU focused patent analysis carried out for hydrogen fuel cell technology, biofuels, hybrid and electric vehicles enable to identify leading countries and companies for such technologies. E.g. patenting technologies relevant for hybrid and electric vehicles quadrupled for the period 2006 to 2009 compared to previous periods, with Germany and France taking the lead in EU (left hand side Fig. 2) as well as German and French companies (year 2007 only, right hand side Fig. 2).

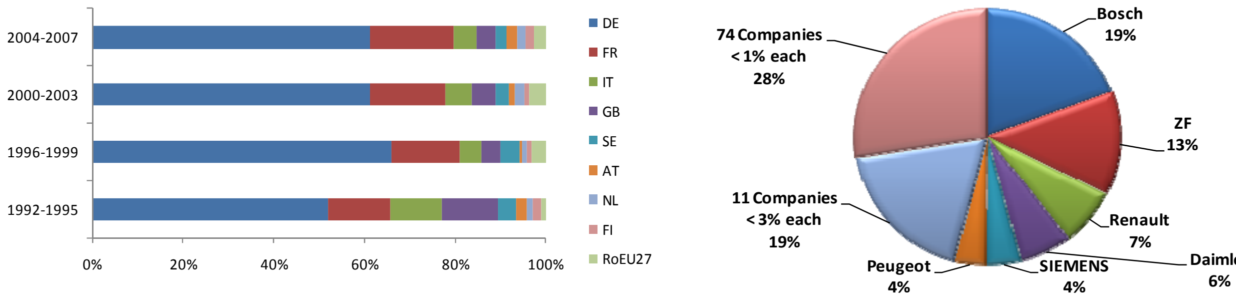

Fig. 2. Example of patent analysis for hybrid and electric vehicles (Leduc et al. 2011 after Fraunhofer ISI)

The concentration of R&D investments, and too lesser extent of patenting activity, can be explained by the market structure of the transport industry, which is mainly oligopolistic competition, and the fact that most of the technological development comes from inside the industry rather than being purchased (as is the case e.g. in the energy sector). However, this picture changes for alternative fuels and new technologies other than conventional internal combustion engines. Here, specialised niche providers have entered the market as well as major industries from non-transport sectors such as electric utilities. Often, new coalitions between established car manufacturers and component suppliers and these newcomers emerged, leading to a relatively rapid sharing of the new knowledge and therefore accelerating innovation within the sector in a vertical way ('supplier path').

3. Scoping of GHG reduction measures and technical reduction potentials.

The first activity to quantify GHG reduction potentials of the different modes and due to alternative fuels consisted of three steps to assess the GHG reduction potentials of individual measures by mode:

(1) A so called **common energy framework** was developed forecasting a reference scenario of energy demand by mode and by fuel type until 2050. Any GHG reduction potential of a single measure was assessed against this energy framework. The energy framework used inputs from European projects (iTREN-2030, ADAM) and tools (TREMOVE, Ex-TREMIS database). The objective of the framework was to obtain a transport energy demand scenario until 2050 that can be differentiated by modes, fuel types and regions as these categories were needed for the assessment of the different measures.
(2) A scoping exercise generated **long lists of potential measures** and their reduction potentials. Measures included technologies (e.g. light-weight construction, solar panels on vehicle roofs, exhaust heat recuperation, sky-sails, etc.) and national or urban policies (e.g. fuel taxation, urban cordon charging, etc.).
(3) Based on an initial assessment of the long lists of each mode **short lists of promising measures** are developed that seem effective and feasible to provide GHG reductions either until 2020 or until 2050. For these short lists the technical potential for GHG reductions by mode was estimated in detail using the common energy framework. Potential measure impacts were calculated in both relative and absolute potentials with regard to quantities of the energy framework. Further, information on practical, technical or political feasibility of a measure was collected.

