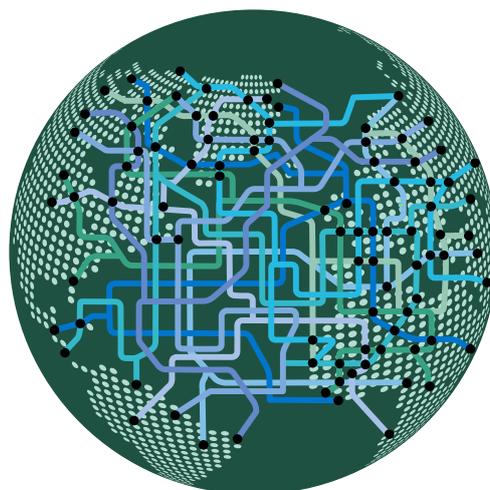


GHG-TransPoRD

Reducing greenhouse-gas emissions of transport beyond 2020: linking R&D, transport policies and reduction targets



Aligned R&D and transport policy to meet EU GHG reduction targets

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Table of Contents

Executive Summary	7
1 Introduction	12
2 Transport policy framework.....	14
2.1 European transport policy framework.....	14
2.2 Global framework: uncertain developments	15
3 Innovations in the transport industry.....	16
3.1 Transport R&D and innovation system.....	16
3.2 The global automotive industry	21
4 Measures for GHG reductions in transport.....	23
4.1 GHG reduction potentials of single measures	24
4.2 Cost assessment and technological learning in transport industry.....	26
5 Holistic scenario tests by GHG-TransPoRD	29
5.1 Modelling tools and definition of scenarios.....	29
5.2 Scenario results.....	34
6 Stakeholder involvement in GHG-TransPoRD.....	39
7 Conclusions.....	40
8 Recommendations	43
9 References.....	48

List of tables

Table 1:	GHG reduction targets by mode for EU27 compared to emissions of 2010 and 1990. Proposal by GHG-TransPoRD	11
Table 2:	Theoretical technical reduction potentials by mode based on aggregation of potentials of single measures	26
Table 3:	Empirical learning rates of selected transport technologies.....	28
Table 4:	Comparison of learning rates of young and mature technologies.....	28
Table 5:	Summary of key trends of endogenous variables in the reference scenario	31
Table 6:	Summary of scenarios tested by GHG-TransPoRD	33
Table 7:	Transport CO ₂ emissions (Mt) in the GHG-TransPoRD scenarios	34
Table 8:	Impact of policy measures on reference transport CO ₂ emissions in the Leeds case.....	38
Table 9:	GHG reduction targets by mode for EU27 compared to emissions of 2010 and 1990. Proposal by GHG-TransPoRD	47

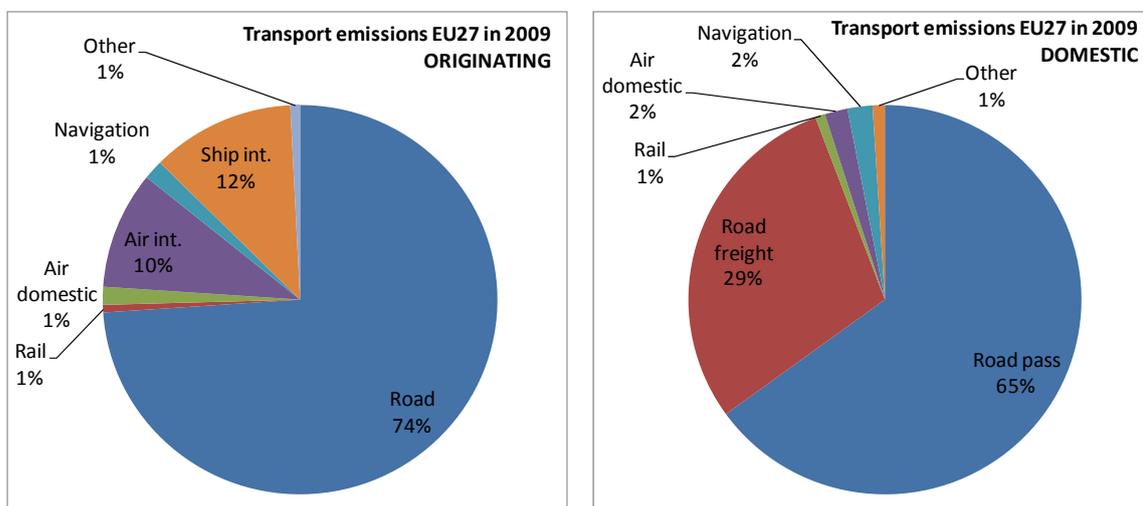
List of figures

Figure 1:	Structure of GHG emissions of transport in EU27 in 2009	7
Figure 2:	Innovation system transport (ISyT) of the global automotive industry	22
Figure 3:	Approach of GHG-TransPoRD to assess GHG reduction potentials of single measures and of policy packages as part of scenarios	23
Figure 4:	Drivers of GHG reductions in AMB_REG scenario in EU27	35
Figure 5:	Car fleet trend in the AMB_REG scenario in EU27	36
Figure 6:	Fuel consumption including blending with biofuels – AMB_REG scenario	37

Executive Summary

The basic structure of GHG emissions of the transport sector in Europe is shown in Figure 1. On the left hand side the distribution of CO₂ emissions for transport originating in EU27 is presented, i.e. including international bunkers for planes and ships leaving Europe, which is the comprehensive figure. On the right hand side, only the domestic transport emissions are presented, i.e. emitted by transport activities within European countries. 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 transport GHG emissions.

Additionally the right hand side of Figure 1 presents the structure of domestic GHG emissions. Road transport there accounts for 94% of EU27 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 shows that priorities for GHG mitigation of transport 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 over the last years, except the crises years 2008/2009, revealed by far the highest growth rates of transport demand and thus emissions.



Source: EEA (2011), Fraunhofer-ISI estimates based on ASTRA model

Figure 1: Structure of GHG emissions of transport in EU27 in 2009

GHG-TransPoRD - Reducing greenhouse-gas emissions of transport beyond 2020: linking R&D, transport policies and reduction targets – is a project funded by the European Commission 7th Research Framework Programme (FP7). It is coordinated by Fraunhofer-ISI, Germany, and is undertaken in collaboration with four European partners, TRT from Italy, JRC-IPTS from Spain, TML from Belgium and ITS Leeds from the UK.

The GHG-TransPoRD project has developed an integrated European transport sector strategy that links R&D efforts with other transport policies and technological measures to achieve substantial greenhouse gas (GHG) emission reductions in transport that are in line with the overall GHG reduction targets of the EU. As part of this strategy, the project is proposing feasible and realistic GHG reduction targets for transport as a whole as well as for each transport mode for 2020 and 2050. These reduction targets are based on quantitative analyses building on three main working steps: (1) quantification of GHG reduction potentials of single measures, (2) cost assessment of single measures, and (3) bundling of measures into policy packages and testing these as part of scenarios with a model-based integrated assessment approach.

In parallel to the model-based analysis the innovation system of the transport sector (ISyT) was analysed and the R&D strategies and efforts of the different modes as well as for alternative fuels were investigated. All in all, our innovation system analysis finds that EU-based transport-related companies are the largest R&D investors of the European society. In 2008 their research effort amounted to 40 bn€. Significant parts of their R&D investments are already dedicated to the reduction of GHG emissions throughout all modes, often influenced by policies that provided regulations which directly or indirectly steered the direction of industrial research. Public research complements industrial research – it is more pronounced in aviation, rail and maritime than in road transport. Within road transport public support concentrates on technologies that are promising long-term options, but which receive less industrial attention given their comparably lower level of maturity. With the growing importance of non-conventional technologies and fuels, a number of niche providers enter the transport market, which otherwise is largely dominated by very few players. Their knowledge is often spread rapidly in a vertical way through coalitions between newcomers and established transport technology manufacturers, while knowledge diffusion among competing manufacturers of e.g. cars remains limited.

The most important conclusion to draw from the model-based analysis is that the transport sector target of at least 60% GHG emission reduction by 2050 compared with 1990 can be achieved. Of course, this target is ambitious such that most of the scenarios and policy packages tested by GHG-TransPoRD failed to deliver the required re-

ductions. 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 the GHG targets.

The concept of the definition of scenarios for the model-based analysis was twofold: (1) the structure of scenarios should allow to differentiate between the big drivers of impacts, i.e. technology, policy and behavioural changes, and (2) 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 into 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 ambitious regulatory scenario (called AMB_REG scenario) could deliver the -60% reductions. Concerning the energy system all scenarios included a shift towards the use of renewables such that in 2050 electricity in EU27 would be produced by 80% from renewables.

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. 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 is moderately reduced by about 15%. However, after 2035 the regulatory measures 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.

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 becomes larger, though a maximum amount of biofuels of 50 mtoe used is observed between 2030 and 2040. Afterwards biofuel demand declines to 40 mtoe. In 2050 about 40% of air energy demand is 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 again 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 for 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.

Building on the scenario calculations and in particular on the AMB_REG scenario the GHG-TransPoRD project proposes the GHG reduction targets for transport as presented in Table 1. 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 1 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.

Table 1: GHG reduction targets by mode for EU27 compared to emissions of 2010 and 1990. Proposal by GHG-TransPoRD

		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%
EU27 target against 1990				
Transport	vs. 1990	+10% to +5%	-20% to -30%	-60% to -70%

Source: GHG-TransPoRD

These proposed targets synthesize our analysis on potential R&D strategies of the different modes and the potential impacts of transport policies, implemented following a certain time path of implementation. Choosing the right time path of policy implementation will be very important to avoid investments that crowd out or lock-in into certain technologies and to bring the most effective new technologies into the market. Considering the requirement of private companies for reliability of long-term planning of major investments will play an important role for policy-making to induce these investments.

1 Introduction

Transport currently contributes about 27% of the total EU greenhouse gas (GHG) emissions. In a trend scenario this share is expected to grow due to continued strong growth of transport demand, in particular of freight transport and air passenger transport, and slower efficiency improvements than for other GHG emitting sectors.

Given the overall EU GHG reduction targets of -20% until 2020 compared with the emission levels of 1990, or -30% if an international agreement is achieved, and of -60 to -80% until 2050 (even -95% is debated), it is obvious that in the future (1) the transport sector will have to contribute to GHG emission reductions such that (2) reduction targets for the different transport modes have to be anticipated and (3) aligned research strategies and transport policies have to be developed to efficiently and effectively meet these reduction targets for the medium to long-term.

The GHG-TransPoRD project aimed at developing an integrated European strategy that links R&D efforts with other transport policies and technological measures to achieve substantial greenhouse gas (GHG) emission reductions in transport that are in line with the overall reduction targets of the EU. As part of this strategy, the project proposed GHG reduction targets for transport as a whole as well as for each transport mode for 2020 and 2050. To develop the R&D strategy and the reduction targets, GHG-TransPoRD has undertaken nine steps:

- Analysis of R&D efforts in transport.
- Analysis of innovation system and diffusion of innovations in transport sector.
- Scoping of measures for GHG reductions generating a long list of potential measures.
- Estimating potentials of GHG reductions of these measures and creating a short list of promising measures.
- Assessing the cost development pathways of the GHG reduction measures in a stand-alone approach.
- Developing (initial) scenarios and policy packages for which an integrated assessment of R&D strategies and policy strategies will be performed.
- Performing the scenario analysis with a modal-based approach applying four models. Refining iteratively the scenarios to meet the GHG reduction target of -60% by 2050.
- Developing an assessment scheme to consider the global framework and uncertainties of the scenarios.
- Synthesizing the scenario results into conclusions and recommendations.

