A TRANSPORT SCENARIO FOR EUROPE UNTIL 2050 IN A 2-DEGREE WORLD

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ABSTRACT

In its 4th Assessment Report the Intergovernmental Panel on Climate Change (IPCC) concludes that the risk of climate change with temperature increases of 4-5°C until 2100 has grown substantially and recommends strong actions to curb greenhouse gas emissions (GHG) until 2020. Though world leaders struggle to define a short-term Post-Kyoto policy to reach this goal, they agree that until 2050 the industrialised countries should reduce their GHG emissions by -70% to -80% compared with 1990 (see e.g. EC Communication COM(2009)39, US President Obama and G8 statements).

Transport in Europe is currently emitting about 23% of all GHG and 27% of CO_2. Thus if transport would not at all reduce GHG emissions until 2050 it would mean that any other European sector (e.g. industry, services, housing, energy conversion) would have to reduce to zero GHG emission. Obviously, the burden of GHG reductions has to be shared between the sectors, in particular as transport disposes of significant reduction options as well.

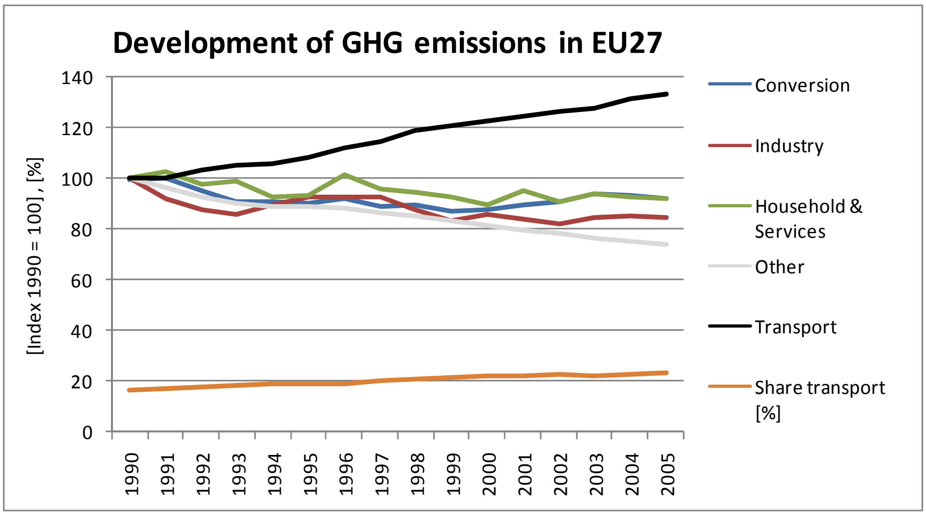
In this paper three transport scenarios for the EU27 until 2050 are presented: a Reference Scenario and two so-called 2-degree scenarios. The latter scenarios are embedded into the larger framework of a global GHG emission pathway and a European emission pathway that would achieve to limit global average temperature increase to 2°C (or CO_2 eq. concentrations of 450/400 ppm). This means the transport scenario considers both the European share on the global pathway and the transport share on the European pathway.

In the 2-degree scenarios transport policy packages with 20+ measures are implemented in Europe that integrates technology policy (e.g. fostering CNG, electric and hydrogen vehicles at different points of time), regulation (e.g. CO2 emission limits, binding use of ultra fluid lubricants, biofuel quotas), pricing policy (e.g. upstream inclusion of transport into the ETS) with organisational improvements (e.g. improved intermodality and railway capacity). In this scenario GHG emissions of transport are reduced by -52% until 2050. The strongest reductions are achieved by new low carbon technologies, by efficiency improvements of all transport modes, and in particular of road mode, and by demand shifts towards rail mode.

Keywords: transport scenario, climate policy, 2050, Europe, -80% CO2, integrated energy and transport scenario, impact assessment.

INTRODUCTION

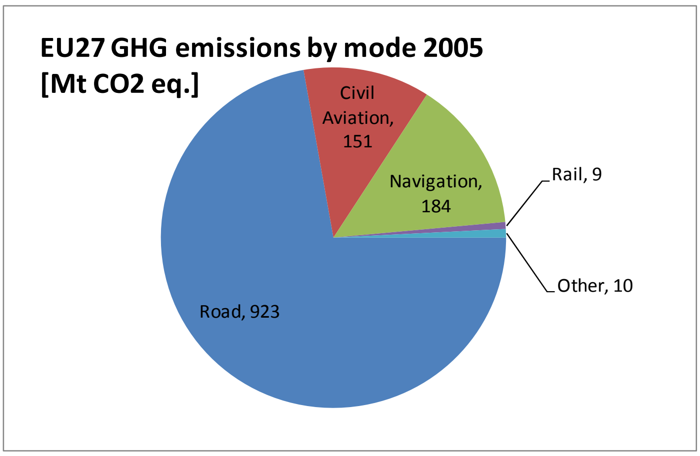
The transport sector in Europe contributed more than 23% of EU-27 GHG emissions in 2005 (1277 Mt CO2 eq.). Due to the high share of fossil fuel use, the share of CO2 emissions is even higher, amounting to more than 27% of EU-27 CO2 emissions in 2005 (1247 Mt CO2). As Figure 1 reveals, the transport sector is the only major sector in the EU-27 in which GHG emissions have risen compared with 1990. The same holds for the CO2 emissions of transport [European Commission 2007a]. Despite this growth trend, the European Commission has agreed on a target of a -10% reduction of GHG emissions by 2020 compared with the year 2005 for the non-ETS sectors, which includes transport [European Commission 2008].



Source: European Commission, 2007a

Figure 1: Development of GHG emissions of transport compared with other sectors in EU-27 (1990 to 2005)

The split of GHG emissions across the major modes of transport is presented in Figure 2. With more than 70%, roads generate by far the largest quantity of GHG emissions. Navigation and Civil Aviation, both including international bunkers, generated about 14% and 12% in 2005, respectively.



Source: European Commission, 2007a

Figure 2: EU-27 GHG emissions of transport by major mode in 2005

The EU has developed its position on climate change and climate policy through a number of communications, which all emphasize the target to stabilize temperature increase at 2-degree Celsius compared with pre-industrial levels [European Commission 2007b, European Commission 2009]. For 2020 this would imply that the EU reduces its GHG emissions by -20% by 2020 compared with 1990, if the rest of the world does not agree on reductions. However, if a joint global agreement similar to the Kyoto Protocol is achieved for the post-Kyoto period after 2012, the EU would accept a reduction target of as much as -30% by 2020. At the global level, the EU formulated the target of a reduction of -50% GHG emissions by 2050 compared with 1990, which according to the Intergovernmental Panel on Climate Change (IPCC) means a reduction of -80 to -95% by the industrialised countries by 2050 [IPCC 2007]. In other words: in 2050 the EU must emit less than 20% of the greenhouse gases emitted today. Comparing this conclusion with the 23% share of transport on today's EU GHG emissions it becomes obvious that transport also has to reduce its emissions drastically – despite the projected transport demand growth.
After this introduction the paper is structured into four main sections and is then closed by conclusions. In the first main section the methodology to set-up a European model system for all economic sectors and to link the global GHG emissions to the European transport system is explained. In the second section the transport policies applied in the 2-degree scenario are presented, which is then followed by the description of scenario results of three scenarios and the fourth section analysing the contributions of different transport and climate policies to the GHG reductions achieved in the transport sector.
The results presented in the paper have been developed in the ADAM project co-funded by the European Commission (ADAM = Adaptation and Mitigation Strategies: Supporting European Climate Policy). The scenarios presented are described in detail in Jochem et al. (2008) for the Reference Scenario and in Schade et al. (2009) for the 2-degree scenarios.

ADAM MODEL SYSTEM AND GHG FRAMEWORK CONDITIONS

The analysis of the EU transport system is embedded into a hybrid model system (HMS) that covers all economic sectors and the macro-economy, which is called ADAM-HMS. The basic concept underlying the ADAM-HMS is based on the following arguments: (1) it is feasible to link different types of models (e.g. top-down and bottom-up models), (2) it makes sense to link these models as each has specific strengths, and (3) the linkage of the models is more than the sum of the single pieces since it alleviates the limitations of the single models e.g. by considering feedbacks that can not be considered just within one of the models.

Two basic types of models have been integrated into the ADAM-HMS: top-down and bottom-up models. The terms emerge from the way these models look at the economy and its different sectors and actors. Top-down models come from the macro-perspective i.e. GDP, national employment or household consumption. Usually they disaggregate their analysis then into a number of economic sectors e.g. agriculture, vehicle manufacturing, construction, banking etc. and describe the interaction between these sectors. Such a model would constitute a macro-economic model (or if the number of sectors is highly disaggregated one would also speak of a meso-economic model). The variables in such a model would mainly represent monetary values. The analysis using such a model would most often be called a (macro-) economic analysis.

Bottom-up models start from technologies and processes. By aggregating their results across technologies they provide statements on (parts of) economic sectors. E.g. a model that considers all the technologies for producing electricity in a country by describing the installation of the power-plants would be describing the electricity generation sector of that country. This could be equivalent to one sector in the top-down model or only to a part of such a sector. The variables in such a model would represent both physical values e.g. energy demand, tons of material and monetary values e.g. cost of the technologies. The analysis applying this type of model would be called a sectoral or partial-economic analysis.

The drawback of the top-down approach is that it lacks the technological foundation for the economic choices made in the different sectors, but on the other hand it is able to consider the feedbacks of impacts between the sectors as well as the second round or indirect effects e.g. effects that occur because one sector stimulates the growth of GDP and via the demand side (i.e. consumption and investment) other sectors are also economically stimulated. The drawback of the bottom-up approach is that it lacks the interaction between the sectors as well as the second round effects, while it is able to describe the competition between different technologies and the structural change within a sector that is driven by the diffusion of new technologies.

The reason for linking top-down and bottom-up models is to overcome the individual drawbacks. The linked top-down model is able to consider technological details in the macro-economic analysis, while the bottom-up models receive the feedbacks from the other sectors and the second round effects from the macro-economy. Thus it came that ADAM developed the linkage between a top-down model (i.e. ASTRA) and a number of bottom-up models (i.e. EFISCEN, MATEFF, RESIDENT, SERVE, ISIndustry, PowerAce, EuroMM, see Figure 3).

Integration of models to form the ADAM-HMS

Figure 3 presents an overview of the ADAM-HMS and the linkages that have been developed between the models. In this paper we concentrate on the results from the ASTRA (in yellow in the figure), which was the bottom-up model for the transport analysis as well as the economic model. The purpose of the different models in the ADAM-HMS is the following:

- **POLES**: world energy system model that delivers fossil energy prices aligned with global energy demand as well as a GHG emissions path for Europe aligned with a global mitigation pathway.
- **ASTRA**: EU structural economic model that calculates the macro-economic effects of climate policy (top-down model applied in the ADAM-HMS).
- **RESIDENT**: bottom-up model describing the energy demand of the household sector for all purposes linked to housing (heating, electricity, etc.) but not for transport.
- **SERVE**: bottom-up model describing the energy demand of the service sectors for all purposes besides transport (heating, electricity, etc.).