The measures were classified by four broad categories of how they are reducing GHG emissions (ASIF approach), which supports a decomposition analysis of major sources of GHG reductions:

- **A**ctivity reduction: means that the measure would reduce transport demand. Usually these are valid for demand management measures (i.e. transport policy).
- Modal **s**hift: means that a measure would affect the modal shift such that low carbon modes increase their modal share. Usually hold for demand management measures (i.e. transport policy and infrastructure policy).
- Energy **i**ntensity: means that measure improves energy efficiency: Usually valid for technical measures in vehicles (e.g. engine efficiency, rolling resistance).
- Carbon intensity of **f**uels: means that a measure reduces the carbon emissions per unit of fuel consumed. Usually that would mean to use alternative fuels i.e. non-fossil or low carbon fossil (e.g. biofuels, CNG).

The elaborated shortlists contained 19 bundles developed from more than 60 measures concerning road technologies differentiated into car and truck measures, 26 measures related to urban and (national) road policies, 11 air measures, 11 rail measures and 10 shipping measures related to the four categories of the ASIF approach. Based on these short lists that largely neglect the interaction between different measures the medium and long-term **theoretical reduction potentials** by mode against the reference of the energy framework have been estimated. These represent maximum potentials and the realizable reductions are expected to be smaller e.g. taking into account costs, barriers and interactions between measures. Such realizable potentials were later identified by the scenario assessment with the models (see section 5). The results of the analysis of single measures are summarized in Table 2. These figures constitute the highest potentials compared with the economic potentials and the potentials that finally were estimated by our scenario analysis.

Table 2. Theoretical technical reduction potentials by mode based on aggregation of potentials of single measures, %-relative reduction to energy framework (Source: Akkermans et al. 2010)

Mode	**Type of measures**	**2020**	**2050**
Road	Technical cars*	-40 to -45%	-60 to -68%
	Technical trucks	-30 to -36%	-57 to -63%
	Urban measures**	-43%	-70%
	National policies***	-40%	-70%
Rail	Technology non-urban traffic	-10%	-42%
	Technology urban traffic	-8%	-55%
Air	Technology & policy	-15%	-41%
Shipping	Technology & policy	-5%	-20 to -25%
Biofuels	Technology****	-20%	n.a.

* Potentials are calculated using the reference energy mix for electricity. Potentials can be higher if electricity would be produced carbon free, as then upstream emissions of electric vehicles would become zero.

** Taking into account most relevant and compatible urban measures.

*** Assuming reasonable combinations of national policies.

**** Not considering the impacts of land use changes. The economically realizable potential for reductions by use of biofuels is significantly smaller than the theoretical technical potential. And it strongly depends on external factors like the price of fossil fuels.

4. Techno-economic assessment of cost of GHG reduction measures.

The previous assessment step did not consider the cost of each measure. To consider the cost to assess GHG reduction potentials is relevant in particular for the technological measures as both they have to compete with each other and vehicle brands as well as modes are in competition with other vehicle manufacturers and other modes, respectively. Looking at the time horizon 2020, 2030 and 2050 costs of technologies will not remain static. Depending on the innovation process and the production numbers the cost will reduce over time due to learning-by-searching (e.g. effect of R&D investment), learning-by-doing (e.g. effect of accumulated production and sales) and/or economies of scale (i.e. effect of mass production at industrial scale).

The ideal approach to project cost trajectories for new technologies in dependency from R&D and sales would be implemented by applying learning curves. In particular the two factor learning curve seems suitable in which one factor would constitute an R&D related parameter (e.g. R&D spending, patents) and the other factor a production or sales related parameter. Only for very few technologies sufficient data or studies were available to carry out such cost estimations. In much more cases it was possible to derive a one-factor learning curve only with production or sales driving down the cost. In other cases, we could only identify cost assessment studies providing cost projections for one or a few technologies or had to derive plausible cost pathways from roadmaps. In particular for road transport technologies and for biofuels it was possible to implement learning curve models in the ASTRA model providing the vehicle fleet forecast and the POLES/BioPol model. Typical learning rates identified for young technologies lie in the range of between 10% and 25%, while for mature technologies cost improvements occur at slower speeds with between 3% and 6% (see Table 3). These orders of magnitude could also be confirmed for the analysed transport technologies, with some of the alternative engine technologies being at the lower end of the range (e.g. hybrid vehicles and pure electric vehicles).