The analyses undertaken in GHG-TransPoRD had to deal with complex interacting systems. Not only that the different transport modes can not be analysed separately as competition and modal-shift always need to be considered. Also the interactions 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 case for ASTRA and POLES models, and partially sequential as the case for TREMOVE and MARS models that received inputs from the former two models. With this suite the global, European, national and urban spatial levels were covered as well as the transport, energy and economic systems. Second, as models provide tools for structured thinking and rethinking intermediate results of the GHG-TransPoRD project were presented to and discussed with stakeholders. An important element of GHG-TransPoRD was to take into account the feedback of stakeholders, 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. We are very grateful for all these valuable comments and inputs to our analyses. Of course, the final choices to be taken and the generation of our results presented in this Final Report and our other Deliverables of the project had to be made by the GHG-TransPoRD project team.

This final report is structured into 8 sections following this introduction. Section 2 presents the transport policy framework briefly looking at the European framework, the global framework and uncertainties associated with them. Section 3 describes innovative capacity of the European transport sector and highlights the importance of the global view concerning the transport industry, and in particular the automotive industry. Section 4 presents our analysis of the GHG reductions potentials of the single measures and the cost assessment approach of the promising measures. Section 5 elaborates on the scenario analysis and the quantitative findings concerning feasible transport GHG reduction targets for 2020 and 2050. Section 6 summarizes the stakeholder involvement followed by the conclusions in section 7, recommendations derived from the conclusions in section 8. Finally the references and a glossary are presented.

2 Transport policy framework

2.1 European transport policy framework

Developing transport policies to reduce greenhouse gas emissions (GHG) must be integrated and fitted into the general policy framework of the European Union (EU). This framework is currently shifting from the overall objective of being the most competitive region in the world, as postulated by the Lisbon Strategy in 2000, towards the so-called EU 2020 strategy of 2010. This strategy is more balanced as it mentions sustainability and the social dimension explicitly amongst its three top priorities (European Commission 2010a):

- Smart growth;
- Sustainable growth;
- Inclusive growth.

In particular, the second priority is relevant for GHG-TransPoRD as it incorporates the main theme of the study: to design a resource-efficient, green and competitive transport system as part of the overall economy. Looking at the seven flagship initiatives of the EU 2020 strategy, again one of them can be highlighted as being most relevant for our analyses, i.e. Resource-efficient Europe, as this initiative proposes decoupling economic growth from resource use and modernising the transport sector to support the shift of the EU economy towards a low carbon economy (European Commission 2010a).

The update of the global European policy strategy for the next decade also had to consider the need to recover from the financial and economic crisis of the years 2008/2009. Also there the link with transport policy can be observed, e.g. as part of the European Economic Recovery Plan, the Green Cars Initiative was established, which provided EU R&D funding to support the development of efficient cars and electromobility.

In March 2011 the new Transport White Paper *Roadmap to a Single European Transport Area – Towards a Competitive and Resource-efficient Transport System* (European Commission 2011a) was published. As a very important element, this new White Paper builds on the European objective of reducing greenhouse gas emissions (GHG) by -80 to -95% until 2050 compared to 1990 (European Commission 2011b). Transport in the New White Paper is expected to contribute to these GHG reductions by decreasing its GHG by at least -60% compared to 1990, while maintaining a competitive and resource-efficient transport system.

2.2 Global framework: uncertain developments

On the global level there are many developments that may reveal a great diversity of how they could potentially develop in the future raising the question of uncertainty in any prospective project. Not all of these developments will cause a significant impact on transport. Kiel et al. (2012) have identified 15 major challenges that will influence mobility until 2030, amongst others scarcity of oil and other resources, public debt, inequality, ageing, migration, urbanisation or climate change. For several of them the impact on transport can be somehow assessed. Others depend on policy-making like public debt or migration thus being important sources for uncertainty. Hence, GHG-TransPoRD tried to assess uncertainties associated with the results of our scenarios.

The biggest source of uncertainty lies in the definition of the Reference Scenario, in particular if a study looks into a long-term future. As one example, it makes a big difference over a period of 40 years if an average annual GDP growth rate is 2% or 1.5% over such a time horizon. Therefore the climate science community has developed a number of shared socio-economic pathways (SSP) to describe different Reference Scenarios for climate policy studies (Arnell,/Kram et al. 2011). We can ask the following questions to classify our Reference Scenario into one of these five SSP categories:

- Will there be an increased or decreased level of globalisation? How will this impact upon the development of technology (given that technology development is now globalised)? How will this impact upon levels of population change, both in the EU and in the rest of the world?
- What will be the level of growth in GDP for Europe? Will this growth be spread evenly across the whole of Europe or be concentrated in certain regions?
- What changes in social/cultural attitudes might take place between now and 2050? Such changes are liable to have an important impact upon policy scenarios for reducing GHG emissions.

The Reference Scenario of GHG-TransPoRD is taken from PRIMES and ASTRA models (see section 5). We classify it as SSP5 type of reference scenario, which describes *“a world with large challenges to mitigation but reasonably well equipped to adapt, could be one in which, in the absence of climate policies, energy demand is high and most of this demand is met with carbon-based fuels. Investments in alternative energy technologies are low, and there are few readily available options for mitigation. Nonetheless, economic development is relatively rapid and itself is driven by high investments in human capital. Improved human capital also produces a more equitable distribution of resources, stronger institutions, and slower population growth, leading to a less vulnerable world better able to adapt to climate impacts”* (Arnell, Kram et al. 2011).

3 Innovations in the transport industry

In the context of the target of -60% reductions of the GHG emissions as defined by the New Transport White Paper, a key question to be answered is whether the sector's research capacities are up to meet this challenge. This is discussed in the following section, describing the current R&D efforts of the transport sector as well as the source of R&D funding. As the road sector reveals the largest R&D budgets and is capable to provide the largest absolute GHG reductions but is also subject to a global market it is looked at specifically in the second section.

3.1 Transport R&D and innovation system

While the inherent uncertainty in linking R&D efforts with technology improvement makes it difficult to postulate the future level of research needed for successfully offering the technological options required, an analysis of the present transport research capacities is a first step towards answering this question. To this end, GHG-TransPoRD analysed the volume and direction of present research efforts of both industry and public players, supplemented by an analysis of patent applications. This quantitative snapshot is complemented by the qualitative assessment of the innovation system transport (ISyT), which goes beyond the narrow focus of R&D but sketches out the interlinkages between major R&D players, instruments, functions etc. that are relevant for innovation in the transport sector. To this end GHG-TransPoRD sketched out the full analysis of the Innovation System of Transport (ISyT), concentrating the analysis on a modal scope, but providing the recommendation to extend the analysis by three integrative analyses: logistics technologies, passenger and freight transport. This analysis is reported in GHG-TransPoRD Deliverable D1.1 (Leduc et al. 2010).

Concerning the quantitative snapshot it should be pointed out that officially available data did not allow for a comprehensive assessment of R&D efforts in the transport sector. Hence, an assumption-based bottom-up analysis has been applied in order to nevertheless derive some results at the EU-level for industrial and public research efforts. This approach combines information on companies total R&D investments taken from the companies annual reports, as collected and processed in the EU Industrial R&D Investment Scoreboard, with a number of other pieces of information that can be used as an indication of the allocation of total research investment in various technologies. This approach implies that the results are associated with elevated uncertainties and therefore provide a rough indication only. Moreover, as the analysis of industrial R&D efforts concentrates on a limited number of actors (yet, the main ones), the actual figures may be higher. Similarly, lack of data for some EU Member States and the fact that the figures obtained for public R&D investments often do not include neither re-

gional funds nor institutional budgets mean that the results tend to be an underestimation. Finally, the focus of the assessment on the latest year for which most data has been available at the time of preparation of the report – 2008 – implied that the recent dynamics in transport related research, much of which triggered by the economic downturn, have not been fully reflected.

Taking into account the three different approaches combined by GHG-TransPoRD – i.e. the quantitative assessment of R&D investments; the analysis of patents; and the qualitative description of the innovation system transport – and comparing with other scattered pieces of information allows drawing policy-relevant conclusions on transport R&D¹.

1. The transport sector is the largest industrial R&D investor in the EU with an investment volume of around €40 billion in 2008. 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 find 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 and the consequently high price pressures mean 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, the fuel efficiency of new trucks is an important purchase criterion. Nevertheless, transport companies will follow a strict economic calculus when buying new equipment and are not ready to pay for 'innovative technologies' as such. This situation is different in passenger 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, 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. 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.

EU-based transport companies hold a large share in global transport-related R&D investment, followed by companies with headquarters in Japan and the USA. Con-

¹ The results of the WP1 of GHG-TransPoRD reported by Leduc et al. (2010) have been updated in follow-up activities and have been published in Wiesenthal et al. (2012). We refer here to the updated results.

sidering the truly global nature of the transport industry with most of its players acting at world level, however, this geographical allocation is of limited significance.

2. Industrial R&D investments are highly concentrated in a few main players, with 15 companies² accounting for 80% of the total transport-related R&D investments. This 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 emerge, leading to a relatively rapid sharing of the new knowledge and therefore accelerating innovation within the sector in a vertical way ('supplier path'). At the same time, however, the high competition between the major car manufacturers means that horizontal knowledge exchange is limited to those areas where car manufacturers consider collaboration advantageous, such as collaborative research projects under the EU research framework programmes. In aviation, the particular situation of close links between military and civil developments creates an important knowledge transfer, which is very pronounced in this sector.
3. The role of public R&D investments (both from Member States and EU FP7 funds) is very heterogeneous between the different transport modes. While it is comparably low in the automotive sector (<5% of the total) as a whole, which is also due to the fact that the total investments of this sector are by far the largest of all modes, its role is much more pronounced in other modes. Public funds account for around one quarter for aviation, 22% for rail and 35% for maritime. Each mode has particular circumstances that account for this. In aviation EU-wide support is very important due to programmes such as the Clean Sky Joint Technology Initiative and the SESAR Joint Undertaking. The rail industry still has a considerable degree of public ownership of railway systems and operations (e.g. SNCF and Deutsche Bahn). The maritime sector in the EU is limited to mainly specialist products and military production. Military procurement leads to a high level of public R&D for initially military applications.
4. All modes dedicate an important part of their R&D efforts to technologies that reduce emissions of GHG³, taking into account investments *both* from industrial and public funders. For the road sector, this part has been estimated to be around one third (increasing to more than 40% if including also technologies to reduce the emissions of air pollutants). It is also around one third in aviation, but this figure may

² Note that the analysis is undertaken at the level of parent company, not on individual brands.

³ Note that technologies that can reduce GHG emissions are not necessarily being developed for this purpose only but by other than environmental considerations, e.g. to increase the 'joy of driving', and may be (partly) outweighed by more performant cars etc. They are nevertheless allocated to 'GHG emission reduction' for the purpose of the present assessment.

include some R&D focusing on other environmental issues, such as reduction of noise or air pollutant emissions. For rail, the part is more limited (20%), whereas it is higher for maritime transport (almost 50%).

A crucial factor in guiding industrial research into the development of environmental technologies has been public policies via the setting of standards and/or the creation of incentives to foster no- or low-carbon vehicles. These policies are not only a driver for R&D but also create a market demand for innovative products, ensuring companies that their development pays off. Yet, these policies cannot be seen as taken unilaterally by governments; on the contrary, the non-negligible influence of the transport industry on policy making suggests that they are more consensual. Moreover, there are co-benefits for investing in R&D on technologies that reduce GHG emissions such as reduced fuel consumption and thus improved energy security with respect to reducing fossil fuel dependence, which may have been another important driver for allocating efforts to the technologies.