- **ISIndustry**: bottom-up model estimating the energy demand of basic industries and the manufacturing sectors.

- **ASTRA-Transport**: bottom-up model calculating the energy demand of the transport sector. The transport model is directly integrated into the ASTRA model and thus the connection to ASTRA-Economics differs compared with the other bottom-up models.

- **PowerAce**: bottom-up model describing the market diffusion of renewables into the energy markets, in particular for electricity.

- **EuroMM**: bottom-up model modelling the full energy sector integrating the inputs of all final energy sector models.

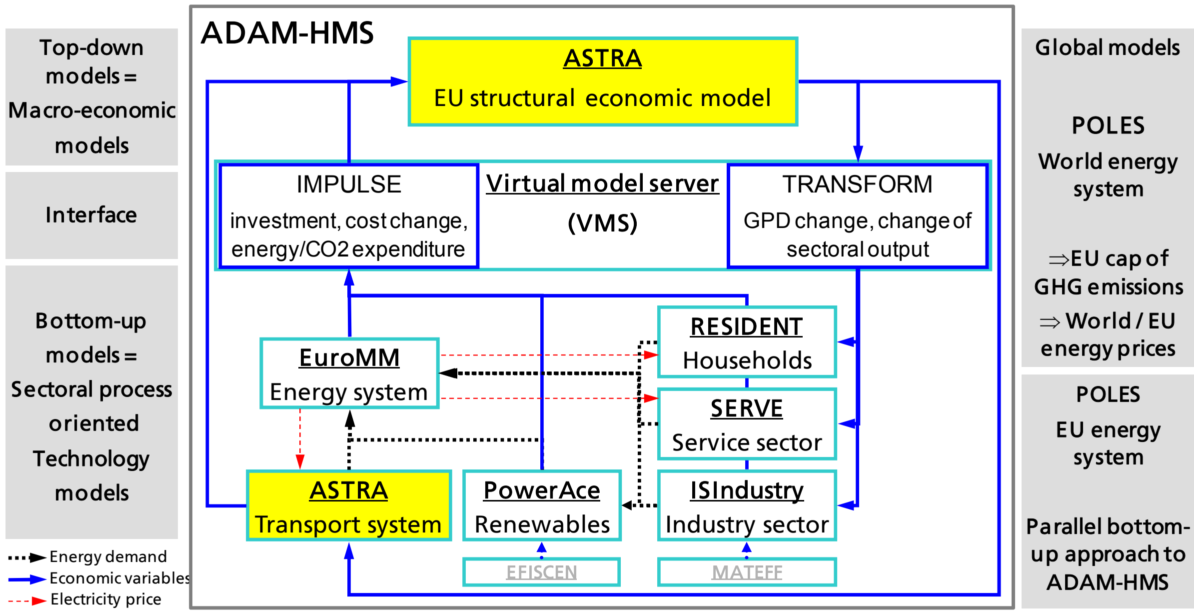
- **EFISCEN**: forest model estimating the biomass potentials of EU forestry and providing them to PowerAce i.e. no full integration into the feedback loops of ADAM-HMS.

- **MATEFF**: basic materials and material efficiency model providing savings potentials of materials to the other models, in particular to ISIindustry. Not fully integrated into the feedback loops of ADAM-HMS.

- **Virtual model server** (VMS): is a tool that simplifies, structures and semi-automates the multilateral data exchange between the various models as to create the scenario results the models had to be applied iteratively exchanging their results several times.

Figure 3 presents an overview on major data flows between the models. These consist of three major types of information: energy demand, energy prices and economic variables. The core of the exchange of data between the bottom-up models consists of the estimated energy demand by the different final energy sectors (black dotted arrows), which is provided to PowerAce and EuroMM from residential, services, industry and transport sector. In turn EuroMM calculates a new mix of power plants and a new electricity price using the world fossil energy prices of POLES. The new electricity price is fed back to the final energy models (red dotted arrows).

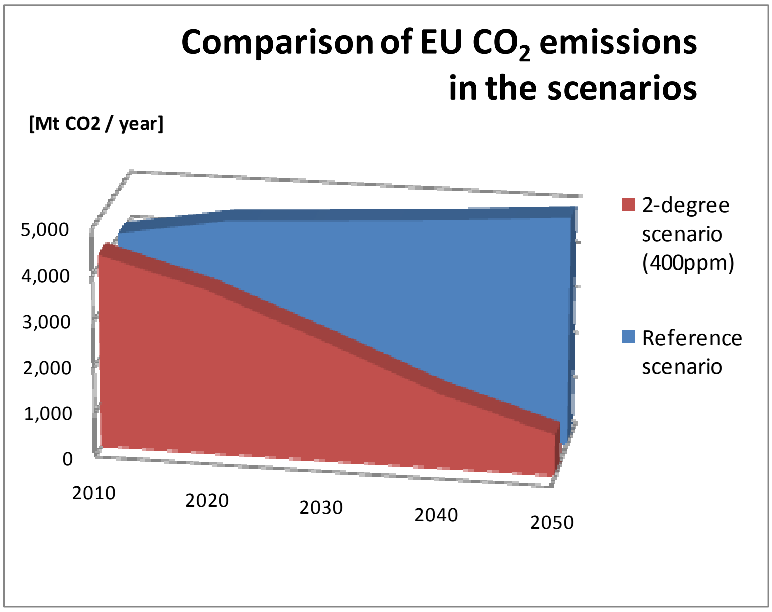
The second major group of data exchanged concerns the economic variables. These are needed to close the feedback loop between the bottom-up models and the top-down models (blue solid arrows). In the direction from top-down to bottom-up models the data to be transferred concerns mainly the drivers shaping the demand in the bottom-up models. Such drivers would be the GDP or income, the population, the trade flows, the sectoral output and the sectoral employment. In the direction from bottom-up to top-down models the data consists of investments that are induced by the mitigation policy as well as the avoided investment (e.g. reduced investment in coal power plants), changes of energy cost and/or energy expenditures in the different sectors, the reductions of imports of fossil energy, the prices and/or expenditures for CO_2 (or carbon). The interface via which the data is exchanged is the Virtual Model Server.



Source: Schade et al. (2009)

Figure 3: ADAM hybrid model system (ADAM-HMS) and global framework

Figure 4 demonstrates the need for strong reductions of CO_2 in the EU27 until 2050. As it can be seen for the Reference Scenario still a growth of about 25% from 2010 until 2050 is expected, while in the 2-degree scenario a reduction of more than 80% has to occur to align Europe with a global mitigation path to achieve that global average temperature increases until 2100 only by 2 degree Celsius compared with pre-industrial levels.



Source: Jochem et al. (2008), Schade et al. (2009)

Figure 4: EU27 CO2 emissions in reference scenario and 2-degree scenario

SCENARIO FRAMEWORK

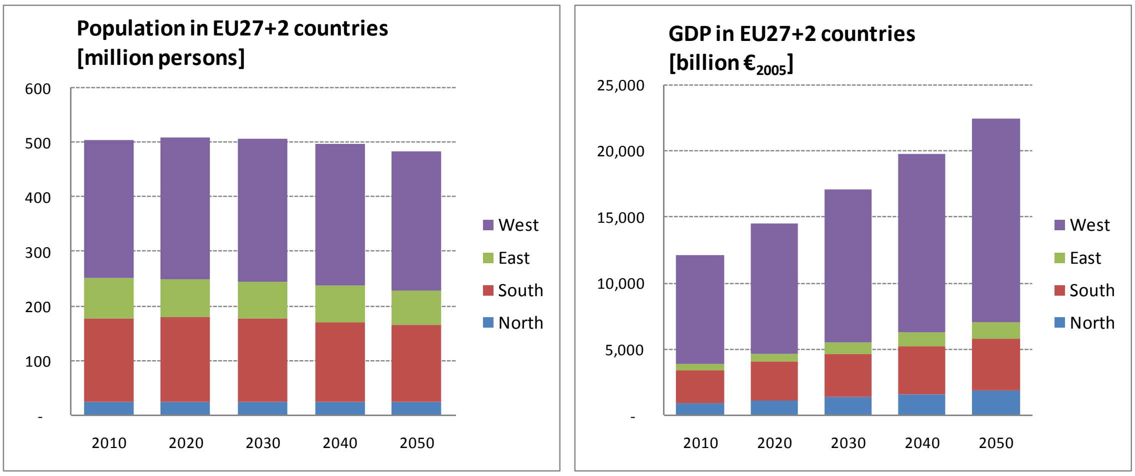
The scenario framework includes two elements: firstly, a definition of a Reference Scenario against which two different climate policy scenarios are compared, and secondly setting-up of boundary conditions to which all models have to comply to make the ADAM-HMS consistent.

The **Reference Scenario** describes a world which is facing an increase of global average temperature by +4-degree Celsius by 2100 compared with pre-industrial levels. With such an increase of temperature the energy system will react (e.g. by using more air-conditioning in buildings and vehicles or by requiring more or differently equipped power-plants in summer to cope with the reduced cooling capacity of rivers) which is considered by the ADAM-HMS.
The **2-Degree Scenario** is developed in two variants reflecting the uncertainty about with which level of $CO2_{eq.}$ concentrations the increase of temperature can actually be limited to 2-degree Celsius until 2100. The two variants represent (1) a concentration of 450 ppm $CO2_{eq.}$ in the long run and (2) a concentration of 400ppm $CO2_{eq.}$ of which the former would provide a 50% likelihood that the 2°C target is achieved and the latter a 70% likelihood. In the 2-Degree Scenarios after 2008 mitigation policies are implemented and climate change is successfully limited to +2°C, such that adaptation impacts to climate change remain very limited. The comparison between the Reference Scenario and the 2-Degree Scenarios then reveals the cost (or benefit) of mitigation policy.

Population and GDP for the European countries have been aligned between all models of the ADAM-HMS for the Reference Scenario. Both variables are estimated endogenously by the ASTRA model such that changes of these variables in the policy scenarios affect the bottm-up models. The ASTRA trends are presented in Figure 5. Population in EU27+2 grows until 2020 and then starts to decline leading to a reduction of -4% by 2050 compared with 2010.[1] However, the situation differs between the regions. The Southern and Eastern EU countries loose about -10% of population, while the Northern countries increase by about +5% and the Western countries remain nearly stable.