Table 3. Comparison of learning rates of young and mature technologies (Source: Schade et al. 2011 building on Kahouli-Brahmi 2008)

Level of innovation	learning-by-doing rate	learning-by-searching rate
Young technology	15-25%	10-15%
Mature technology	4% in average	3-6%

5. Stepwise scenario building and model-based assessment of scenarios and their GHG reduction pathways.

The analyses undertaken in GHG-TransPoRD had to deal with complex interacting systems. Not only that the different transport modes should not be analysed separately as competition and modal-shift always need to be considered. Also the interactions and feedbacks of transport with the energy system, with the drivers of the economic system, the demographic dynamics and the global trade have to be taken into account. Hence, GHG-TransPoRD decided for two approaches to tackle the complexity: first, a set of four models were applied, partially integrated with each other as the two core models of the analyses, ASTRA and POLES, and partially sequential as the case for TREMOVE and MARS models that received inputs from the former two models.

- ASTRA (Assessment of Transport Strategies). A System Dynamics model applied for transport-economic integrated assessment of policy strategies of the EU27+2.
- POLES (Prospective Outlook for the Long term Energy System). A System Dynamics global sectoral simulation model for the development of global and European energy scenarios.
- TREMOVE. A policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector of EU27+4 running until 2030, only.
- MARS. An urban dynamic Land Use and Transport Integrated (LUTI) model (the version developed for Leeds has been used).

With this suite the global, European, national and urban spatial levels were covered as well as the transport, energy and economic systems. The second approach to deal with complexity concerned to involve the relevant stakeholders and academics. The models also provide a tool for structured thinking and rethinking intermediate results of scenario analyses. Such results were presented to and discussed with stakeholders, whose feedback was then taken into account for modified scenario simulations, let it be their propositions of further GHG reduction measures to be considered, their comments and support to the cost assessments, their proposal which measures could be combined into a policy package and which measure combinations might be contradictory as well as their criticism on our initial scenarios and the proposals to improve the policy packages of these scenarios.

The concept of the definition of scenarios for the model-based analysis was threefold: (1) a stepwise approach was chosen commencing with low ambition scenarios and increasing the ambition of GHG reduction with each new round of scenarios, (2) the structure of scenarios should allow to differentiate between the big drivers of impacts, i.e. technology, policy and behavioural changes, and (3) initial scenarios started with a low number of single measures integrated into their policy package and to generate further scenarios gradually further measures are added to the policy packages. Thus three major levels of scenarios can be distinguished: (A) technology scenarios, (B) policy scenarios on top of (A), and ambitious regulatory scenarios on top of (B).

The technology scenarios either focussing on efficiency of conventional cars or on alternative technologies would deliver about -34% to 37% percentage point reductions of GHG emissions until 2050. Adding policies in the policy scenarios, in particular pricing policies to foster behavioural change, would roughly add another -10% reduction. But only if further ambitious regulations were added, i.e. the phase out of conventional fossil fuel cars around 2035 and a modal-shift of about 4% percentage points away from road freight to rail and shipping the most ambitious of the analysed scenarios called AMB_REG scenario (ambitious regulation scenario) could deliver the -60% reductions of GHG emissions of transport by 2050. Concerning the energy system all scenarios considered a very significant shift towards the use of renewables such that in 2050 electricity in EU27 would be generated by 80% from renewable energy sources.