5. For the automotive sector, a further breakdown of research efforts into three technology groups has been performed. From this it becomes obvious that within the GHG emission reduction R&D efforts, and herewithin focusing on engine technologies, the largest focus of industrial research lies on the optimisation of conventional internal combustion engines. Electric vehicles (including hybrids) are the most relevant field of developing non-conventional engine technologies. This is strongly supported by evidence from an analysis of patent applications, which also hint at the rapid increase in the importance given to this technology in recent years. Fuel cell vehicles and biofuels show comparably lower industrial R&D investment. Unlike for electric vehicles with strong dynamics, the patent search indicates for fuel cell technologies a stagnating trend in later years. This can be interpreted as these technologies losing relative importance compared to booming electric vehicles, meaning that there is a possibility of lock-in to electric vehicles, considering also that the major firms or technology alliances are now concentrating on electric vehicles. Nevertheless, there are also synergies between the development of battery electric and fuel cell (electric) vehicles.
6. Public R&D funds follow more or less opposite trends, hence complementing the industrial research efforts. Within the above technologies, they are most elevated for fuel cells, and more limited in the case of EV and conventional engines. This becomes even more pronounced when looking into the relative contribution of public funds: they rise from a mere 2.5% for conventional engines to some 30% for biofuels and 36% for fuel cells. This finding is well supported by innovation theory. In general, technologies that are close-to-market and thus require expensive pilot plants and up-scaling would face larger industrial contribution, while technologies that are further from market are mainly publicly financed as industry would not want to take the risk. Having in mind that hydrogen-fuelled fuel cell vehicles (FCV) are both not likely to enter the market in large quantities soon and have been researched more intense in the first years of the last decade already, the limited corporate R&D investments dedicated to them in 2008 do not come as a surprise. Nevertheless, FCV are seen as a strategic long term option also over battery vehi-

cles for longer range vehicles (see Thomas, 2009; Campanari et al., 2009; Offer et al., 2010), which explains that industry also keeps investing in them, but with a lower urgency.⁴

7. The economic downturn has largely affected the transport sector in 2009. Net sales of the sample of EU-based manufacturers of passenger cars have decreased by around 10% compared to 2008, and by around 33% for manufacturers of commercial vehicles. Also R&D investments have decreased, but at a considerably slower pace than the turnover. Compared to 2008, R&D investments fell by some 11% for passenger car manufacturers and ca. 7% for truck manufacturers. This implies a constant R&D intensity for passenger car manufacturers and an increase for road freight vehicle manufacturers. At the same time, there are indications of R&D investments getting more focused on technologies with a shorter expected return on investment. Also the importance of research dedicated towards 'green technologies' seems to increase according to scattered pieces of information available.

To some extent these findings may indicate that companies consider investments in R&D as a strategy for overcoming the times of crisis being well positioned compared to their competitors in the expected uptake after the crisis. Experience from the effect of liberalisation on R&D in the energy sector also suggests that a higher price pressure favours incremental innovations with lower risks, which would confirm our findings. One nevertheless needs to take into account that a one-year change can also be influenced by a number of other factors, such as inertia in adapting R&D budgets on a short term, and should therefore not be over-interpreted.

All in all, the analysis finds that EU-based transport-related companies are the largest R&D investors of the European society. Significant parts of their R&D investments are dedicated to the reduction of GHG emissions throughout all modes, often influenced by policies that provided regulations which directly or indirectly steered the direction of industrial research. Public research complements industrial research – it is more pronounced in aviation, rail and maritime than in road transport; within road transport it concentrates on technologies that are promising long-term options, but which receive less industrial attention given their comparably lower level of maturity. With the growing importance of non-conventional technologies and fuels, a number of niche providers enter the market, which otherwise is largely dominated by very few players. Their knowledge is often spread rapidly in a vertical way through coalitions between newcomers and established manufacturers, while knowledge diffusion among competing manufacturers of e.g. cars remains limited.

⁴ Recently the dynamics of FCV development accelerated again as car manufacturers and hydrogen suppliers organised in the initiative H2-Mobility have recently announced to bring FCVs to the market in 2015.

3.2 The global automotive industry

As described above: the road sector needs to contribute the largest GHG reductions and in Europe it represents also the sector with the largest R&D budgets. From this point of view the challenge and the capability to reduce GHG fit together. However, the automotive industry delivers to a global market. Therefore the GHG-TransPoRD project invited experts from China and the US to describe in a paper ongoing innovation activities and policy-making related to the automotive industry in their countries, which today represent the other two largest automotive markets next to Europe.

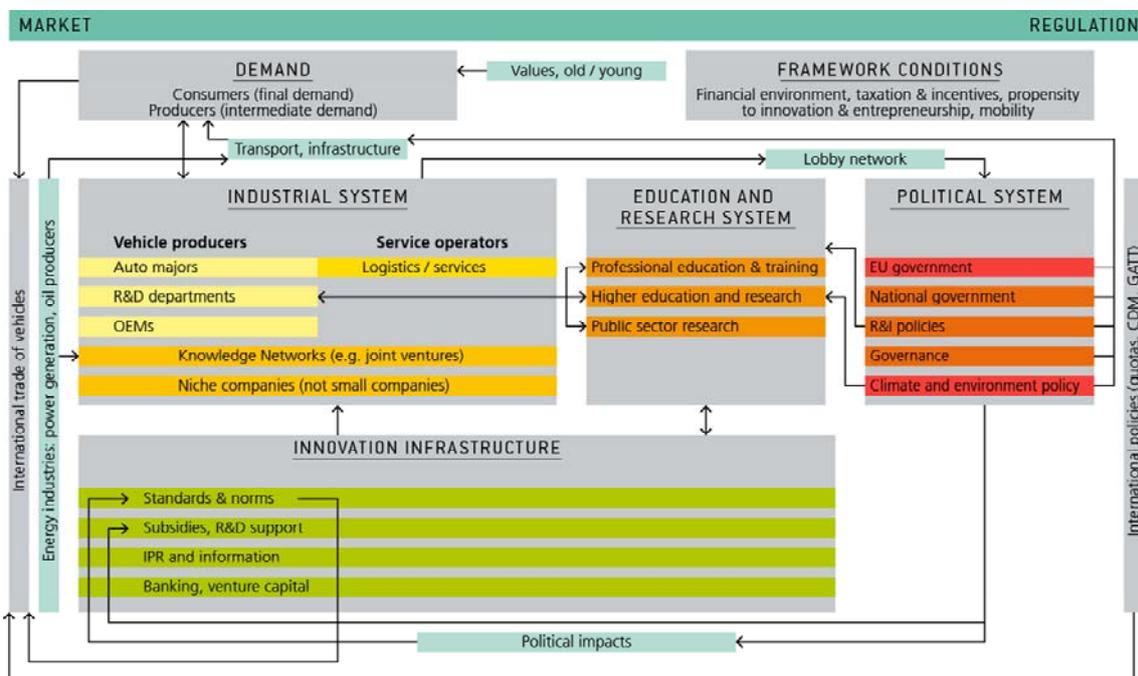
Sperling/Nichols (2011) focussed their paper on the Californian policy model for GHG reductions in transport as they argue that California acts as a frontrunner in this policy field, in recent years even having overtaken Europe in ambitions. They confirm the huge potentials to reduce GHG emissions from cars also identified by GHG-TransPoRD (see sections 4 and 5) expecting that gasoline cars will double their fuel efficiency between 2010 and 2025. They argue in favour of a bottom-up approach – and California is implementing that approach - including a variety of instruments e.g. standards, taxation, incentives instead of arguing that simply getting the prices right is sufficient e.g. by a carbon tax or a cap-and-trade system as many economists would like to solve the problem. According to Sperling/Nichols the two most relevant policies will be (1) setting GHG/efficiency standards for vehicles, and (2) defining low carbon fuel standards, a finding that is shared by GHG-TransPoRD, in particular concerning the importance of the GHG/efficiency standards.

Wang/Su (2011) report in their paper on the efforts in China to develop the automotive industry, in particular to manage the transition towards new energy vehicles. The basic conclusion is that the innovation system in China is not sufficiently well developed to bring new energy vehicles as fast as planned into the market. However, the government is aware of the need to improve the innovation system and supports it by high R&D funding and many initiatives to bring the required industrial actors together, such that it is expected that the innovation system will fast develop and the same should hold for its output: the efficient alternative engine vehicles. The government has also set efficiency standards as one important measure to influence the direction of innovations in the automotive industry.

These examples show that the global automotive industry is entering a phase of transition. However, *“All the major countries and many of the lesser ones have policies for the development of ‘their’ automotive industry and in total these plans are incompatible”* as Wells pointed out (Wells 2010). In such a world we might end at the 2 billion cars expected by Sperling/Gordon in 2030 (Sperling/Gordon 2009), but would they need to

be inefficient heavy private cars? Alternatives seem feasible following the policy programmes briefly described above and later on by GHG-TransPoRD, thus translating the automotive industry into a sustainable mobility industry, developing highly efficient, low/no carbon emitting, light-weight vehicles and offering also sustainable mobility services (Wells 2010, Schade et al. forthcoming).

The common global framework to do so is described by Figure 2 , which presents the innovation system of the global automotive industry, with the strong interaction between actors of the industry and the political system, but also with the influence of changing values triggering the industry from the demand side.

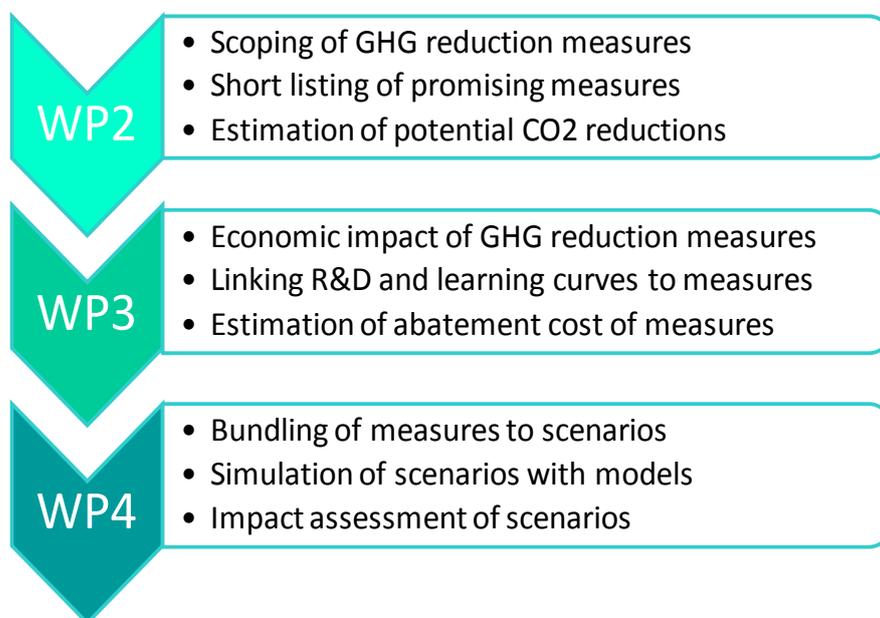


Source: Fraunhofer-ISI

Figure 2: Innovation system transport (ISyT) of the global automotive industry

4 Measures for GHG reductions in transport

Figure 3 presents the workflow of activities to analyse scenarios for GHG reduction potentials of transport in GHG-TransPoRD. In the first step work package 2 (WP2) constitutes the bottom-up approach to analyse measure by measure for each mode the GHG reduction potential as well as their feasibility to become implemented. The result was a short list of promising GHG reduction measures by mode. This is reported in section 4.1 and Deliverable D2.1 (see Akkermans et al. 2010). In the second step in WP3 in-depth analysis of the previously short-listed measures was carried out to estimate the cost and investment impacts from a modal perspective. New methods were developed, in particular based on the learning curve approach, to carry out these estimates. The results were cost pathways for the different technologies, which were largely specified as cost functions in dependency of the market sales of a certain technology. This is reported in section 4.2 and Deliverable 3.1 (see Schade et al. 2012). In the final step in WP4 the measures were successively bundled into policy packages and the scenarios were then tested by the model suite of GHG-TransPoRD (ASTRA, MARS, POLES and REMOVE) to obtain quantitative results about the GHG reduction effects of each scenario. These results enabled an assessment if and how the -60% GHG reduction target for transport could be achieved by 2050. This is reported in section 5 and Deliverable D4.1 (see Fiorello et al. 2012).