In terms of GDP the situation differs. The EU27+2 grow by about +85% between 2010 and 2050 (in real terms). The strongest growth is expected for the Eastern countries (about +170%) followed by the Northern and Western countries (around +90%). The Southern countries loose ground with a slower growth of about +60%. In particular, this means that the catch-up process in the Eastern countries will continue until at least 2050.

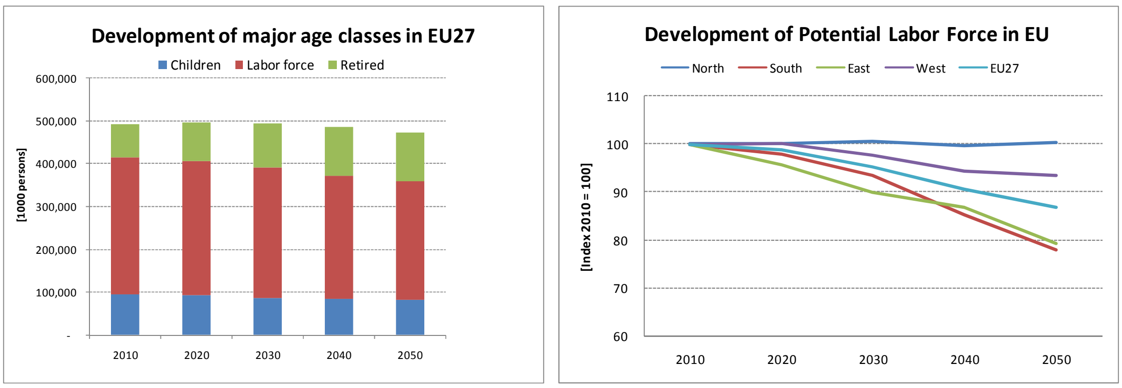
[1] The population projections allow for a net inwards migration into the EU between 1.3 and 1.4 million persons annually.



Source: Schade et al. (2009)

Figure 5: Population and GDP framework in the Reference Scenario

Particular attention should be paid to the changing demographic structure and the implications for employment. Figure 6 presents on the left hand side the age composition of the EU27 population. It can be observed that the number of children and the potential labor force reduces until 2050, while the number of retired persons is increasing. These numbers are calculated with children being persons that are 18 years old or younger and retired being persons that are 65 years old or older. Compared with 2010 the number of children would be 15% lower in 2050. For the potential labor force (i.e. those persons that are in the working age classes independently of they are employed or not) the reduction is -13%, while the retired persons will increase by +46% until 2050. As can be seen by the right hand side of Figure 6 the decline of the labor force differs for the European regions. In the Northern countries it remains nearly stable, while in Western countries it is reduced by about -7% and in Southern and Eastern countries by more than -20% until 2050 compared with 2010. Such changes of population also impact the transport demand.



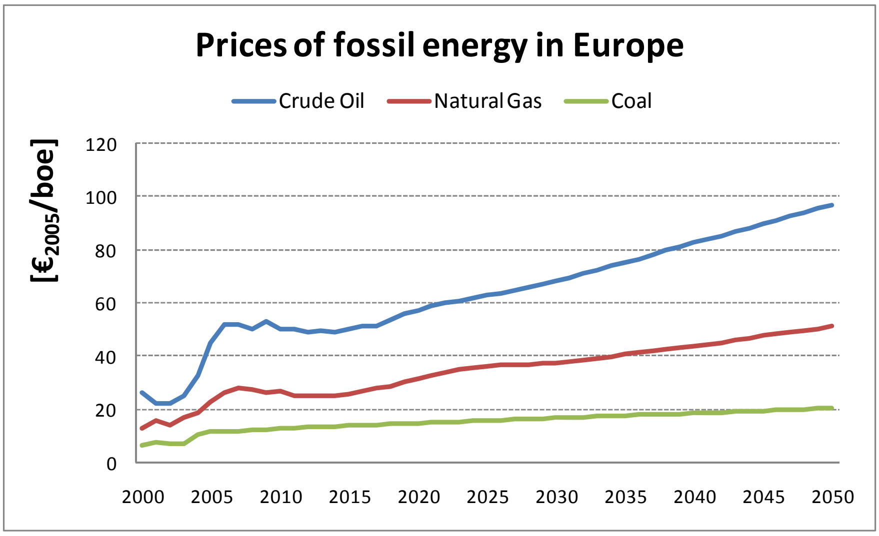
Source: Schade et al. (2009)

Figure 6: Population structure and labor force in the EU regions

The energy prices are provided by the POLES model and are used in the sectoral bottom-up models. This concerns the prices of crude oil and derived fossil fuels, e.g. gasoline, diesel, coal or heating oil. Electricity prices are estimated by EuroMM and PowerAce models.

Figure 7 presents the development of fossil energy prices in Europe. The prices reflect the global market concept or at least European market concept according to which basically the European countries all pay the same price for their fossil energy (which is mostly imported), such that differences in final energy prices (e.g. gasoline) would mainly result from taxation differences.

It can be observed that the price structure remains the same as today with crude oil being most expensive followed by gas and then coal. Compared with 2010 both the crude oil price and the natural gas price will increase by about +90% by 2050. The coal price increases by about +60%. This price path reflects an optimistic point of view, projecting the peak of world oil production around 2030 as well as assuming the feasibility of replacing reduced conventional oil production by unconventional oil such that the world oil production roughly remains stable until 2050. Given that other studies expect the peak of oil production between today and 2015 [e.g. EWG 2007] or at least report a sharp decline of production of mature oil wells of -5% per annum, which requires a new production capacity of 3.5 million barrels per day annually [IEA 2008], the fossil energy price path of oil and gas in the scenarios seem to be at the lower end of the possible scenarios.



Source: Schade et al. (2009)

Figure 7: Prices of fossil energy in Europe in Reference Scenario

MODEL RATIONALE OF ASTRA TRANSPORT MODEL

This section presents the rationale and structure of the transport model in ASTRA, which is made up of four of the nine ASTRA modules.[2] Major boundary conditions affecting the transport system have been explained in the previous section. Further it should be considered that urbanisation process continues in Europe meaning that more people will live in urban areas compared with today which are then better served by public transport, car-sharing or bicycles than by private cars.

[2] A detailed description of the ASTRA model can be found in [Schade 2005].

The ASTRA model focuses on intra-European transport, i.e. those transport activities within European countries (EU-27 plus Norway and Switzerland) and across them. This is particularly relevant for the navigation and aviation modes. Here, intercontinental transport is excluded, i.e. transport leaving the EU to other continents or entering the EU from other continents. Pipeline transport is excluded as well from the analysis. The ASTRA model distinguishes five modes for passenger transport: Slow modes (i.e. non-motorised transport by foot and by bike), car transport, bus transport, rail transport including trams and metros for short distances and air transport (domestic and intra-EU-27+2). For freight transport, three-plus-one modes are differentiated: Road mode differentiating heavy duty vehicles (HDV, larger than 3.5 t gross vehicle weight) and light duty vehicles (LDV, smaller than 3.5 t gross vehicle weight), Rail mode integrating inland waterways (IWW) in those countries where they play a role and allowing a separation of rail and IWW for selected indicators and ship mode, which means the short sea shipping occurring within and between the European countries.

The ASTRA model enables transport emissions occurring over the whole life-cycle to be calculated but excludes those arising from vehicle scrapping. That means the emission calculations consider the emissions from the driving activity including cold start emissions, upstream emissions of fuel production and upstream emissions of vehicle production. In the ADAM project, only the emissions and energy consumption of the driving activity (the so-called hot emissions) are taken from the ASTRA model. The other types of emissions and the energy demand in the transport sector are considered by other models of ADAM-HMS.

In ASTRA, the spatial representation consists of 76 zones. Each of the larger EU15 countries is spatially divided into four zones (apart from Denmark and Ireland with three zones), while Eastern European countries in particular have only one or two zones. ASTRA estimates the transport demand within each zone and across all zones for five different distance categories for passenger transport and four distance categories for freight transport. The ASTRA transport model consists of four models that are embedded into the socio-economic framework provided by the economic models of ASTRA. The four transport models are:

- Transport infrastructure model (INF module).
- Passenger transport model (REM and TRA module).
- Freight transport model (REM and TRA module).
- Vehicle fleet model (VFT module).

Transport infrastructure in the infrastructure model is driven by the investment in infrastructure that in turn depends on (1) GDP development, and (2) policy choices about which types of infrastructure should be financed, e.g. the Trans-European-Transport-Networks (TEN-T), rail freight corridors, ports etc. The capacity of infrastructure then influences the travel times and thus the destination and mode choices in the passenger and freight transport model.

Figure 8 presents the major interdependencies of the passenger transport model. The main output of the model is the passenger transport performance by mode as well as the vehicle-kilometres-travelled (VKT) by mode. The core of the model is a classical four-stage transport model [see Ortuzar/Willumsen 2004] with a rather limited assignment component (4^{th} stage). However, the first three stages act in an integrated and dynamic way, i.e. at none of these stages (generation, distribution, mode choice) are any assumptions made about structural stability. In the generation stage, e.g. changes in population, degree of (un-)employment or the car fleet may alter the number of generated trips. In the distribution stage, of course, changes may stem from generation, but more important is the **aggregated generalised transport cost** between any origin (O) and destination (D) in Europe. These aggregated costs consist of monetary costs and time costs and thus represent an accessibility measure for each European OD-relation described by the ASTRA functional zoning system.

Accessibility is influenced by the travel time (depending on infrastructure and network load) and the travel cost (depending, e.g. on tariffs, car prices, fuel prices, car taxes etc.) by mode. The same influences also affect the mode choice for each OD relation and each distance band (0-3.2 km, 3.2-8km, 8-40km, 40-160km, >160km distance). As a starting point for travel distances and travel times for each OD relation, the input from a European network model (SCENES model [ME&P 2000] and recently TRANSTOOLS model) is integrated into ASTRA. Distances and travel times change due to exogenous (e.g. growth of average distances within distance bands) and endogenous influences (e.g. investment in infrastructure, destination choice shifts to further away destination zones).

In the final step, passenger transport performances by mode are converted into vehicle kilometres using distance- and mode-specific occupancy rates. The occupancy rates are taken from national travel surveys (e.g. UK national travel survey) and decrease over time. The major outputs of the passenger transport model comprise the energy demand, emissions, transport expenditures, transport tax and toll revenues.