The story of the AMB_REG scenario reads as follows for passenger transport. Demand in terms of pkm increases by 36% until 2050 compared to 2010 (see Fig. 3). GHG emissions continuously decline from 2014 until 2050. Until about 2035 the decline of GHG emissions largely comes from reductions of intensity of energy (i.e. energy efficiency improvements), but it seems that around 2035 a plateau is achieved beyond which further efficiency improvements are hard to implement. Until that point is reached in 2035 the carbon intensity of fuels could be moderately reduced by about 15%. However, after 2035 the regulatory measures (in particular the ban of conventional fossil fuel cars) enable to sharply reduce carbon intensity until 2050 and thus continuously reduce GHG emissions of passenger transport. This means on the passenger side the GHG reductions result from combined improvement of energy intensity and carbon intensity. For freight transport the main driver of reductions is the decrease of intensity of energy use, while reduction of carbon intensity plays a limited role.

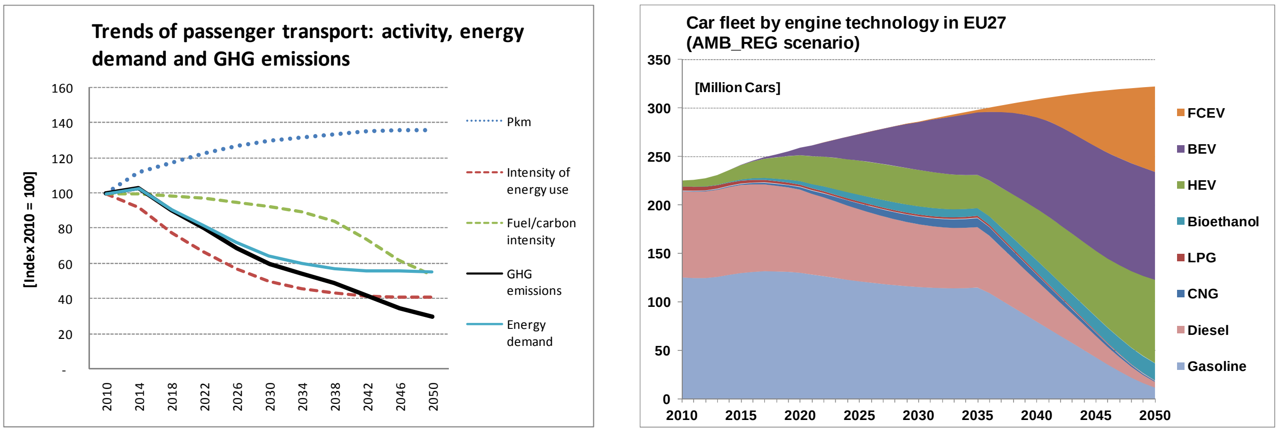

Fig. 3. Ambitious regulation scenario (AMB_REG): ASIF decomposition of passenger transport (left hand side) and vehicle fleet structure (right hand side, ASTRA model), FCEV: fuel cell electric vehicle, BEV: battery electric vehicle, HEV: hybrid electric vehicle, LPG: liquefied petroleum gas, CNG: compressed natural gas/biogas (Fiorello et al. 2012)

Turning to discuss the fuel use in the AMB_REG scenario. In 2010 fossil fuels dominate, including only a minor share of blended biofuels. The strong influence of energy efficiency improvements sharply reduced the demand of fossil fuels until 2050. In parallel the fraction of biofuels consumed increases, though a maximum amount of biofuel use of 50 mtoe, largely for air transport, is observed between 2030 and 2040. Afterwards biofuel demand declines to 40 mtoe. In 2050 about 40% of air energy demand would be supplied by biokerosene. Electricity demand of transport reveals the highest growth rates between 2020 and 2040, while hydrogen use starts to grow strongly towards 2040 and 2050. In 2030 biogas is completely replacing fossil natural gas, though due to limited uptake of gas vehicles in the fleet the demand side constrains an increased use of biogas.

Road transport, and in particular car transport, has to deliver the largest absolute reductions of energy demand and GHG emissions. With more than 90% of domestic transport GHG emissions accounting for road transport this is obvious, as well. However, as road transport, and in particular cars and light duty vehicles, disposes of the largest potentials to both reduce energy demand and to switch to low-carbon or carbon-free energy sources these two findings of GHG-TransPoRD are consistent and fit together. Finally, it should be noted that the AMB_REG scenario achieving the -60% reduction target of the EU27 poses an abatement cost on transport users and corresponding a minor reduction of GDP but on the other hand it reveals a negative abatement cost for the society, or in other words an abatement benefit.