Source: GHG-TransPoRD

Figure 3: Approach of GHG-TransPoRD to assess GHG reduction potentials of single measures and of policy packages as part of scenarios

4.1 GHG reduction potentials of single measures

GHG-TransPoRD started with a creation of a knowledge base of single GHG reduction measures for each mode and for alternative fuels (i.e. biofuels and hydrogen). The knowledge base of GHG reduction measures covers, among others, the techno-economic characteristics and reduction potentials identified during an extensive literature study, expert interviews and two workshops organised in collaboration with the International Energy Agency (IEA). This knowledge base was refined and used in subsequent working steps of GHG-TransPoRD to elaborate cost assessments and to provide a number of future scenarios that should help to ascertain where additional effort in terms of research and development seem worthwhile.

Three steps have been undertaken 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.
- (2) A scoping exercise generated **long lists of potential measures** and their reduction potentials.
- (3) Based on our initial assessment **short lists** of 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.

The common energy framework was created based on the iTREN-2030 (running until 2030) and ADAM projects (running until 2050), as well as on the REMOVE model and the Ex-TREMIS database. As the purpose of the use of the energy framework was not an exact forecast but the development of a ranking between different measures GHG-TransPoRD did not aspire to develop a sophisticated projection. It was more relevant to have a transport energy demand scenario that can be differentiated by modes, fuel types and regions as these categories were needed for the assessment of the different measures. Further such a reference scenario should be explicit regarding measures/improvements that are part of the reference.

Based on the common energy framework of GHG-TransPoRD the energy savings and the potential savings of GHG emission of transport measures could be estimated. Possible effects were calculated in both relative and absolute potentials using energy demand estimates made in the energy framework.

From the long lists of potential measures five shortlists of measures were created, one for each of the transport modes (road, air, sea, rail) and one for alternative fuels. The measures that were included consisted of either stand-alone measures, groups of similar or corresponding measures or measures that are implemented parallel to each other. The scope of measures includes technologies, urban measures, behavioral changes, (national) policies, etc. Information on possible effects towards the reduction of greenhouse gas emissions by 2020 and 2050 as well as on practical, technical or political feasibility was collected.

The measures were classified by four broad categories of how they are reducing GHG emissions (ASIF approach):

- (1) **Activity reduction**: means that the measure would reduce transport demand. Usually valid for demand management measures (i.e. transport policy).
- (2) **Modal shift**: means that a measure would affect the modal shift such that low carbon modes increase their modal share. Usually valid for demand management measures (i.e. transport policy and infrastructure policy).
- (3) **Energy intensity**: means that measure improves energy efficiency: Usually valid for technical measures in vehicles (e.g. engine efficiency, rolling resistance).
- (4) **Carbon intensity of fuels**: 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. The realizable reductions e.g. taking into account costs, barriers and interactions between measures are expected to be smaller and were later subject to the scenario assessment with the models (see section 5). The results of the analysis of single measures are summarized in Table 2 providing the **theoretical technical reduction potentials**, which were 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

Mode	[%-relative reduction to reference]	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.

4.2 Cost assessment and technological learning in transport industry

Each short listed measure has been made subject to a cost assessment. The basic principle of cost assessment in GHG-TransPoRD is that for each measure the project required a cost pathway to enable to simulate market penetration and economic effects in the model suite of GHG-TransPoRD (ASTRA, POLES, TREMOVE and MARS models). Cost assessment means to estimate a time path of cost development of a measure from now until 2020, 2030 or even 2050.

As maturity and empirical database differ strongly between different measures a cost assessment approach was developed differentiating **five levels of sophistication**. The preferred level 1 for analyses in GHG-TransPoRD would be the most sophisticated assessment method while level 5 would be the most simplified version. In any level the output would be a cost development of a measure over time. The three most sophisticated levels build on the learning curve concept. The five levels were:

- **Level 1 (2FLCe): empirically based two-factor learning curve** that integrates learning-by-doing and learning-by-searching terms in the equation. Parameter estimation of the learning can be derived from the measure under analysis (i.e. when implementation has already started) or from very similar measures.
- **Level 2 (2FLCt): two-factor learning curve** that integrates learning-by-doing and learning-by-searching terms in the equation. The **parameters are based on a typology** of results i.e. using learning rates from plausible ranges to develop the curve. This seemed to be the most probable option to implement learning in the models and to make them sensitive to R&D and diffusion pathways of technologies.
- **Level 3 (1FLC): one-factor learning curve** that is based only on learning-by-doing i.e. cost development depend on production or sales numbers. The advantage is the reduced data requirement compared with the two 2FLC approaches in level 1 and level 2.
- **Level 4 (CS):** the cost assessment is taken as evidence from **cost assessment studies** elaborating on diffusion pathways of measures and providing future cost estimates. This approach still delivers cost estimates. The concerns related to the approach are that the scenario assumptions (e.g. on oil prices, competing technologies) possibly differ from GHG-TransPoRD scenarios such that transferability of the cost estimates is limited.
- **Level 5 (RM):** the cost assessment is **derived indirectly from roadmaps** that suggest a diffusion pathway of a new technology. Cost estimates of competing technologies might be needed to assume from the cost pathway of the competing technology to the GHG reduction measure of GHG-TransPoRD, since diffusion would only occur when their cost come close to the cost of competing technologies.

The ideal approach that could link R&D activities and cost assessment would have been to apply a two-factor learning curve as such an approach would enable to link learning-by-doing (i.e. accumulated production or sales) and learning-by-searching (i.e. R&D expenditures or patents) to estimate future cost of GHG reduction measures as well as the related R&D efforts.

However, studies estimating learning rates for our specific measures were limited. In general, it was found that learning rates for road transport are in the range of 5% to 26%. In some cases, there are analyses on the same technology that come to rather different results, e.g. on hybrid electric vehicles for which an older study finds 6% as the learning rate, while a more recent study finds 15%. In that case, we expected that the more recent findings will be more appropriate as research intensity on that topic is increased drastically in recent years, increasing the speed of learning also by the factors not yet measured by learning curves like learning-by-using and learning by interacting.

In the case of biofuels the observed learning rates range between 1% and 29%. The very low rate for 2nd generation biofuels points to the fact that in recent years the breakthrough of this technology was expected, but never occurred as the large scale demonstration plants did not become operational as planned.

Table 3: Empirical learning rates of selected transport technologies

Area	Technology	Reference	Learning rate
Road	Hybrid electric vehicles	AEA, 2009	15%
	Hybrid electric vehicles	Pill-Soo, 2003	6%
	Battery electric vehicles	Pill-Soo, 2003	5%
	Fuel cell vehicles	Schwoom, 2006	10-20%
	PEM fuel cell	Tsuchiya/Kobayashi, 2004	14-26%
	Electrical motors (industry)	Jardot et al. 2010	9%
	Downsizing (cars and vans)	AEA, 2009	10%
	Biofuels	Ligno-cellulosic ethanol	GHG TransPoRD D3.1
BTL		GHG TransPoRD D3.1	9%
DME		GHG TransPoRD D3.1	17%
Ethanol (Brazil)		Goldemberg et al. 2004	29%

Source: compilation by GHG-TransPoRD from references quoted in table.

A further relevant observation on the different learning rates of young and mature technologies is presented in Table 4. Based on 71 learning-by-doing rates and 17 learning-by-searching rates of energy technologies it was found that young technologies have about four times higher learning-by-doing learning rates than mature technologies. The learning-by-searching rates are about three times higher for the young technologies compared with the mature technologies.

Table 4: Comparison of learning rates of young and mature technologies

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

Source: GHG-TransPoRD elaboration based on Kahouli-Brahmi (2008).

5 Holistic scenario tests by GHG-TransPoRD

After for each mode the potential GHG reduction measures have been assessed separately, first regarding their GHG reduction potential (see section 4.1), and second for the more effective measures also in terms of their cost and cost developments (see section 4.2) in the next step the measures have been bundled into policy packages and the GHG reductions of these policy packages have been quantified applying four models. These results are summarised in the following two sections and are reported in Deliverable D4.1 (Fiorello et al. 2012).

5.1 Modelling tools and definition of scenarios

The core of modelling in GHG-TransPoRD is to simulate GHG mitigation scenarios consisting of policy packages addressing the European transport sector. Simulation results are delivered as quantified indicators describing the development of the European transport, energy and economic systems until 2050. Four tools were used: three European/global ones and one regional/urban one. The four tools were:

- ASTRA (Assessment of Transport Strategies). A System Dynamics model applied for 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 energy scenarios.⁵
- REMOVE. A policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector of EU27+4.
- MARS. An urban dynamic Land Use and Transport Integrated (LUTI) model (the version developed for Leeds has been used).

The four tools were applied in a combined way. ASTRA and POLES, both models running until 2050 and together describing the energy, transport and economic systems, performed their simulations in an integrated way iteratively exchanging results and producing aligned model simulations. Specific output of these simulations was provided to the REMOVE and MARS models, enabling them to perform simulations consistent with the European scenarios of the ASTRA-POLES model combination.

The Reference Scenario is the scenario against which the policy packages were tested by the models. The Reference Scenario includes assumptions about exogenous trends

⁵ In this project the POLES-GHG-TransPoRD version was applied, that is linked with the BioPol model to simulate cost and supply of biofuels and with the ASTRA model from which economic drivers and transport demand is fed into POLES.

(e.g. economic growth) but also about the endogenous variables in GHG-TransPoRD such as e.g. transport demand, energy supply and demand, transport emissions. Furthermore, the reference scenario includes some transport policies. The GHG-TransPoRD Reference Scenario is based on two main sources. Until 2030 the Reference Scenario is taken from the PRIMES model as defined in the document “EU energy trends to 2030 — UPDATE 2009” (European Commission 2010b). This reference scenario is the one used for assessment of the New Transport White Paper of the European Commission. From 2030 to 2050 the Reference Scenario is extended using the ADAM reference scenario and the ASTRA model (Schade et al. 2009).