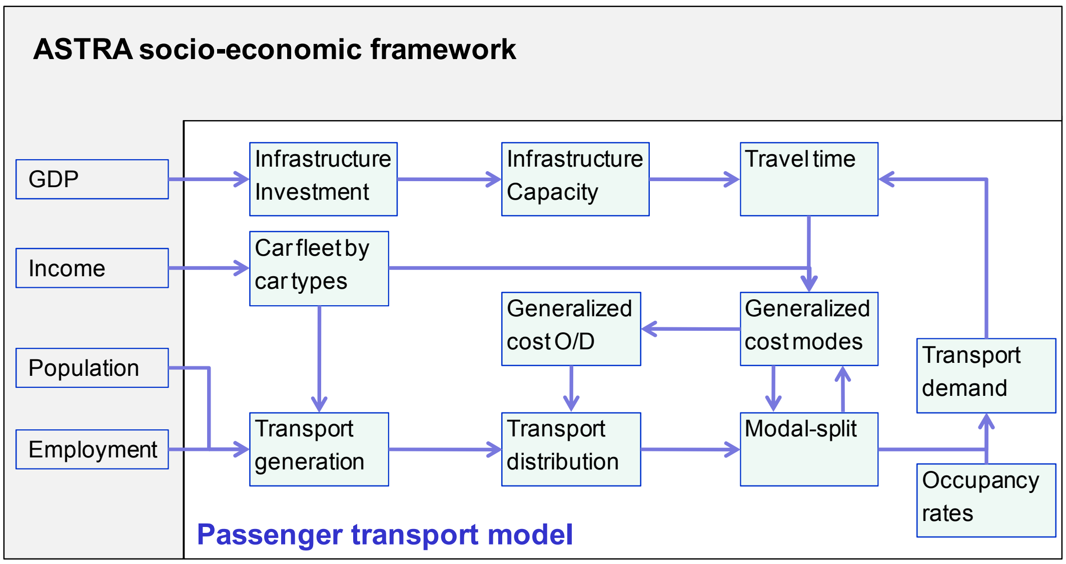


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Figure 8: ASTRA passenger transport model

Figure 9 shows the major interdependencies of the freight transport model. The main outputs of the model are the freight transport performance by mode as well as the vehicle-kilometres-travelled (VKT) by mode. The basic structure of the freight transport model is similar to that of passenger transport; it is a classical four stage transport model including only a limited 4th stage for assignment. A major difference concerns the distribution model of international freight transport, which derives the freight flows for the OD relations based on foreign trade flows. National transport flows are derived from the sectoral output of each goods producing sector (15 sectors) in the 29 European countries.

In the final step, freight transport performances by mode are converted into vehicle kilometres using distance- and mode-specific load factors. The load factors are taken from the SCENES model and exogenously increase over time due to the assumption of improved logistics. Further, the load factors are endogenously altered by transport cost, e.g.. to reflect organisational improvements in response to higher fuel prices or fuel taxes. The major outputs of the freight transport model comprise the energy demand, emissions, investments in freight vehicle fleets, transport tax revenues and toll revenues.

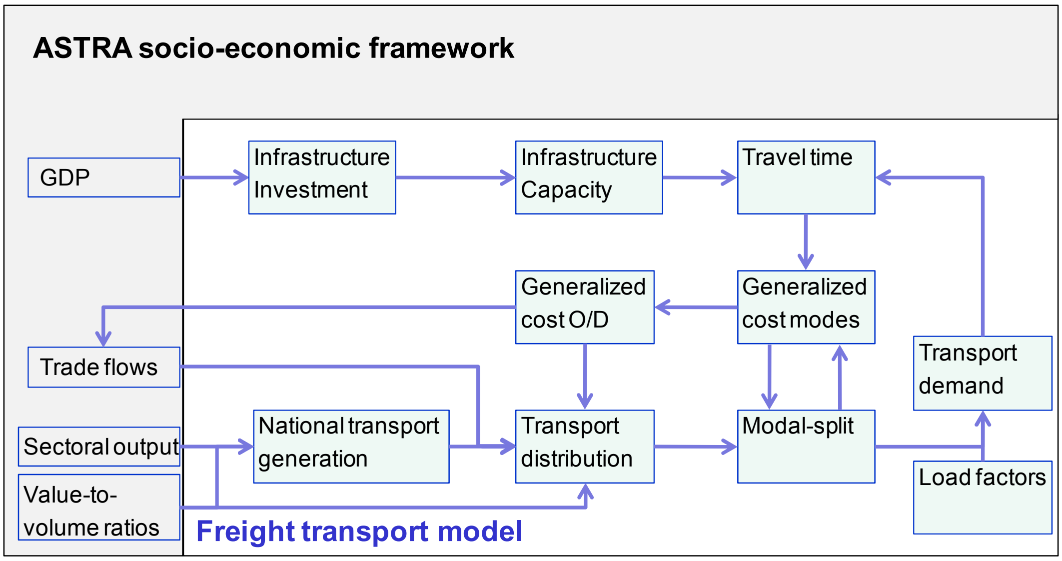

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Figure 9: ASTRA freight transport model

A third model relevant transport related climate policy is the car fleet model consisting of a stock model, a purchase model and a choice model for the selection of newly purchased cars. The car fleet model constitutes one of the most policy-sensitive model elements in ASTRA as it reacts to policies that support new technologies (e.g. subsidies or ‘feebates’, a novel combination of fees and rebates), to taxation policies (i.e. car and fuels) and to fuel price changes including changes of CO_2 taxes/certificates and energy tax changes. Other socio-economic drivers also affect the development of the car fleet, especially income, population and the existing level of car-ownership.

The car fleet model starts with the purchase model, which determines changes in the absolute level of the car fleet. Depending on changes in income, population and fuel prices, the level of the car fleet is estimated for the next time period. Together with information on the scrappage of cars which mainly depends on the age structure of the fleet, the number of newly purchased cars is then calculated. Purchase of cars via the second-hand market from other countries is neglected, which is a simplification that played a role for the new Member States before they joined the EU.

In the second step, the newly purchased cars are transmitted to the choice model, which determines the types of cars that are purchased. Car types include: Gasoline cars: three types differentiated by cubic capacity (<1.4l, 1.4-2.0l, >2.0l); Diesel cars: two types differentiated by cubic capacity (<2.0l, >2.0l); Compressed natural gas (CNG) cars; Liquefied petroleum gas (LPG) cars; Bioethanol cars, i.e. cars that can run on 85% bioethanol (E85) and more (incl. flex fuel); Hybrid cars, meaning advanced hybrid cars depending on timing, i.e. plug-in hybrids with the ability to run for a significant distance on electricity; Battery electric cars, i.e. smaller cars running in battery-only mode; Hydrogen fuel cell vehicles (hydrogen internal combustion engine is not considered a reasonable option).

The choice of new car depends on fuel prices (incl. taxes), car prices, taxation of car technologies, efficiency of cars, filling station network and, in the case of new technologies, on subsidies or feebates (combined fee and rebate system). In the case of electric vehicles, preferences are also altered by adapting the choice parameters in the model equations. Emission standards are also considered in the car fleet model. The point of time when a new car is purchased determines to which emission standard it belongs and which emission factors have to be applied to model its emissions. ASTRA distinguishes nine emission standards (2 pre-euro standards, euro1 to euro 7 standard). For example, if a car is purchased in 2005, it is assumed that it complies with the euro 3 standard. The third element is the stock model of the existing fleet. This model provides the number of cars and the age distribution in the fleet.

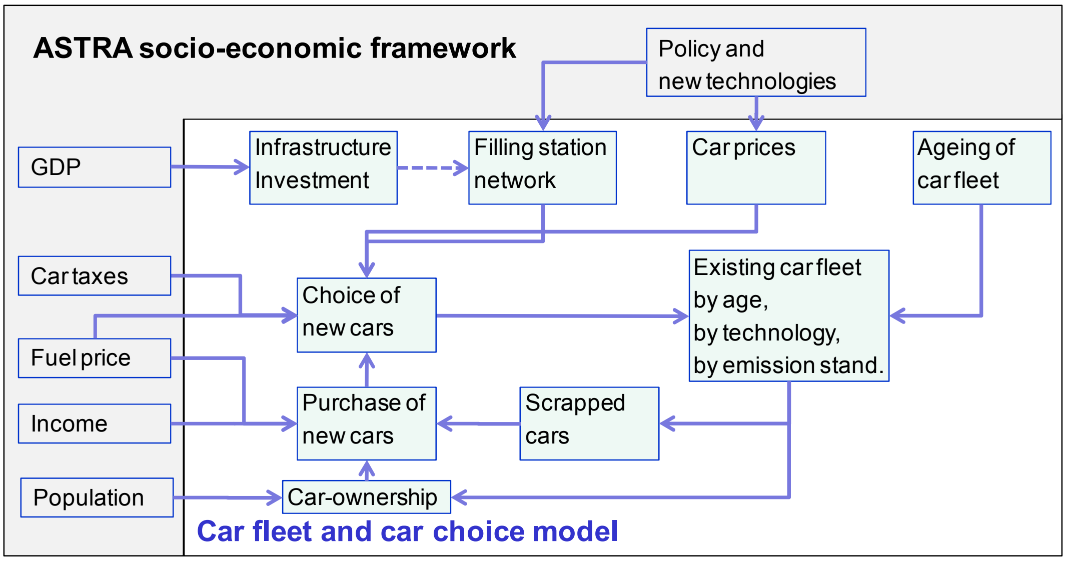

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Figure 10: ASTRA car fleet and car choice model

The major function applied in most of the transport models are discrete choice functions, i.e. logit functions [Ortuzar/Willumsen 2004]. These are, for instance, used to model the destination choice, mode choice and car purchase choice. The following two equations illustrate the mode choice calculation for passenger transport resulting in the transport demand by mode and trip purpose for a specific origin-destination pair:

$$D_{m,TP,OD} = D_{TP,OD} * \frac{e^{-\lambda_{m,TP} * GC_{m,TP,OD} + MC_{m,TP}}}{\sum_m e^{-\lambda_{m,TP} * GC_{m,TP,OD} + MC_{m,TP}}} \qquad \text{(eq. 1:)}$$

$$GC_{m,TP,OD} = DIST_{m,OD} * C_{m,TP} + DIST_{m,OD} * SP_{m,TP,OD} * VoT_{TP} \qquad \text{(eq. 2:)}$$

Where: D = transport demand (by purpose and origin destination (OD) pair) [trips]).
GC = generalised cost [€].
λ = logit parameter defining the elasticity of the modal shift [1/€].
MC = modal constant.
DIST = distance between origin and destination of trip [km].
C = specific cost per km by mode and trip purpose [€/km].
SP = speed of mode [h/km].
VoT = value-of-time [€/h].
m = index for modes (i.e. car, bus, rail, air, slow).
TP = index for trip purposes (business, private, tourism).
OD = index for origin and destination zones i.e. OD-matrix.

For clarity reasons, the index for European countries has been omitted. In the ASTRA model, all these equations would additionally include a country index representing the 28 European countries modelled in ASTRA. Instead of the GC-term (generalised cost), the equivalent logit equation for the car purchase choice would have a term that describes the utility parameters of cars, e.g. the vehicle price, fuel price, fuel efficiency, fuelling station network and vehicle taxation.