6. Synthesis on suitable GHG reduction strategy for transport.

The Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA 2011) both emphasize the requirement for a peak of GHG emissions during the current decade until 2020. This means early reductions of GHG emissions from European transport will be preferential compared with later reductions. In the next two decades only road mode will be able to contribute both significant and early GHG reductions. The other modes will mainly rely on operational measures to reduce their GHG emissions during that period due to slow fleet turnover. This can be identified by the tested maximum efficiency scenario (Max_E&M), which was designed by GHG-TransPoRD to implement the most effective efficiency technology in a fastest and market-driven way, in what concerns technology choice. Until 2020 it generates close to 46% stronger reductions than a pure electric vehicle (EV) scenario, 60% stronger reductions than the hydrogen fuel-cell (HFC) scenario, and 24% more reductions than the combined EV+HFC scenario. The driver of the substantial GHG emission reduction is massive introduction of efficiency technology of road vehicles to be either implemented due to the climate mitigation awareness of the automotive industry or by setting of strict CO_2 emission standards through European and global legislation. To ensure achieving the target, policy-makers should choose the second option.

However, our analysis revealed that around 2035 conventional fossil fuel vehicles need to be banned from the market completely to achieve the -60% reductions until 2050. Only with such a policy the alternative technologies like EVs, HFC and PHEV would diffuse into the market fast enough, and according to our analysis doubts must be raised if this would happen without such a ban. But this means, over the next 10 to 15 years investments into efficiency technologies of conventional fossil fuel cars need to be substantial, despite these vehicles could only be sold some 20 years longer. Of course, some innovations like light-weight design and improved aerodynamics can be implemented into any car independent from its engine technology. Other technologies would constitute transitory techniques that bridge to the development of alternative fuel vehicles, while there would probably also be improvements of the combustion engines, which would become obsolete after conventional cars have been phased-out from the market. The challenge to identify those technologies that improve efficiency most effective and could as well be applied longer into the future has to be solved by the automotive industry, in particular after 2020.

The A(S)IF structure of the AMB_REG scenario demonstrates that looking at the full period until 2050 during the first two decades the reduction of energy intensity (in other words improvement of energy efficiency) constitutes the dominating source for reductions of GHG emissions, while between 2030 and 2050 the reduction of carbon intensity, in particular through electrification of transport and the parallel transition of electricity production to a renewable based system, will be the dominating source of GHG reductions. **In short, first capture fast the energy efficiency potentials and than focus on the carbon-free energy potentials.**

However, this should not be understood in a way that alternative fuel vehicles should not be developed and brought to the market in the first two decades. But it has to be considered that even in the automotive industry, being the sector with the biggest R&D budgets in Europe, these budgets are limited and investments need to be prioritised. Then priority at least in this decade should be given to efficiency improvements, while from the climate mitigation point of view alternative fuel vehicles (in particular EVs and HFCs) could receive a lower priority. This should by no means lead to a halt of their development, but rather to a shift of their massive introduction to a few years later as this seems to be reasonable, at least under a constrained investment budget. Nevertheless, it must be ensured that these vehicles get onto their learning curve, e.g. by selling them only to early adopter markets, which in the case of EVs would be fleet operators in certain sectors, instead of intending to sell them to a mass market from the beginning of market diffusion. Such specific markets should also be considered when designing policies to foster alternative fuel vehicles.