The PRIMES reference scenario assumes that the economic crisis has long lasting effects leading to a permanent loss in GDP. At the same time, while the average EU-27 growth rate for the period 2000-2010 is only 1.2% per year, the projected rate for 2010-2020 is recovering to 2.2%, similar to the historical average growth rate between 1990 and 2000. Therefore, the PRIMES scenario can be considered on the optimistic side. Between 2020 and 2030 the growth rate is slightly reduced to about 2% per year. Between 2030 and 2050 the growth rate, taken from the ADAM reference scenario, is further lowered to 1.8%. The demographic projection includes a dynamic immigration trend which helps keeping positive growth rates but is not sufficient to sustain higher growth. Both total population and active population are assumed to grow at positive, albeit very low, growth rates over the entire projection period; this contrasts past scenarios.

The assumptions concerning the energy prices trend was taken from POLES rather than from the PRIMES scenario (also to get a consistent picture until 2050), however the two projections are quite similar until 2030 as far as oil price is concerned. It was assumed in the Reference Scenario that they rise from present prices and then remain at high levels at around 80 €/2005/bbl in 2020, almost 90 €/2005/bbl in 2030 and nearly 110 €/2005/bbl in 2050. Gas prices are assumed to increase in a similar pattern but at a slower pace, reflecting the dynamics of the inter-fuel competition and the rising supply costs. Coal prices increase by only one third due to the ample reserves. Table 5 presents the trend of endogenous variables of the transport sectors in the Reference Scenario.

Table 5: Summary of key trends of endogenous variables in the reference scenario

Variable	Average growth rates per year (%)	
	2010-2030	2030-2050
Passengers-km	1.2	0.0
Tonnes-km (maritime excluded)	1.9	1.6
Energy demand (transport)	0.5	0.3
CO ₂ Emissions (transport, well to wheel))	0.5	0.3
CO ₂ Emissions (total)	-0.2	0.3

Source: GHG-TransPoRD, ASTRA-POLES models

In summary, in the Reference Scenario the transport sector is very far from any emissions reduction target. Despite some gains in energy efficiency, which allows to slow down the growth of transport energy demand, CO₂ emissions in the year 2050 are significantly above the 1990 level.

The GHG-TransPoRD project applied a two-step approach to define the policy packages to be tested against the Reference Scenario in the different (policy) scenarios. The first step of scenario definition was to define preliminary scenarios and to discuss their results with stakeholders at a workshop using the outcomes of the discussions to refine the scenarios and develop the final set of scenarios relevant for the analyses. The concept of the definition of scenarios was twofold: (1) the structure of scenarios should allow to differentiate between the big drivers of impacts, i.e. technology, policy and behavioural changes, and (2) 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 into the policy package. During this process of scenario design, testing and assessment the two major models applied for the European analysis, ASTRA and POLES, were each roughly undertaking 500 simulations of scenarios. Finally, the following six core scenarios have been agreed and tested by the various models:

- **MAX_E&M** scenario: Maximum Efficiency at Market conditions. This scenario includes most of the technological measures for all modes, including both conventional and innovative cars. Neither the latter nor biofuels are supported by dedicated policy to promote their penetration in the market. Market diffusion thus depends on relative cost of different options and the cost development paths estimated with the learning curves.

- **EV** scenario: Electric Vehicles. In this scenario the technological effort is concentrated on electric vehicles (battery electric and plug-in hybrids). Market driven technological development is assumed also for conventional road vehicles and other modes. Furthermore, additional supporting policies for electric vehicles (e.g. feebate schemes) are supposed to be in place to promote the diffusion of electric vehicles.
- **HFC** scenario: Hydrogen Fuel Cells vehicles. This scenario follows the same approach of the EV scenario, but the technological effort and the supporting policies is concentrated on the development and market diffusion of Hydrogen Fuel Cell vehicles.
- **EV+HFC** scenario. This scenario is the combination of the EV and HFC scenarios. In particular, supporting policies do not select in advance one of the two technologies, but are applied to promote both (roughly with the same amount of resources split between the two). Additional, loss of fuel tax revenues is compensated by fuel tax increase.
- **AMB_TP** scenario: Ambitious Technology and Policy. This scenario shares the same technological measures as in the MAX_E&M scenario plus the additional supporting policies for Electric and Hydrogen Fuel Cells vehicles. Additionally other policy instruments are assumed at urban and universal level (including urban charges, promotion of walking and cycling, promotion of efficient logistics. Last but not least, a huge increase of fuel taxation (on average up to +200% with respect to 2010 value) is assumed in order to contrast demand rebound effect and offset fuel taxation revenues loss determined by more efficient vehicles. With this respect it was also discussed that this scenario should be a maximum technology and policy scenario (MAX_TP).
- **AMB_REG** scenario: since with the previous scenarios it was difficult to achieve GHG reduction levels suggested by the IPCC and proposed by the Transport White Paper this scenario assumed further regulations that would phase out the purchase of fossil fuel based cars after about 2035. For freight transport the scenario shifted freight demand from road to rail and shipping, as in most other scenarios the relatively faster improvement of energy efficiency of road transport improved the competitive position of road transport increasing road modal-share and counterbalancing part of the reductions of GHG emissions.

As suggested by the stakeholders at the previous workshop of GHG-TransPoRD all policy scenarios share an ambitious structural change of the energy system towards renewable energy sources, that are supposed to become largely dominant until the year 2050 (i.e. about 80% renewable electricity in 2050). Table 6 provides a summary of the scenarios and of their content.

Table 6: Summary of scenarios tested by GHG-TransPoRD

Policy bundles		MAX_E&M	EV	HFC	EV+HFC	AMB_TP	AMB_REG		MAX_LP	TAX_COMP
Technologies										
Conventional road		X	x	x	x	X	X		X	X
Electric vehicles		X	X		X	X	X			
Fuel cells vehicles		X		X	X	X	X			
Non road		X	x	x	x	X	X		X	X
Policy bundles										
Universal						X	X		X	X
Urban						X	X		X	X
Support innovative vehicles			X	X	X	X	X			
Drastic fuel taxes					X	X	X			X
Phase-out fossil cars							X			
Freight modal-shift							X			
Energy system transition										
Biofuels	RES directive reach	X	X	X	X	X	X		X	X
	Subsidies 2 nd gen.		X		X	X	X			
	BTL invest. program		X		X	X	X			
	HVO invest. program		X		X	X	X			
	DME invest. program			X	X	X	X			
Renewables		X	X	X	X	X	X			

X = full implementation; x = partial implementation

Source: GHG-TransPoRD.

Additional urban scenarios to explore impacts of urban policies in more detail are simulated in MARS. In particular, alternative packages of urban measures are associated to the MAX_E&M scenario in order to highlight the contribution of urban policies (compared to the results of MAX_E&M scenario in MARS).

Further, for selected scenarios also sensitivity simulations have been undertaken varying the increase of oil prices (i.e. assuming higher oil prices) and the fuel taxation levels.

5.2 Scenario results

Table 7 presents the results for the CO₂ emissions of transport in the six core scenarios in comparison with the Reference Scenario. Only one out of the six scenarios would deliver the required GHG emission reductions of -60% until 2050 that are formulated by the Transport White Paper of 2011: the AMB_REG scenario. The technology scenarios either focussing on efficiency of conventional cars (Max_E&M) or on alternative technologies (EV+HFC) would deliver about -34% to 37% percentage point reductions. Adding policies, in particular pricing policies to foster behavioural change, would roughly add another -10% reduction. But only if further ambitious regulations are 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 AMB_REG scenario could deliver the -60% reductions. Concerning the energy system all scenarios included a shift towards the use of renewables such that in 2050 electricity in EU27 is produced by 80% from renewables.

Table 7: Transport CO₂ emissions^(a) (Mt) in the GHG-TransPoRD scenarios

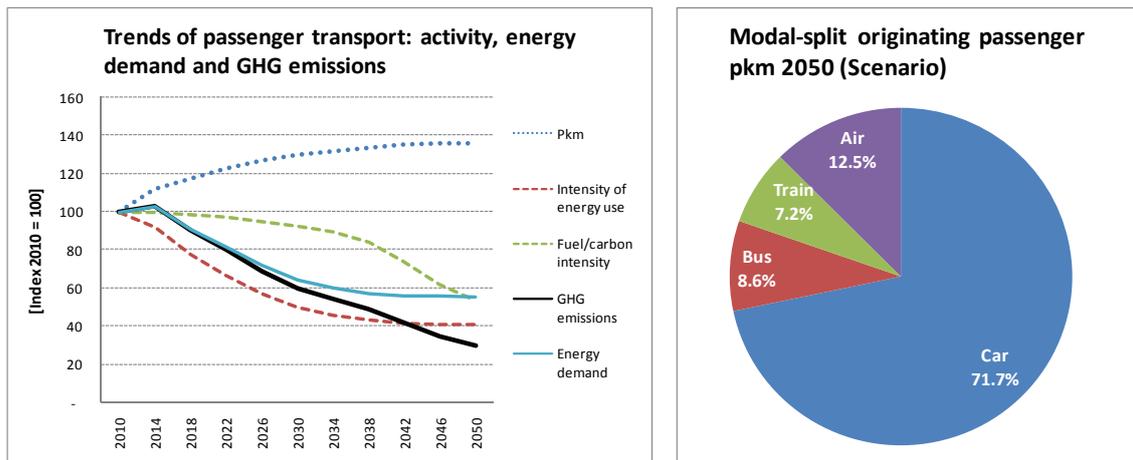
Scenario	2020	2030	2050	Var. % 1990-2050	
				Stat. 1990	Model Base
REF	930	946	1,029	+23%	+20%
MAX_E&M	754	582	541	-35%	-37%
EV	835	679	682	-18%	-20%
HFC	859	734	674	-19%	-22%
EV+HFC	691	548	552	-34%	-36%
AMB_TP	729	530	483	-42%	-44%
AMB_REG	727	526	337	-59%	-64%

(a) Tank to wheel transport emissions in the EU27 countries

Source: GHG-TransPoRD, ASTRA –POLES models

The following figures describe further findings derived from the AMB_REG scenario. Figure 4 presents the ASIF indicators for passenger transport in the AMB_REG scenario. Transport demand increases by 36% until 2050 compared to 2010. GHG emissions of EU27 transport continuously decline from 2014 until 2050. Until about 2035 the intensity of energy (the reverse of efficiency) is strongly and continuously reduced, but it seems that around 2035 a plateau is achieved beyond which further efficiency improvements are hard to implement (see red dashed line). Until that point is reached in 2035 also the carbon intensity is reduced, but only for about 15%. However, after 2035 the regulatory measures, in particular to phase out conventionally fuelled cars, sharply