TRANSPORT TECHNOLOGY TRENDS

Though the internal combustion engine has been the dominant propulsion technology in the transport system for about one hundred years, it cannot be expected that this will continue in the next decades as well. The growing scarcity of fossil fuel resources, the challenges of combating climate change and the availability and competitiveness of new technologies will lead to a diversity of fuels and engine technologies in transport over the next 40 years. Backed-up by corresponding cost developments of vehicles and fuels in the ASTRA model, the following specific trends are expected to play a significant role in the mitigation scenarios:

- Conventional cars with internal combustion engines still have high energy efficiency potentials. The efficiency potentials for gasoline are higher than those for diesel cars in the future [TNO 2006].

- The breakthrough in battery technology (in particular in lithium-ion batteries) will enable battery electric city cars to gain large market shares in short and medium distance car transport. Currently it can be observed that many European countries support the development of markets for battery electric vehicles either by R&D, fleet demonstration tests or direct subsidies to purchase such vehicles.

- Electric engines and batteries will also be available for light duty vehicles used for last-mile delivery in cities.
- It will not be possible to replace the internal combustion engines in heavy duty vehicles and air transport with alternative engines in the next 40 years. Thus besides efficiency improvements, the main option to reduce the GHG emissions of these modes is to switch to higher shares of second (third) generation biofuels.
- CNG starts to play a role as a low carbon fossil alternative to gasoline and diesel for cars, buses and trucks as well as a bridge technology towards hydrogen for transport.
- After 2030 hydrogen fuel cell vehicles also begin to enter the market, but their share remains limited as long as fossil fuels are still available and renewable energy production is limited.
- For maritime shipping, the use of wind power (e.g. sky sails, turbo sails, Flettner rotors) will start to play a role due to growing fossil fuel and CO_2 prices. This was not considered for the short sea shipping in the ASTRA model, which underestimates the potentials of these technologies.

POLICY CHOICES FOR TRANSPORT IN THE EU

To simulate the mitigation scenarios in the ASTRA model it was necessary (1) to take into account the cross-cutting policies relevant for all sectors, and (2) to make a selection of the available transport policies.

The main cross-cutting policy considered for transport is the existence of a CO_2 certificate system, which would be the EU-ETS to start with that is extended in the post-Kyoto period to a global ETS system. Rail transport is subject to the EU-ETS from the beginning as far as electric rail transport is concerned. Air transport and ship transport become part of the ETS around 2012 and the remaining road transport is integrated into the ETS via an upstream system around 2020.

However, strong impacts of an ETS should not be expected for road transport in particular as even at prices of 100 €/t CO_2, the price increase of one litre gasoline fuel would be around 26 cent/l, which will only have limited impacts, if this is not accompanied by other measures. On the other hand, including road transport is important to obtain a closed system, i.e. one covering all the major sources of emissions, in order to be able to calculate the cap on CO_2 and GHG emissions. As including transport in the ETS via an upstream approach has the same effect as increasing the fuel tax, no further change of fuel taxation policy was considered.

Table 1 presents the transport policies that have been selected to simulate the ADAM mitigation scenarios. The selection is based on the heuristics of the feasibility, technical availability and comparative cost of the measures, but not on a detailed analysis and optimisation of cost competitiveness. This seems a better course to pursue than optimisation given the uncertainties of scenarios that run 40 years into the future.

The policies taken differ between the two climate policy scenarios i.e. the 450 ppm scenario and the more ambitious 400 ppm scenario.. Broadly speaking, the 450 ppm scenario can be characterised as focusing on passenger transport, urban freight transport, new engine technologies (in particular electric city vehicles and hydrogen fuel cells) and biofuels. The 400 ppm scenario adds measures for long-distance freight transport, in particular the efficiency improvements of HDV, improved logistics, improved competitiveness of railways and a modal shift to rail freight. Air transport in both scenarios is mainly addressed by the introduction of biofuels and the impact of including it in the ETS, which has a dampening impact on air transport growth in the longer run when CO_2 prices reach levels of 50 to 100 €/tCO_2.

It is also assumed that the European policy to improve the competitiveness of rail transport for both passengers and freight is continued and even augmented. In terms of passenger transport, this means the continued expansion of the high-speed rail network, upgrading speed restricted sections to standard speeds and the consistent introduction of synchronised timetables all of which increase the reliability and frequency of rail transport.

In terms of rail freight transport, this means eliminating bottlenecks, i.e. building dedicated freight rail tracks for sections or nodes that are relevant for long-distance rail freight but that face capacity constraints. In addition, cooperative logistics, i.e. logistic planning across different forwarding companies, should be fostered such that sufficient freight demand is generated to load full trains for long-distance shipments. Since such improvements also require infrastructure investments, these should be funded by revenues from the ETS payments of transport.

Table 1: Transport policies in the ADAM climate policy scenarios

Area	450 ppm scenario	400 ppm scenario
Cross-cutting policy		
Inclusion in ETS (air/ship 2012, road 2020)	Path to 80€/t in 2050	Path to 198€/t in 2050
Car transport		
CO_2 emission limits for cars	Up to -10% fuel efficiency compared with REF	The same
Efficiency labelling of cars	Avg. -3% energy demand	The same
Low resistance lubricants binding legislation	-2.5% energy demand	The same
Battery technology breakthrough (E-mobility), policy support and linkage of battery vehicles with increased use of renewable electricity	City cars only, diffusion by R&D&prototype-sup-port 2010, market share 3% in 2020, 8% in 2050	Additional feebate for market entry, market share 8% in 2020, 21% in 2050
Hydrogen fuel cell breakthrough, policy support for R&D, field tests and subsidies at market entry. Fuelling station network build-up.	Market entry 2025, market share 1% in 2030, 8% in 2050	The same
Bioethanol quota (partly by blending in gasoline)	10% of gasoline in 2020 (flex fuel cars & blended)	Quota increase to 20% in 2035, 25% in 2050
Rail passenger transport		
Increased competitiveness compared with long distance road and air transport	---	Rail infrastructure and services improved
LDV transport		
Battery technology breakthrough (E-mobility)	Starting 2015, reaching 10% new LDV in 2030, and 30% in 2050	The same
CO_2 emission limits for LDV enforced early	Up to -10% fuel efficiency compared with REF starting 2016, fully effective 2024	The same
CO_2 emission limits for LDV medium-term enforcement	---	Up to -10% fuel efficiency compared with 450ppm starting 2025, fully effective 2040
HDV transport		
CO_2 emission limits for HDV in medium-term	---	Starting 2030, reducing CO_2 -5% by 2040 and -10% by 2050.
Additional reaction of logistics to cost increase of CO_2 certificates	---	+15% / 21% increased load factor short/long
Driver education	---	Up to -10% fuel efficiency relative to REF
Low resistance tyres	---	Up to -5% fuel efficiency relative to REF
Logistics		
Improved logistics for all freight modes reduces vehicle-km	Corporate logistics, network logistics etc.	The same
Improved rail logistics, improved rail freight accessibility+information => modal-shift to rail	---	Starting 2020, +5% rail mode share in 2050
Biofuel		
Quota for biodiesel in road transport (in REF scenario the quota is already 9% in 2020)	Increase to 12% in 2030 and 16% in 2050	Increase to 17% in 2030 and 30% in 2050, increase mainly HDV
Quota for biodiesel in rail transport for diesel engines	Starting 2015, 5% share in 2030, 15% in 2050	The same
Quota for biofuel in air transport (e.g. Jatropha based)	Starting after 2012, 4% in 2020, 10% in 2030, 25% in 2050	Starting after 2012, 4% in 2020, 20% in 2030, 50% in 2050 (doubling)

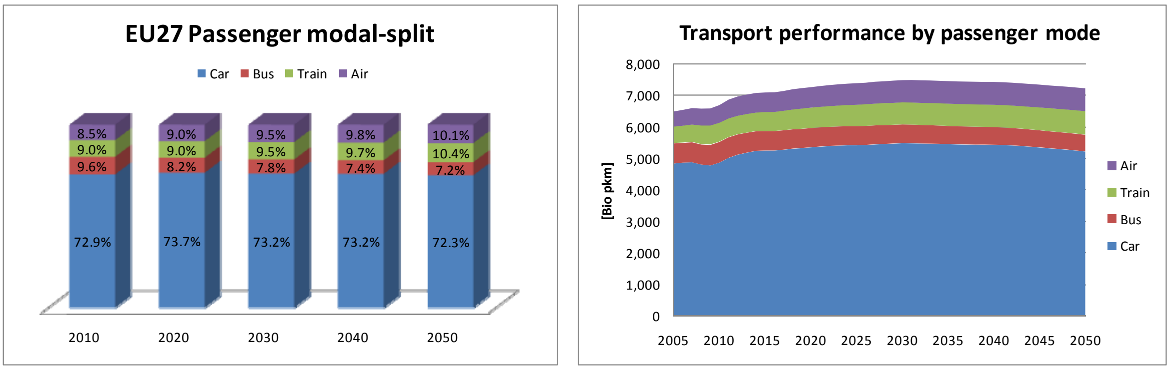
Source: Schade et al. (2009)

RESULTS OF SCENARIOS

This section presents the scenario results for the transport sectors for the two variants of the ADAM 2°C scenario: the 450 ppm scenario (450 ppm) and the 400 ppm scenario (400 ppm). Since, the comparison with the Reference Scenario (REF) is often used to illustrate the results, this section starts with a brief presentation of the major transport trends in the Reference Scenario until 2050.

Overview of the Transport Reference Scenario

Figure 11 presents the trends for passenger transport. Total demand increases only slightly until about 2035 and then declines due to the demographic development in Europe, i.e. the population decrease, which actually starts more than a decade earlier. It should be noted that air transport only includes intra-European transport, i.e. excludes the fastest growing segment - intercontinental air transport. It can also be observed that road transport will remain the most important mode with a modal share of more than 70% of all passenger-km (pkm). Air transport shows the strongest increase in modal share, but rail transport also increases its modal share due to the greater availability of high-speed rail connections in the EU. On the other hand, bus transport has a reduced modal share as a result of the demographic development (i.e. fewer children and less demand for transport to education centres), changes in transport behaviour in Eastern Europe (i.e. growing car-ownership and less use of public transport) and changed trends in the older generations (i.e. more retired persons own a car than was the case in the past).