Efficiency improvements of road transport in climate mitigation scenarios were much faster than increase of energy prices, given the moderate increases estimated for the scenarios. Thus in all scenarios that do not counterbalance efficiency gains by increasing other transport cost (e.g. fuel duties, road tolls, urban road charges) very strong rebound effects have been found leading to a strong modal-shift towards road transport and away from the more efficient rail mode and public transport. Such a rebound effect may cannibalise a significant part of the GHG savings, such that counterbalancing measures need to be taken. The ambitious scenario (AMB_TP and AMB_REG) both increase fuel duties and introduce urban charges such that they generated higher GHG emission reductions than the scenarios without such measures and a pure focus on efficiency and alternative technologies. Increasing road transport taxes and tolls brings about the co-benefit that government revenues from the transport sector are stabilised, while pure efficiency and alternative technology scenarios deteriorate the government revenues from the transport sector, which would in turn be required to fund infrastructure and operation within the transport sector e.g. for railway infrastructure and public transport.

7. Conclusions

The most important conclusion to draw from the integrated analysis is that the -60% GHG reduction target for the transport sector is feasible to be achieved by 2050 compared to EU27 transport related emissions of 1990. Of course, the target is ambitious such that most of the scenarios and policy packages tested by GHG-TransPoRD failed to deliver the required reductions. However, the scenario analysis concluded that scenarios combining:

- fast development of efficiency technology,
- alternative engine technologies able to build their energy supply on renewable electricity,
- ambitious policy-making to counterbalance rebound effects and maintain financial stability of government transport revenues,
- ambitious regulation phasing out fossil fuel cars around 2035 together with a moderate modal-shift from road towards more energy efficient modes, and
- adaptation of the electricity system to become largely renewable based

will enable to achieve these targets. Such a scenario was developed and tested in the AMB_REG scenario by GHG-TransPoRD. Sensitivity analyses confirm that with higher oil prices even more stringent GHG reduction targets could be achieved. The largest reductions have to come from road transport, while in the medium term the slow fleet turnover of shipping and air mainly enables reductions through operational measures. For rail and waterway transport it would be more relevant to be put in a position of being able to carry a larger share of demand than to focus only on technological or organisational improvements within the mode.

Building on the scenario analyses and the understanding of technological potentials, economic constraints and feedbacks between modes and measures the GHG-TransPoRD project proposes GHG reduction targets for transport in EU27 as presented in Table 4. The targets are defined by mode as well as for the total transport sector. The table contains in the upper part reduction targets referring to a GHG emissions base calculated for the year 2010, as the measures implemented and tested in GHG-TransPoRD commence in 2011. The lowest row then presents proposed reduction targets for total EU27 transport in comparison with 1990, which is the base year usually applied in climate policy. It should be pointed out that Table 4 builds on absolute values of GHG emissions such that targets e.g. for rail transport and road freight transport consider modal-shift from road to rail as it was observed in the scenarios.

Table 4. GHG reduction targets by mode for EU27 compared to emissions of 2010 (top) and 1990 (bottom). Proposal by GHG-TransPoRD (Source: Schade/Krail 2012)

		2020	2030	2050
Road	Passenger	-20% to -30%	-40% to -55%	-70% to -85%
	Freight	-10% to -20%	-30% to -45%	-40% to -60%
Air		0% to -5%	-10% to -20%	-40% to -55%
Ship		(+15% to 0%)	(+30% to 0%)	(+50% to -20%)
Rail		+10% to -10%	0% to -20%	-10% to -35%
Transport	(excl. ship)	-10% to -20%	-40% to -50%	-70% to -90%
Transport	vs. 1990	+10% to +5%	-20% to -30%	-60% to -70%

The transport strategy identified by GHG-TransPoRD provides both: research and policy recommendations. R&D recommendations include to support R&D for biofuels, in particular for air transport, and R&D for cross-modal transport. The policy strategy suggests in early years a focus on road transport (i.e. efficiency of internal combustion engines and of vehicle structures like aerodynamics and lightweight construction) and in medium-term time horizon on alternative energy technologies (i.e. electricity and hydrogen both produced from renewable electricity). Additionally the transport strategy must include pricing measures and ambitious regulations (e.g. ban of selling conventional fossil fuel cars after 2035) also changing behaviour.

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