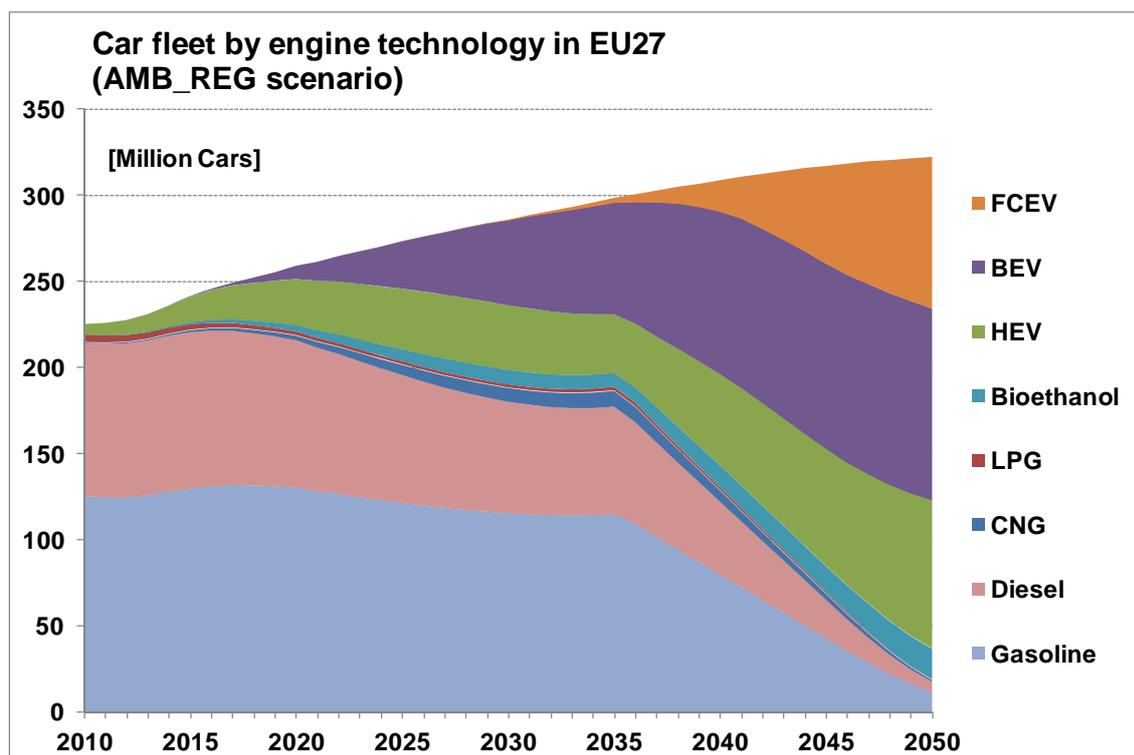
reduce carbon intensity until 2050 (see green dashed line). The trend of intensity of energy use is mirrored in the trend of transport energy demand (blue line), while the trend of GHG emissions is generated by overlaying the developments of intensity of energy use and carbon intensity of fuels. For freight transport the main driver of reductions is the decrease of intensity of energy use, while reduction of carbon intensity plays a limited role.



Source: GHG-TransPoRD, ASTRA-POLES models

Figure 4: Drivers of GHG reductions in AMB_REG scenario in EU27

Figure 5 shows the composition of the car fleet until 2050 in EU27. From about 2015 onwards the fleet of conventional diesel and gasoline cars stagnates and different alternative engine/fuel vehicles diffuse into the market, with the most dominant share coming from hybrid vehicles, plug-in hybrid vehicles and range extended vehicles all part of the hybrid category. CNG, Bioethanol (E85) and Battery Electric Vehicles (BEV) after 2015 also start to play a role. However, only with the ban of conventional fossil fuel cars the alternative vehicles gain market share and in particular FCEVs significantly replace the conventional vehicles. As electricity and hydrogen will be produced at least from 80% carbon free (i.e. renewable) electricity this fuel switch away from fossil fuels enables a sharp drop of GHG emissions of transport, having in mind that car passenger transport was the largest single source of transport GHG emissions in 2009.



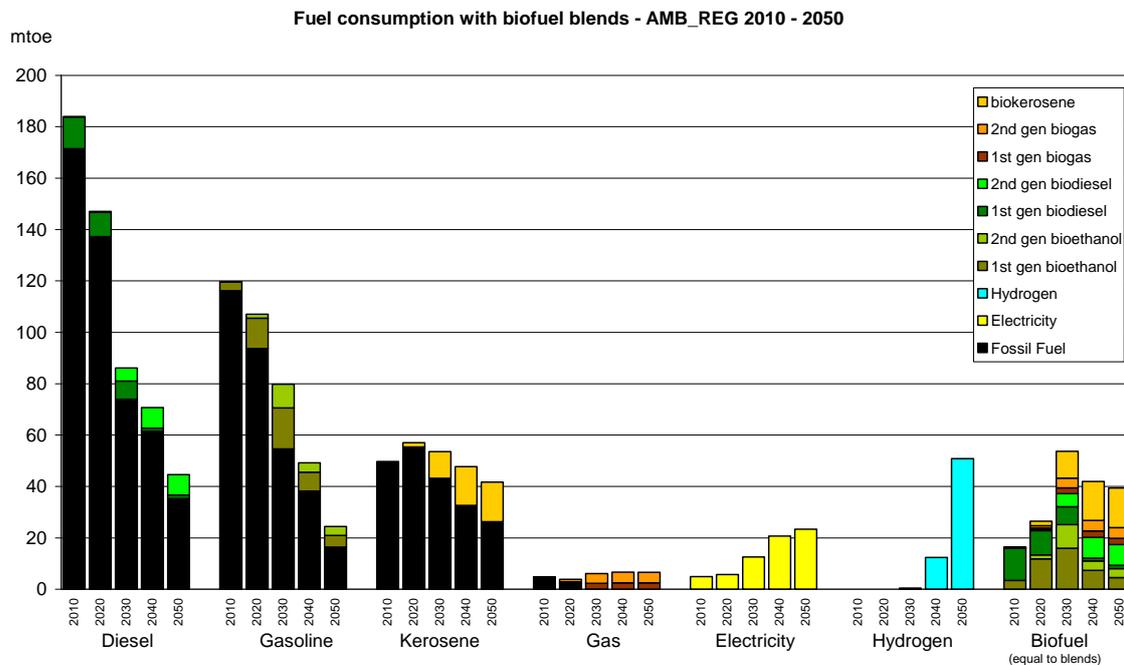
Source: GHG-TransPoRD - ASTRA model

Figure 5: Car fleet trend in the AMB_REG scenario in EU27

The structure of the fuel consumption is shown in Figure 6. In 2010 the fossil fuels dominate, including only a minor share of blended biofuels that is indicated by the coloured boxes on top of the black bars representing the fossil fuels. The strong influence of energy efficiency improvements is obvious looking at the shrinking bars of the fossil fuels over time until 2050. Also the fraction of biofuels becomes larger, though a maximum absolute amount of biofuels used is observed between 2030 and 2040. Afterwards the biofuel demand declines to 40 mtoe. In 2050 about 40% of air energy demand is 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. Until 2030 about half of biofuels comes from 2nd generation production, and first generation biofuels nearly phases out until 2050.

Through sensitivity simulations varying the oil price development it was found that demand and supply of biofuels as well as the distribution between first and second generation of biofuels strongly depends on the oil price development. Obviously, higher oil

prices would increase biofuel demand, in particular of biokerosene, though an early oil price increase would drive down the cost of first generation biofuels increasing their share on demand at the expense of second generation biofuels.



Source: GHG-TransPoRD – ASTRA-POLES models

Figure 6: Fuel consumption including blending with biofuels – AMB_REG scenario

The UN concludes that between 40% and 70% of GHG emissions are generated within cities globally (UNHABITAT 2011). For transport the EC assumes that 40% of all transport GHG emissions occur in European urban areas. This shows that urban transport needs to be considered when discussing GHG reduction measures for transport. This holds in particular as urban areas reveal specific characteristics concerning transport: (1) usually the variety of alternative transport modes is larger i.e. public transport, walking and cycling can be comfortable options, (2) transport distances are shorter, but congestion may play an important role for mobility choices, (3) small electric vehicles may represent an alternative mode already in the years to come, and (4) local circumstances vary, thus cities try different policy approaches and some policies may be identified that perform better than others in general.

Therefore GHG-TransPoRD performed a specific urban case study applying the MARS mode to the city of Leeds and combining the six core scenarios of GHG-TransPoRD with specific urban measures applicable to Leeds. Table 8 summarizes the main findings of the urban analysis. In the Urban Reference Scenario GHG emissions of transport increase by 4% compared with 1990. Policy measures alone like pricing measures, public transport measures, parking measures or smarter choices achieved only a few percentages reductions (-1 to -4%) of GHG emissions. Combinations thereof like smarter choices and urban charging could deliver up to -10% GHG reductions. The only option that drastically reduced GHG emission was the combination of visionary walking & cycling policies with behavioural change, which roughly halved GHG emissions compared with the reference. The technology scenario (e.g. Max_E&M) could deliver a similar reduction, and the combination of core scenarios with urban policy packages (e.g. AMB_TP with visionary walking&cycling and urban charging) would reduce GHG emissions to one fourth of the value of 1990. We can thus conclude that on urban level GHG reductions in relative terms will probably be highest until 2050.

Table 8: Impact of policy measures on reference transport CO₂ emissions in the Leeds case (index: 1990 emissions = 100)

Scenario / Measure	Year			
	2020	2030	2040	2050
REF – Urban Reference Scenario	97	100	103	104
Walking & cycling visionary (without behaviour change)	90	91	95	96
Walking & cycling visionary (with behaviour change)	88	78	60	53
Smarter choices	93	94	99	100
Smarter choices & Urban Charging	86	88	93	95
Max_E&M – no specific urban measure	68	51	50	47
Max_E&M & Walking + cycling visionary & urban charging	58	38	29	25
AMB_TP & Walking + cycling visionary & urban charging	64	40	28	25

Source: GHG-TransPoRD - MARS model

6 Stakeholder involvement in GHG-TransPoRD

Stakeholders have been intensively involved in the GHG-TransPoRD project. Stakeholder involvement was guaranteed by public events, interviews, a stakeholder council and a website (www.ghg-transpord.eu) that enabled to disseminate findings and to send responses to the project. 23 industry experts have been participating in detailed interviews, many of them several times during the course of the project. Further the project team was keeping regular contacts to industry experts from all modes, such that also via informal meetings the issues related to GHG-TransPoRD have been often discussed.

GHG-TransPoRD organised four workshops and a final conference, in which always between 50 and 90 experts and policy-makers participated. The workshops consisted of presentations from the project and selected external experts (e.g. from the World Bank, from research platforms like ERTRAC, from US and Chinese policy advisors, from the European Commission as well as from companies of the transport industry). The purpose of such workshops always was to enable discussions and thus reserved time for longer question & answers sessions, as well as that break-out group sessions and expert panel sessions were included in the program of these public events. The following events were organised by GHG-TransPoRD:

- GHG reduction potentials in road and rail transport and the role of RD&D. Joint workshop with the International Energy Agency (IEA) in Paris, June 17th 2010.
- GHG reduction potentials in air and maritime transport and the role of RD&D. Joint workshop with the International Energy Agency (IEA) in Paris, June 18th 2010.
- R&D strategies, innovations, learning and cost of measures to reduce greenhouse-gas emissions of transport. Workshop in Brussels, December 14/15th 2010.
- Techno-economic analysis of scenarios and policy packages to achieve GHG reductions of transport. Workshop in Brussels, September 26/27th 2011.
- Reducing greenhouse-gas emissions of transport beyond 2020: linking R&D, transport policies and reduction targets. Final Conference hosted by the European Economic and Social Committee (EESC) in Brussels, November 29th 2011.

For each of the public events input papers/notes were provided to participants and a summary of discussions and findings were prepared and published on the project website. The GHG-TransPoRD project was also supported by a stakeholder council that was invited to comment on reports or to participate actively in the events (e.g. as speaker, panellist or session chair). Further GHG-TransPoRD participated in clustering events with other parallel projects, in particular TOSCA (Technology Opportunities and Strategies Towards Climate-Friendly Transport) and REACT (Supporting Research on Climate Friendly Transport).

7 Conclusions

The most important conclusion to draw from the model-based analysis is that the -60% GHG reduction target for the transport sector is feasible to achieve. Following the New Transport White Paper published in 2011 this target should at least be achieved by 2050 in comparison with the GHG emissions of transport in 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.

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 again 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.

The Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) 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 Max_E&M scenario, which is designed 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% more reductions than the EV scenario, 60% more than

the HFC scenario, and 24% more than the combined EC+HFC scenario. The driver of this reduction is massive introduction of efficiency technology of road vehicles to be either driven by the climate mitigation awareness of the automotive industry or by setting of strict CO₂ 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, FCEV and PHEV would diffuse into the market fast enough, and currently 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 constitute transitory techniques that bridge to the development of alternative fuel vehicles, while there would probably also be improvements of the combustion engines, which can not be applied anymore when conventional cars are phased-out. The challenge to identify those technologies that improve efficiency most effective and can be applied longer into the future as well 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 then 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 considering 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 FCEVs) 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. Neverthe-

less, 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 will be much faster than increase of energy prices. 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 AMB_TP and AMB_REG scenarios both increase fuel duties and introduce urban charges in total then generating higher GHG emission reductions than the scenarios without such measures and thus with a pure focus on efficiency and alternative technologies.

Increasing road transport taxes and tolls then induces 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 in turn at least partially is required to fund infrastructure and operation within the transport sector e.g. for railway infrastructure and public transport.

Biofuels could supply about 40 to 50 Mtoe of transport energy demand. The peak of their supply and demand in the different scenarios will be during the decade 2030 to 2040. After 2040 the demand for biofuels reduces, driven by reduced demand from road transport. However, for air transport the use of biokerosene constitutes the main option to significantly reduce its GHG emissions. Therefore GHG-TransPoRD suggests to emphasize R&D for use of biofuels in air transport as well as to ensure that in case biofuel and biomass supply gets limited their use in air transport is prioritised.

Finally, it should be noted that the scenario achieving the -60% reduction target 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.

8 Recommendations

General

The Transport White Paper postulates that “curbing mobility is not an option”. We understand that this excludes behavioural and organisational change, as in principle these could also reduce transport demand. The question should rather read, “which contributions technological change and behavioural change have to make to achieve the target of -60% GHG reductions of transport”. Our analysis reveals that pure technological change might contribute three fifth of these required GHG reductions. And it is not that simple to argue the remaining part would come from behavioural change. Instead we would argue, four key aspects need to be considered to fulfil the major target of the New Transport White Paper of reducing GHG emissions of transport by -60%:

- **Technological change**, i.e. efficiency **and** alternative energy for transport.
- Autonomous **behavioural change** that can already be observed, i.e. climate change awareness, multi-modality, new life style products (e.g. pedelecs) and re-urbanisation in green cities.
- Ambitious **policies** setting incentives for both technological and behavioural change.
- Governmental and societal **coherence of transport taxation** and revenues.

Development of new transport technologies requires financial resources as well as their market introduction might require financial support. Over a longer period a large share of global savings has been invested into financial markets or real estate at the risk of creating bubbles. As this risk became more obvious in the last years and thus investors are looking for new opportunities, the transport sector and its technological transition could provide such investment opportunities. Governments should attempt to drive more savings towards the transport sector to fund the technological transition towards a highly efficient and low/no-carbon based transport system.

Mode and fuel specific

The following paragraphs summarize key recommendations that we draw with regard to the policy objective of the Transport White Paper to reduce transport GHG by -60% until 2050 as opposed to 1990. These recommendations have been presented to the stakeholders at the final conference of GHG-TransPoRD in November 2011 in Brussels.

Road transport

Car transport bears the largest GHG reduction potentials within the shortest time horizon. The scenarios indicate that CO₂ emission limits for the average new car and applying tank-to-wheel calculation (i.e. one electric car counts as one car with 0 gCO₂/km emissions) should be in the range of 70 to 90 gCO₂/km for 2020 and 50 to 60 gCO₂/km for 2030. Alternatively less stringent limits could be set if they exclude to account for EVs and HFCs. Two different pathways could achieve these reductions: (1) implementing all available efficiency technology for internal combustion engines cars (ICE), and (2) combining a cost efficient GHG efficiency strategy for ICEs with alternative fuels strategy (i.e. EV and HFC). The latter are required in the long run and thus the 2nd pathway would be recommended. It requires pricing incentives to promote market introduction of EVs and HFCs preferably into specific early adopter markets i.e. by fee-bates, strongly differentiated registration or circulation taxes. However, significant GHG reductions from EVs and HFCs can only be expected in the long run when the energy system is renewable. Nevertheless, policies must ensure that EV and HFC vehicles are enabled to enter their learning curves e.g. by policies focussing on specific early adopter markets for these technologies.

For truck transport priority should be on implementing efficiency technologies. 40% efficiency improvement until a time horizon 2020-2025 seems feasible at an extra cost of 25%. Biofuels could play a limited role for heavy trucks, while for medium-size trucks CNG/biogas would be relevant options.

The innovation system analysis has proven that road transport is the largest investor of private R&D. Policy-making should thus concentrate on guiding these R&D investments by reliable regulation providing targets and planning certainty for investments, but also by highlighting the investment opportunities in that sector.

Air transport

In the short term GHG reductions of air transport will have to come from operational measures, including the installation of the SESAR system. For air transport biofuels come close to being the silver bullet to significantly reduce GHG emissions until a time horizon of 2050. Additionally the open rotor technology should be developed for use in freighters and medium distance passenger aircraft. Both will require substantial R&D support. The latter could pave the way for new plane design in the form of blended-wing bodies, though these should become technology ready only after 2050 and bear high R&D expenditures and risk.

In parallel to such an R&D strategy it seems reasonable to prepare the grounds for demand management measures, such that if the R&D activities should fail as well as if the ICAO GHG emission targets for air transport would not be achieved demand management e.g. via pricing measures could be implemented around 2030. This would imply to work on adapting international agreements such that either energy taxes or emission taxes, ticket taxes and/or value-added taxes become feasible policy options to be implemented for air transport as is the case for the other modes.

Ship transport

In the short-term ship GHG emissions can be reduced largely by operational measures, of which the most effective is slow steaming. Long-term setting efficiency standards for new ships, as proposed by the Energy Efficiency Design Index (EEDI), constitutes an important policy. This should be supported by R&D on the one hand focussing on incremental improvements by optimising rudder and propeller as well as by adapting the ship surface and using renewable energies (e.g. wind energy). On the other hand step changes could be achieved by R&D support to develop new design of ship hulls and ship sizes.

Rail transport

Most important for GHG reductions of rail transport is to enable modal-shift by increase of capacity and attractiveness. This holds for freight transport requiring to build dedicated rail freight infrastructure at certain bottlenecks including intermodal terminals and to support collaborative logistics to increase bundled volumes on long distance connections. For passenger rail transport the extension of a high-speed rail network well connected to regional feeder networks is the key, though it seems not always be required to run at top speeds. Continuing electrification should be an ongoing activity incrementally improving the GHG efficiency of rail.

Cross-modal transport

Using the optimal vehicle for each transport purpose bears high potentials of GHG reductions. This will effect modal-split and requires innovations both in operations and enabling technology. However, the agents in cross-modal transport have low incentives to innovate and act under strong market pressure such that R&D support is required to foster cross-modal transport. For freight transport this means to develop a consensus roadmap and involve SMEs in such activities. For passenger transport the concept of a seamless multi-modal urban passenger transport system (fifth mode) seems to be most important. With such a regime private cars in cities might be replaced by flexible multi-

modal vehicle use, in which the vehicle is selected by users suiting most for the purpose of their trip, let it be a bike, public transport, ride-sharing, car-sharing or a combination of these options. Enabling technology for such a fifth mode would be smartphone apps allowing the user to select, book, use and pay for his or her mobility purposes with one tool and having a contract with one mobility provider, only, who integrates all the services into one platform.

Biofuels

The policy side of developing biofuels is important to establish criteria that guarantee minimum GHG reductions strengthened over time and avoid competition with food as well as indirect land use changes. It seems that developing sustainable biofuels for air transport should be prioritised due to limited number of GHG reduction options of air transport. For specific biofuels the potential mismatch between supply and demand should be taken into account. This holds for bioethanol and biogas, both generating a supply that in the analysed scenarios was larger than demand from the road vehicle fleets.

R&D support should focus on developing biofuels for air transport as well as developing the second generation (i.e. whole crop, non-food crops, residues) and third generation (i.e. algae) of biofuels.

GHG reduction targets proposed by GHG-TransPoRD

Building on the scenario calculations and in particular on the AMB_REG scenario (see D4., Fiorello et al. 2012) and in line with the aforementioned policy recommendations the GHG-TransPoRD project proposes the GHG reduction targets for transport as presented in Table 9. 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 9 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.

Table 9: GHG reduction targets by mode for EU27 compared to emissions of 2010 and 1990. Proposal by GHG-TransPoRD

		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%
EU27 target against 1990				
Transport	vs. 1990	+10% to +5%	-20% to -30%	-60% to -70%

Source: GHG-TransPoRD

These proposed targets synthesize our analysis on potential R&D strategies of the different modes and the potential impacts of transport policies, implemented following a certain time path of implementation. Choosing the right time path of policy implementation will be very important to avoid investments that crowd out or lock-in into certain technologies and to bring the most effective new technologies into the market. Considering the requirement of private companies for reliability of long-term planning of major investments will play an important role for policy-making to generate these investments.

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Glossary

The following glossary describes terminology, stakeholder, projects and models that are of relevance in the context of GHG-TransPoRD. These terms have not necessarily been mentioned in this deliverable, but maybe relevant in the context of other tasks of the GHG-TransPoRD project.

ASIF approach	Approach to categorize the options to reduce GHG gases, where A stands for <i>activity</i> (transport demand) reduction, S for modal- <i>shift</i> towards low carbon modes, I for reducing energy <i>intensity</i> (i.e. energy use per travelled distance), and F for reducing carbon intensity of <i>fuel</i> (i.e. carbon emissions per unit of fuel consumed).
ASSESS	Assessment of the contribution of the TEN and other transport policy measures to the mid-term implementation of the White Paper on the European Transport Policy for 2010 – EU project preparing the assessment and update of the EU White Paper from 2001.
ASTRA	<p>ASTRA is an integrated assessment model applied for strategic policy assessment in the transport and energy field. It covers EU29 countries and integrates a vehicle fleet model, transport model, emission and accident models, population model, foreign trade and economic model with input-output tables, government, employment and investment models. The model runs until 2050 and provides sophisticated tools for sensitivity analyses. It is developed and maintained by Fraunhofer-ISI and TRT (Schade 2005).</p> <p>Technology assessment capabilities cover in particular the road vehicle fleets (car, bus, trucks) for which detailed vintage models with technology differentiations are implemented. For other modes average fuel efficiency and emission factors represent the technological development. For all modes the cost and investment parameters of new technologies can be fed into the model to assess the transport and economic reactions to these new technologies e.g. the impact on GDP and employment.</p> <p>Policy assessment capabilities in ASTRA cover a wide range of policies with flexible timing and levels of the policy implementation. Potential policies include standard setting, infrastructure pricing, fuel taxation, speed limits, carbon taxes, trade policies etc. A strong feature of ASTRA is the ability to simulate and test integrated policy packages and to provide indicators for the indi-</p>

		rect effects of transport on the economic system (Schade et al. 2008). For details see also www.astra-model.eu .
BioPol		A new module developed for the POLES model by the IPTS that improved the capability of POLES to deal with potentials and costs of biofuels in competition with fossil fuels. For each set of exogenously given parameters an equilibrium point is found at which the costs of biofuels equal those of the fossil alternative they substitute, taking into account the feedback loops of the agricultural market and restrictions in the annual growth rates of biofuel production capacity.
COMPETE		Analysis of the contribution of transport policies to the competitiveness of the EU economy and comparison with the United States – EU project coordinated by Fraunhofer-ISI.
Economic potential	po-	Reduction potential for GHG reductions taking into account the economic framework conditions (e.g. fossil fuel prices) as the realizable reduction potentials strongly vary with and depend on external economic factors. In general, if cost of competing technologies/measures are increasing then the economic potential of a technology/measure tends to increase and vice-versa.
Economic reduction potential	re-	
EMOSS		Flemish model for rail, inland ship and port emissions, developed by TML.
ETP – European Technology Platforms		ETPs provide a framework for stakeholders, led by industry, to define research and development priorities, timeframes and action plans on a number of strategically important issues where achieving Europe's future growth, competitiveness and sustainability objectives is dependent upon major research and technological advances in the medium to long term. The ETPs should play a key role in ensuring an adequate focus of research funding on areas with a high degree of industrial relevance, by covering the whole economic value chain and by mobilising public authorities at national and regional levels. In fostering effective public-private partnerships, technology platforms have the potential to contribute significantly to the renewed Lisbon strategy and to the development of a European Research Area of knowledge for growth. As such, they should prove to be powerful actors in the development of European research policy, in particular in orienting the Seventh Research Framework Programme to better meet the needs of industry. ETPs address technological challenges that can potentially contribute to a number of key policy objec-