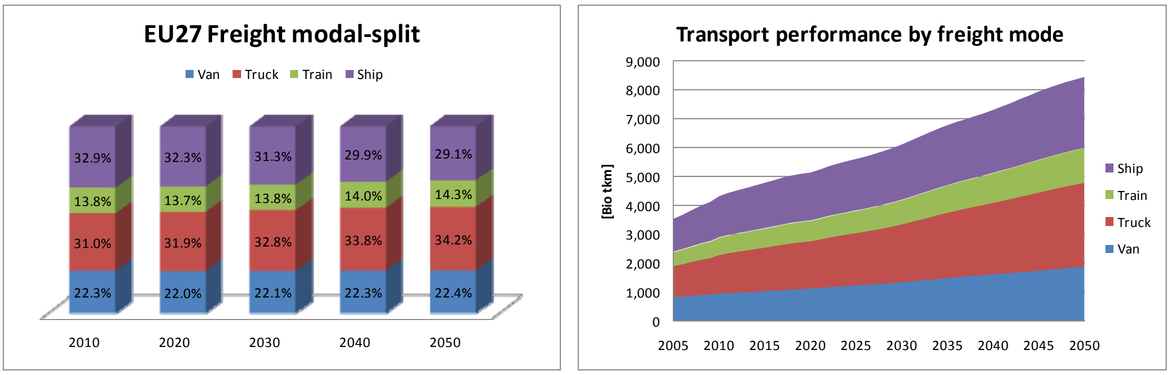


Source: Schade et al. (2009)

Figure 11: Development and structure of passenger transport demand in EU27 (Reference Scenario)

The picture for freight transport demand differs significantly as revealed by Figure 12 . Total freight transport performance increases by more than 130% from 2005 until 2050. Heavy goods vehicles show the strongest growth; their modal share increases by more than 3%. There is also a slight increase in the modal share of rail freight[3] as a consequence of the European railway liberalisation together with the construction of an interconnected European rail network. Short sea shipping suffers a slight loss of its modal share but continues to be one of the two most important freight transport services together with heavy goods vehicles.

[3] In countries featuring IWW, their performances are aggregated into the rail freight mode as the transport characteristics are similar. Thus about 20% of the rail freight figures refer to IWW, with a declining share in the future.

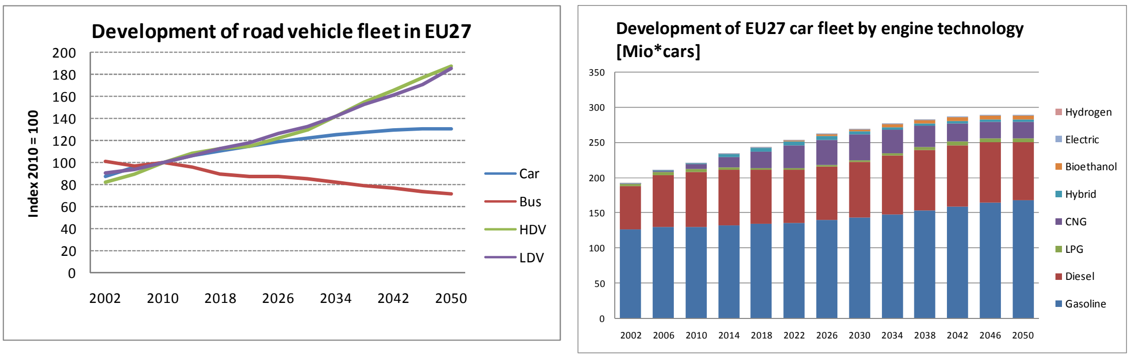


Source: Schade et al. (2009)

Figure 12: Development and structure of freight transport demand in EU27 (Reference Scenario)

The road vehicle fleet develops roughly in line with the transport demand as can be seen in Figure 13. The strongest growth is expected for heavy trucks (HDV) and light trucks (LDV), although improved load factors mean that the fleet does not have to grow as strongly as the transport demand. Compared with 2010, these two fleets increase by about 80%. Over the same period, the bus fleet is reduced by about 15% and the car fleet increases by about 30%, which is stronger than the transport performance and reflects both the reduced annual mileage of cars and the reduction of occupancy rates over time.

The composition of the fleet changes slightly. Due to relatively lower fuel prices and the development of the relevant fuelling station network, CNG cars gain market shares after 2010. The trend towards the dieselisation of cars slows down and gasoline cars increase their market share due to larger efficiency potentials and improvements, particularly in the smaller car categories. Hydrogen does not enter the market, and battery electric vehicles occupy only a small niche market, while advanced plug-in hybrids gain a small market share as do bioethanol (E85) cars.

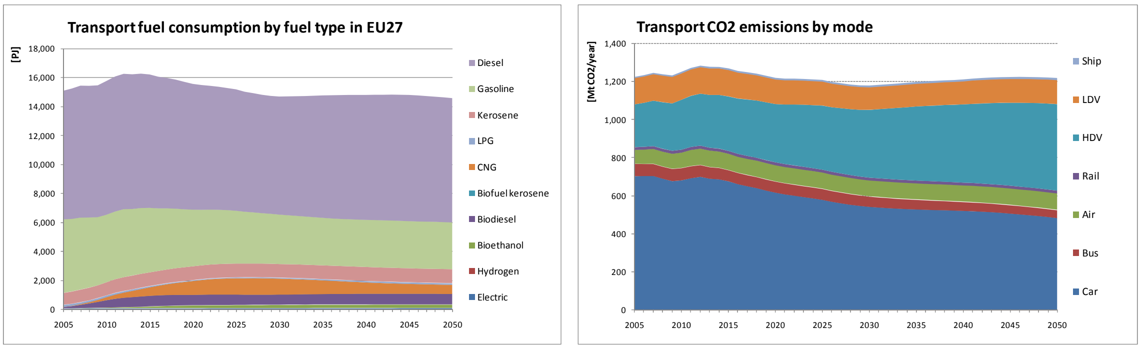


Source: Schade et al. (2009)

Figure 13: Development of vehicle fleets in EU27 (Reference Scenario)

Figure 14 presents the energy consumption of transport by type of fuel and the CO_2 emissions by transport mode. It can be observed that both trends are quite stable, which shows that significant efficiency gains are already expected to occur in the Reference Scenario in the transport sector to compensate for the growth in transport demand. The main growth is in freight transport demand so that a shift occurs between freight and passenger energy demand, with freight accounting for 28% of the energy demand in 2005 and for 40% in 2050. This means that freight energy demand increases continuously, while passenger energy demand declines after about 2012. These trends can also be observed for fuels, where diesel fuel demand remains more or less stable over the whole period, while gasoline demand is significantly reduced due to efficiency gains of cars and the fuel switch to biofuels and CNG.

Accordingly, the CO_2 emissions from cars fall significantly until 2050, while they increase strongly for heavy duty vehicles, and moderately for air, shipping and rail transport. It should be noted once again here that air transport CO_2 emissions exclude intercontinental flights.



Source: Schade et al. (2009)

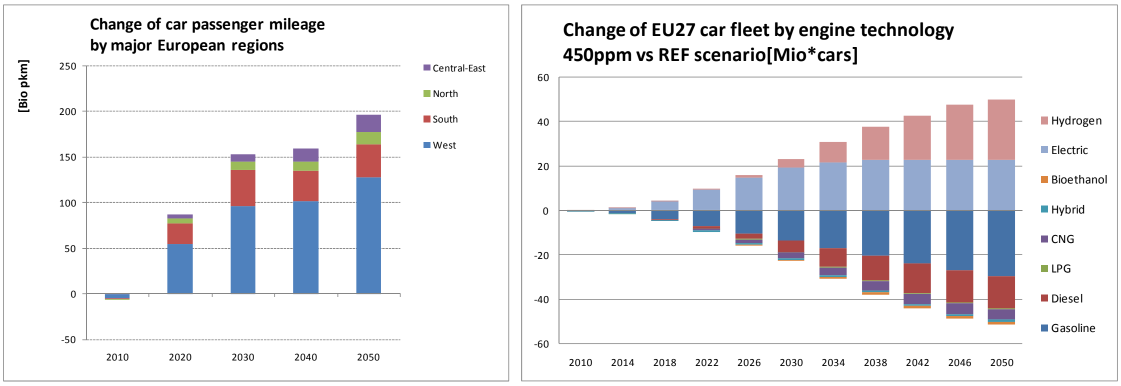
Figure 14: Development of transport energy demand and CO_2 emissions (Reference Scenario)

Transport in the 2°C scenarios

The two variants of the 2°C scenario are assumed to build upon each other. A first set of transport-related policies is implemented in the 450 ppm scenario, and then a second set of policies is introduced in addition to these in the 400 ppm scenario.

Passenger and freight transport react in different ways to the policies. The strongest reaction in passenger transport is in the car fleet, while transport performance is adapted only to limited extent. The composition of the car fleet is tackled by several policies leading to an increase of efficiency and a diffusion of new engine technologies, in particular battery electric vehicles and hydrogen vehicles. As Figure 15 illustrates, there are about 20 million battery electric city vehicles in the fleet in 2050 as well as about the same number of hydrogen fuel cell vehicles. All other technologies relinquish some of their market shares. In particular, small gasoline cars are strongly affected as these have to compete with the battery electric vehicles

These new technologies as well as the efficiency gains in conventional cars have the effect of increasing the cost of purchasing a car, but at the same time they significantly reduce its running costs. This results in a rebound effect in the order of 2 to 5% in terms of car passenger transport performance (see Figure 15).

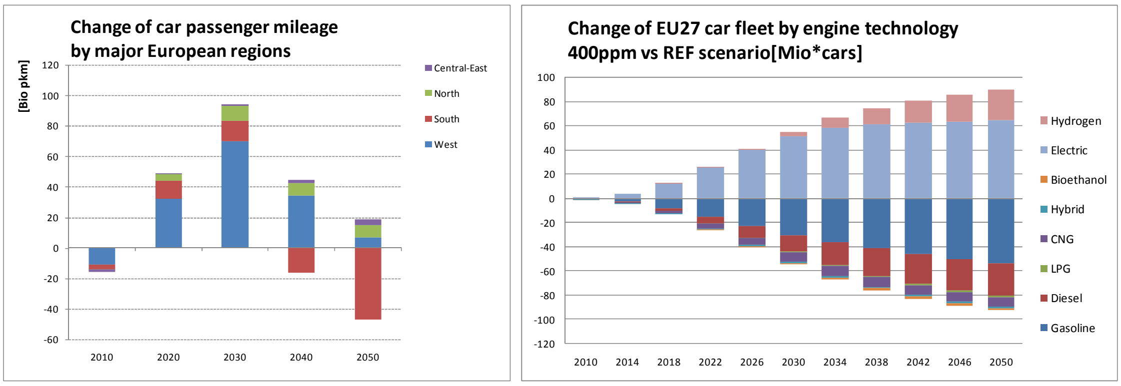


Source: Schade et al. (2009)

Figure 15: Change in car mileage (pkm) and the car fleet in the 450 ppm scenario

The difference in passenger transport in the 400 ppm scenario can be observed in Figure 16. The diffusion of new technologies, in particular battery electric vehicles, is reinforced by policies supporting the market entry of electric vehicles and the greater cost of running fossil fuel based cars due to the increase of the CO_2 certificate price. As a result, the number of battery electric vehicles reaches about 60 million in 2050, which means that they become the main type of car used in cities. This is further supported, e.g. by zero-emission requirements in cities.

The increased energy costs resulting from the higher CO_2 certificate prices have the effect of reducing and, in the last decade with the highest prices, even avoiding altogether the rebound effect of increased demand due to efficiency gains.

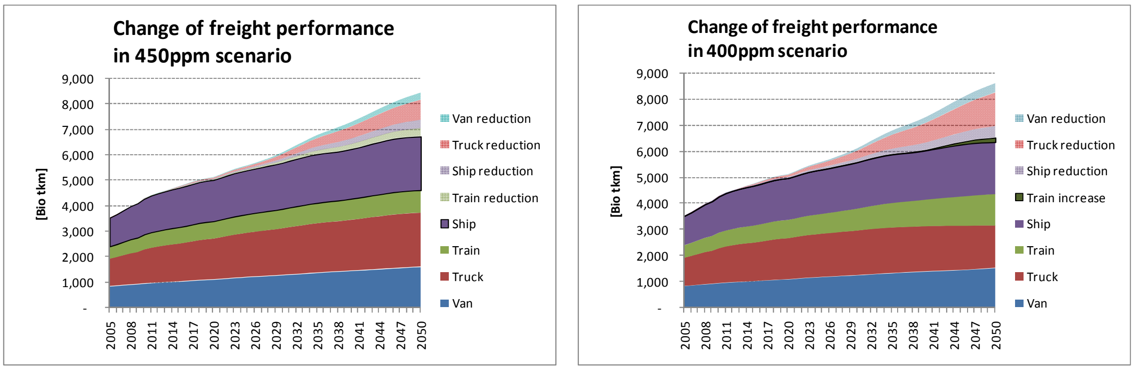


Source: Schade et al. (2009)

Figure 16: Change in car mileage (pkm) and the car fleet in the 400 ppm scenario

For freight traffic, the efficiency of trucks and vans also plays a role as do new engine technologies for vans. However, a demand reduction is also expected and observed here . The first but not the most important reason is the slight reduction of GDP compared with the Reference Scenario which has the effect of reducing freight volumes and consequently also performance.

The second reason is the reduction of freight transport distances due to a number of developments driven by non-transport policies and reinforced by the transport policies. The trend of re-urbanisation concentrates both the centres of consumption and the centres of labour supply, which makes these locations also attractive as production sites, such that transport distances are reduced as a side effect. Further, increased energy prices as well as including the cost of CO_2 force logistics to improve to avoid unnecessary journeys, e.g. to transhipment points and to select instead either fewer transhipments or closer transhipment points. In total, these effects reduce freight transport performance by close to 20% in the 450 ppm variant and by about 22% in the 400 ppm scenario. In the 400 ppm scenario, the increased competitiveness of rail due to infrastructure and organisational improvements leads to an additional modal shift of about 5% in 2050, which further reduces truck transport performance.



Source: Schade et al. (2009)

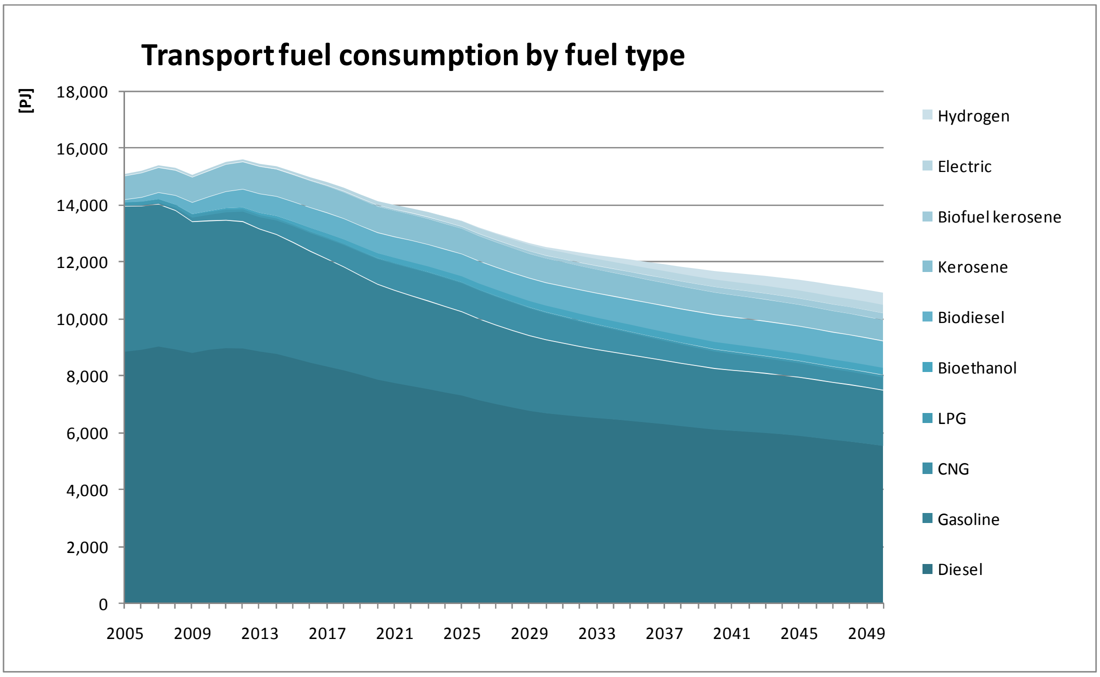
Figure 17: Change of freight performance in the 2°C scenarios

The trends described and the transport sector's adaptations to them influence both energy demand and CO_2 emissions in the transport sector. Table 2 presents the total transport energy demand for different regions and Figure 18 shows the consumption of different fuels in the 450 ppm scenario. In 2050, transport energy demand will be reduced by -24% compared with the Reference Scenario and by -27% compared with 2005. Fossil fuel demand is significantly reduced until 2050, while the demand for biofuels, electricity and hydrogen rises. All fossil fuels are decreased, i.e. diesel, gasoline, kerosene, CNG and LPG, though diesel takes the biggest cut of about 70% (about 3000 PJ). About 40% of the reduction is from passenger transport and 60% from freight transport. However, the timing of reductions differs. Passenger transport responds in a faster manner so that a significant reduction is already achieved by 2020, while the reductions only become significant for freight transport around 2030. The alternative fuels increase to hold moderate shares in 2050 with about 13% for biofuels, 4% for hydrogen and 3% for electricity.

Table 2: Changes of transport energy demand on regional level in the 450 ppm scenario

[PJ]	Reference Scenario			2° Scenario (450 ppm)			Changes (450ppm vs. Ref.)		
Country group	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**
North	1,232	1,241	1,258	1,206	1,144	1,021	-2%	-8%	-19%
South	4,325	4,213	3,736	4,184	3,820	2,876	-3%	-9%	-23%
East	1,413	1,559	1,548	1,377	1,442	1,275	-3%	-7%	-18%
West	9,537	9,282	8,759	9,208	8,370	6,366	-3%	-10%	-27%
EU27	**15,781**	**15,579**	**14,593**	**15,265**	**14,114**	**10,928**	**-3%**	**-9%**	**-25%**

Source: Schade et al. (2009)



Source: Schade et al. (2009)

Figure 18: Transport fuel consumption by fuel in the 450 ppm scenario in EU27

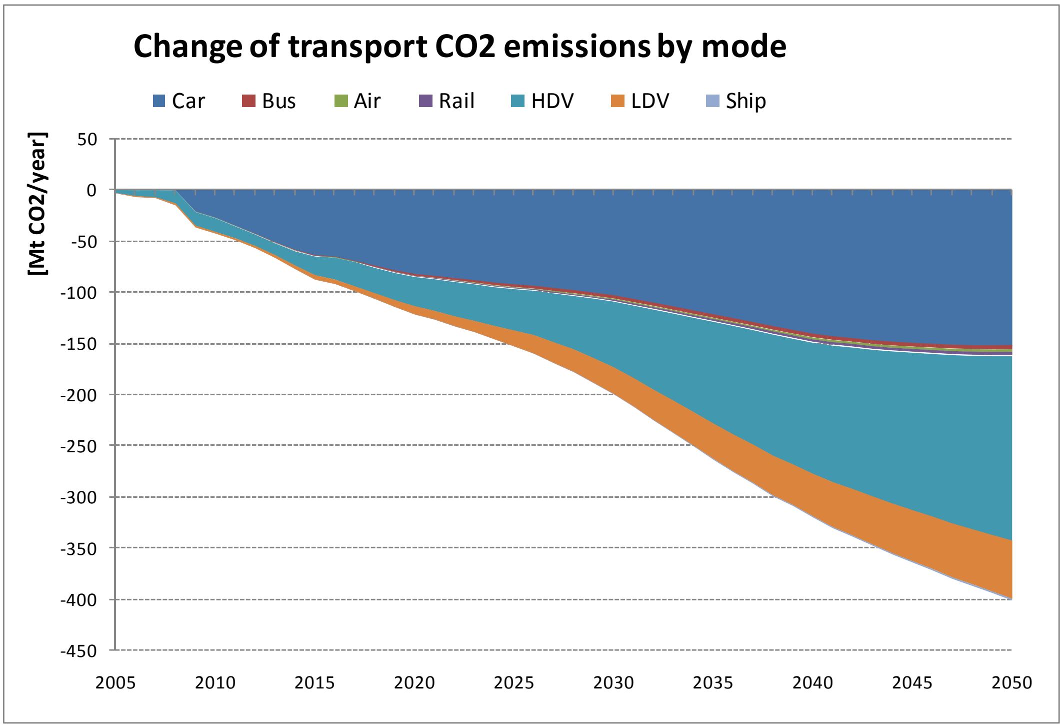
The CO_2 reductions reflect the patterns of energy demand reductions (see Figure 19). The largest decrease is observed for heavy duty vehicles. However, car transport contributes about three quarters of the total reductions in 2020 and remains the second most important until 2050. A further significant reduction comes from the efficiency gains of light duty vehicles (LDV) which are stimulated by the CO_2 emission limits imposed on LDVs and the diffusion of electric engines into the LDV fleet which are then used for zero emission city goods delivery.

Since, at no point in time do bus, rail, ship and air transport together emit more than 20% of the total transport CO_2 emissions, the CO_2savings from these modes are also smaller than for car and truck transport by one order of magnitude. Thus they are illustrated as a small area in Figure 19, contributing altogether less than 4% of transport CO_2 reductions. Partially, their CO_2 reductions are compensated by demand growth due to the modal-shift from the road modes towards rail and ships.