	<p>tives which are essential for Europe's future competitiveness, including the timely development and deployment of new technologies, technology development with a view to sustainable development, new technology-based public goods and services, technological breakthroughs necessary to remain at the leading edge in high technology sectors and the restructuring of traditional industrial sectors.</p>
GALILEO	<p>Galileo is a global navigation satellite system currently being built by the European Union (EU) and European Space Agency (ESA). Transport is expected to be one of the main sectors benefiting from the operation of Galileo.</p>
GHG- TransPoRD So- cioeconomic Pathway	<p>The GHG-TransPoRD Socioeconomic Pathways (GSPs) comprise a set of future background scenarios developed for the GHG-TransPoRD project to investigate the robustness of the main results obtained by the project concerning future potential technologies and policies. These results were based upon testing these policies against a single Reference Scenario (which is similar to one of the GSPs). The basis of the robustness testing was to make a qualitative examination as to what difference would be made to these results if alternative background scenarios had been chosen as reference scenarios. The GSPs are based upon latest information about the five IPCC Shared Socioeconomic Pathways (SSPs) that are currently in a state of development by the climate change research community.</p>
HOP!	<p>Macro-economic impact of high oil price in Europe – 6FP project coordinated by TRT.</p>
HyWays	<p>European hydrogen energy roadmap – 6FP integrated project.</p>
iTREN-2030	<p>Integrated transport and energy baseline until 2030 – 6FP project coordinated by Fraunhofer-ISI. http://www.isi-projekt.de/wissprojekt-de/itren-2030/</p>
JTI – Joint Technology Ini- tiatives	<p>Joint Technology Initiatives are proposed as a means to implement the Strategic Research Agendas (SRAs) of a limited number of European Technology Platforms (ETPs). In these cases, the scale and scope of the objectives is such that loose coordination through ETPs and support through the regular instruments of the Framework Programme for Research and Development are not sufficient. Instead, effective implementation requires a dedicated mechanism that enables the necessary leadership and coordination to achieve the research objectives. To meet the needs of this small number of ETPs, the concept of "Joint Tech-</p>

nology Initiatives" has been developed.

MARS

MARS (Pfaffenbichler and Shepherd, 2003) is a dynamic Land Use and Transport Inte-grated (LUTI) model. The basic underlying hypothesis of MARS is that settlements and activities within them are self organizing systems. Therefore MARS is based on the principles of systems dynamics (Sterman 2000) and synergetics (Haken 1983). The MARS model includes a transport model which simulates the travel behaviour of the population related to their housing and workplace location, a housing development model, a household location choice model, a workplace development model, a workplace location choice model, as well as a fuel consumption and emission model. The sub-models are run iteratively over a 30 year time period. They are on the one hand linked by accessibility as output of the transport model and input into the land use model and on the other hand by the population and workplace distribution as output of the land use model and input into the transport model.

MARS has been used in the STEPS project to assess the impact of alternative fuel technologies and other more traditional urban policy instruments (Shepherd et al, 2008). MARS can take in fleet and emission factors developed from POLES/ASTRA scenarios and currently includes six fuel types within the private car mode. Differentiated fuel types and hence costs impact directly on the mode choice element.

The strength of MARS is its ability to run strategic policy combinations for an urban re-gion including traditional urban policy instruments as well as soft measures such as PT awareness campaigns, bus quality or tele-working. As the model can be run quickly it will be possible to determine the contribution to the reduction of CO₂ of individual instruments and of combinations with the aim to find an optimal combination to meet the suggested target trajectories.

MATISSE

Methods and tools for integrated sustainability assessment – 6FP project.

Measure

A measure is related to the transport sector. It comprises both R&D measures and related market entry of new technologies as well as transport policies (e.g. road pricing, fuel taxation) and in a wider sense including e.g. land use planning measures that would reduce travel.

Mid-term potential	The mid-term potential of renewable energies/biofuels is equal to the <i>realisable potential</i> for the year 2020.
MIME	Market-based impact mitigation for the environment – 6FP project.
NEEDS	New energy externalities development for sustainability – 6FP integrated project.
POLES	<p>POLES is a simulation model for the development of long-term energy supply and demand scenarios for the different regions of the world including a detailed analysis for the EU27 countries. POLES includes models for energy supply, energy demand (38 world regions), three energy markets, large energy consuming sectors (e.g. steel), biofuels and vehicle fleet model and energy trade model. The model runs until 2050 and is developed and maintained by DG JRC/IPTS.</p> <p>Technology assessment capabilities for energy technologies (conventional and renewable energy production) and transport technologies are implemented with capital stock and vintage models. Cost parameters and learning curves drive the diffusion of new technologies into the markets.</p> <p>Policy assessment capabilities and scenario studies with POLES include detailed world energy system scenarios, strategic areas for emission control policies, analysis of RTD strategies, assessment of emission trading systems and their impacts on international markets and price feedback. POLES allows for the study of different interconnected issues such as the consequences of emission control strategies on the price of internationally-traded fuels, on the producers revenues or on the corresponding negative price-feedback's in the consumer countries (EC 2006).</p>
Policy package	Bundle of single policy measures that are applied in the same scenario. Policies could address all modes and could be applied at different points of time and with varying intensity (e.g. variations of taxation levels). They not only include classical transport policy, but also R&D support or information campaigns.
REFIT	Refinement and test of sustainability indicators and tools with regard to European Transport – 6FP project.
Realisable potential	The realisable potential of GHG reduction technologies/measures represents the maximal achievable potential assuming that all existing barriers can be overcome and all driving forces are ac-

Realisable reduction potential	tive. Thus, general parameters as, e.g. market growth rates, planning constraints are taken into account. It is important to mention that this potential term must be seen in a dynamic context— i.e. the realisable potential has to refer to a certain year.
Reference Scenario	The Reference Scenario in GHG-TransPoRD is the scenario against which the policy packages were tested in WP4. Until 2030 the Reference Scenario is aligned with the PRIMES scenario as it is defined in the document “EU energy trends to 2030 — UPDATE 2009” (European Commission 2010b). From 2030 to 2050 the Reference Scenario is in line with the projections of the ADAM reference scenario (Schade et al. 2009).
Scenario in GHG-TransPoRD	Scenarios in GHG-TransPoRD build on the Reference Scenario and add transport policy packages and an adaptation of the energy system to the Reference Scenario. Other framework conditions, in particular population, remain the same across all scenarios. However, GDP and oil prices may vary as consequence of the implementation of policy packages. Both are estimated endogenously by the ASTRA-POLES models.
Shared Socio-economic Pathways	A set of five Shared Socioeconomic Pathways (SSPs) are currently under development by the climate change research community. The SSPs will, when completed, form a set of background (or reference) scenarios against which climate change policies can be tested. The SSPs take into account scenario concepts developed for the more well-established four IPCC SRES scenarios.
SRES Scenarios	The Special Report on Emissions Scenarios (SRES) is a report by the Intergovernmental Panel on climate change (IPCC) that was published in 2000. The greenhouse gas emissions scenarios described in the Report have been used to make projections of possible future climate change. The SRES scenarios, as they are often called, were used in the IPCC Third Assessment Report (TAR), published in 2001, and in the IPCC Fourth Assessment Report (AR4), published in 2007
STEPS	Scenarios for the transport system and energy supply and their potential effects – 6FP project.
Technical potential	If technical boundary conditions for production of renewable energies/biofuels (i.e. efficiencies of conversion technologies, overall technical limitations as, e.g. the available land area to install

wind turbines) are considered the technical potential can be derived. For most resources the technical potential must be seen in a dynamic context—e.g. with increased R&D conversion technologies might be improved and, hence, the technical potential would increase.

TENCONNECT Traffic flow scenario, traffic forecast and analysis of traffic on the TEN-T, taking into consideration the external dimension of the European Union – EU project to assess the options for further development of the TEN-T.

Theoretical potential For deriving the theoretical potential of new technologies or renewable energies/biofuels general physical parameters have to be taken into account (e.g. based on physical laws or on determination of energy flow resulting from a certain energy resource within the investigated region). It represents the upper limit of what GHG efficiency gains can be achieved or what can be produced as biofuels from a certain energy resource from a theoretical point-of-view, based on current scientific knowledge.

Theoretical reduction potential

TREMOVE TREMOVE is a simulation model developed to study the effects of different transport and environment policies on the emissions of the transport sector. The model estimates transport demand, modal split, vehicle fleets, well-to-wheel emissions and welfare levels under different policy scenarios. All relevant transport modes are covered. TREMOVE covers EU27 countries, Switzerland and Norway and it distinguishes between metropolitan, other urban and non-urban regions. The current model version runs until 2030.

The first versions of the model (TREMOVE 1) date 1997-1998, and have been developed by the economic department of Catholic University of Leuven (KUL) and Standard and Poor's DRI for the European Auto Oil II Programme. Since 2001 TML has been developing new (TREMOVE 2) versions of the model, mainly funded by Directorate-General Environment and FP6 projects (a.o. GRACE and iTREN-2030).

TREMOVE can assess impacts of new technologies on overall transport demand, fleets, emissions and welfare, if efficiency improvements and costs of the technologies are provided as input. This can be done for all transport modes, for both well-to-tank and tank-to-wheel emissions, and for urban and non-urban regions. For the road and rail modes, TREMOVE models in detail the fleet by vehicle type, vintage and technology. For inland ships the model distinguishes 21 vessel types (7 size classes for

bulk, cargo and pusher ships). Air transport is classified into 5 distance classes. In the urban regions, also mopeds, metro/tram and urban busses are modelled. TREMOVE calculates well-to-tank emissions for all transport fuels and electricity, thus can evaluate the effects of developments in fuel production pathways. Currently the model is being extended with a material composition module for cars (in collaboration with DG JRC, Seville), allowing further life-cycle analysis.

As the model has a strong economic core, TREMOVE is well suited to simulate the effects of pricing policies (as vehicle and fuel taxation, infrastructure charging, etc.). Also, congestion effects are modelled endogenously, enabling simulations on speed limits and infrastructure management (for details see www.tremove.org).

TRIAS

Sustainability impact assessment of strategies integrating transport, technology and energy scenarios – 6FP project coordinated by Fraunhofer-ISI