Table 3: Changes of transport CO_2 emissions on regional level in 450 ppm scenario

[Mt CO2 / year]	**Reference Scenario**			**2° Scenario (450 ppm)**			**Changes (450ppm vs. Ref.)**		
Country group	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**
North	105	106	114	103	98	86	-2%	-8%	-25%
South	335	328	308	324	296	220	-3%	-10%	-28%
East	109	114	126	106	105	98	-3%	-7%	-22%
West	751	738	763	726	663	501	-3%	-10%	-34%
EU27	**1,242**	**1,228**	**1,250**	**1,203**	**1,109**	**854**	**-3%**	**-10%**	**-32%**

Source: Schade et al. (2009)



Source: Schade et al. (2009)

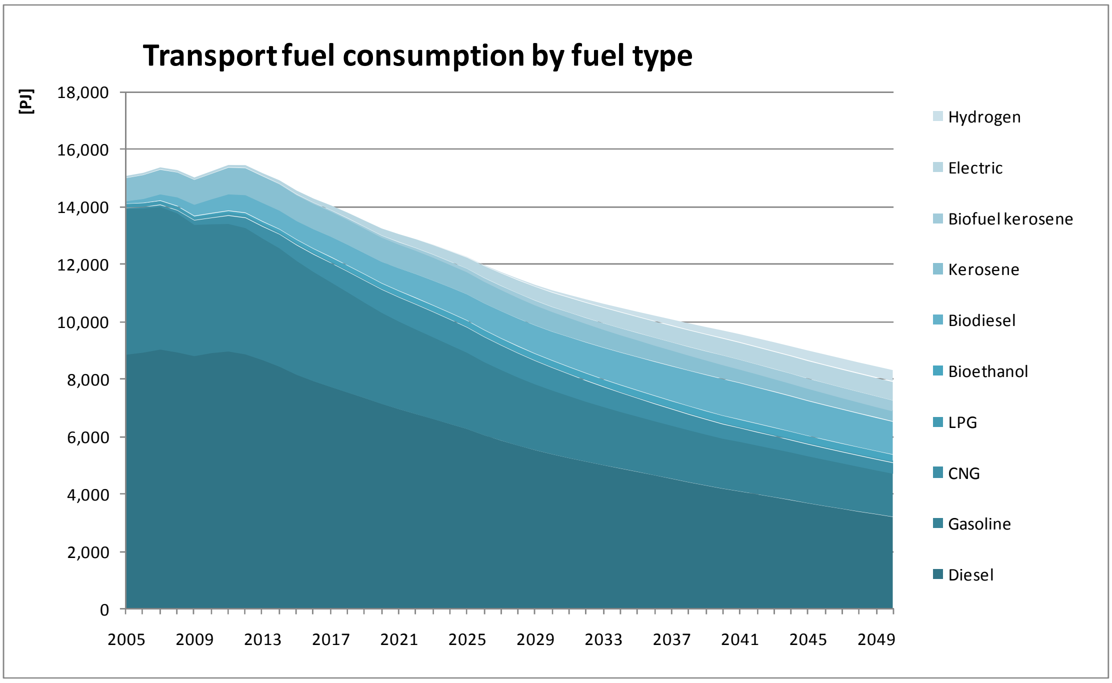
Figure 19: Change of CO_2 emissions of transport in 450 ppm scenario in EU27

Table 4 provides the total transport energy demand and Figure 20 the consumption of different fuels in the 400 ppm scenario. In 2050, transport energy demand will be reduced by -42% compared with the Reference Scenario and by -45% compared with 2005. Fossil fuel demand is significantly reduced until 2050, while the demand for biofuels, electricity and hydrogen increases. All fossil fuels are decreased, i.e. diesel, gasoline, kerosene, CNG and LPG, although about 65% (about 5300 PJ) comes from a reduction of diesel. In 2050, about 40% of the reduction comes from passenger transport and 60% from freight transport. However, the timing of reductions differs. Passenger transport responds faster so that about 60% of reductions are due to passenger transport in 2025, while the reductions in freight transport only kick in after this. The alternative fuels increase to higher shares in 2050 with about 21% for biofuels, 8% for electricity and 5% for hydrogen.

Table 4: Changes of transport energy demand on regional level in the 400 ppm scenario

[PJ]	**Reference Scenario**			**2° Scenario (400 ppm)**			**Changes (400ppm vs. Ref.)**		
Country group	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**
North	1,232	1,241	1,258	1,204	1,060	782	-2%	-15%	-38%
South	4,325	4,213	3,736	4,177	3,650	2,317	-3%	-13%	-38%
East	1,413	1,559	1,548	1,373	1,341	990	-3%	-14%	-36%
West	9,537	9,282	8,759	9,186	7,818	4,705	-4%	-16%	-46%
EU27	**15,781**	**15,579**	**14,593**	**15,231**	**13,242**	**8,294**	**-3%**	**-15%**	**-43%**

Source: Schade et al. (2009)



Source: Schade et al. (2009)

Figure 20: Transport fuel consumption by fuel in the 400 ppm scenario in EU27

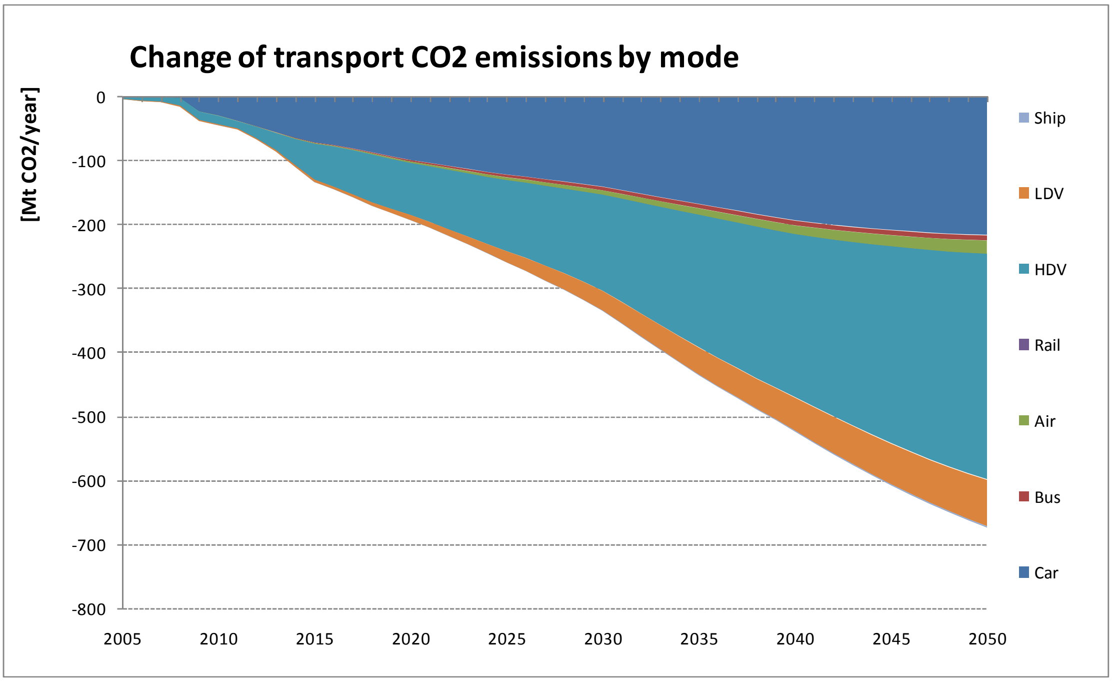
Figure 21 illustrates the changes in transport CO_2 emissions in the 400 ppm scenario. Transport reduces its CO_2 emissions by -52% compared with 2005, which means the applied policy programme does achieve a significant reduction , but not sufficient to achieve -80% GHG emissions by 2050. 70% of the additional reduction compared with the 450 ppm scenario is from the freight sector due to the increased use of biofuels, efficiency improvements of HDV and to a large extent from logistics improvements and the modal shift to rail.

In this scenario, air transport also contributes about 7% reduction compared with the 450 ppm scenario due to the increased use of biofuels and the higher certificate prices added onto the air ticket prices, which reduces demand and gives higher incentives for efficiency improvements in air transport.

Table 5: Changes of transport CO_2 emissions on regional level in the 400 ppm scenario

[Mt CO2 / year]	Reference Scenario			2° Scenario (400 ppm)			Changes (400ppm vs. Ref.)		
Country group	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**	**2010**	**2020**	**2050**
North	105	106	114	103	90	60	-2%	-14%	-47%
South	335	328	308	324	281	162	-3%	-14%	-47%
East	109	114	126	106	97	68	-3%	-14%	-46%
West	751	738	763	725	613	324	-4%	-17%	-58%
EU27	**1,242**	**1,228**	**1,250**	**1,201**	**1,031**	**575**	**-3%**	**-16%**	**-54%**

Source: Schade et al. (2009)

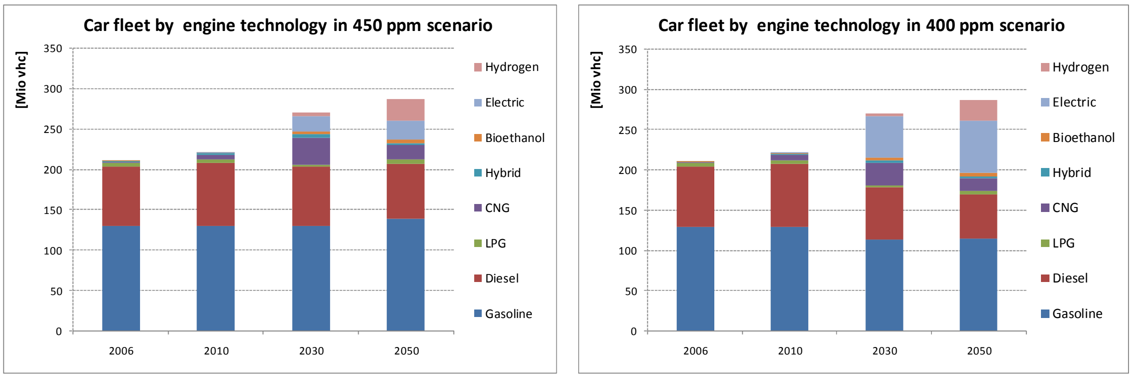


Source: Schade et al. (2009)

Figure 21: CO_2 emissions of transport in the 400 ppm scenario in EU27

The trends for the car fleet can be observed in Figure 22. The number of fossil-based cars remains more or less stable in the 450 ppm scenario and drops in the 400 ppm scenario. However, their average efficiency improves by between 30 and 45% in the different countries until 2050 compared with 2010. In the medium-term, CNG cars gain a market share of up to 10% since they represent a suitable option to reduce CO_2 from transport, can also run on bio-methane and provide a bridge to the hydrogen fuel cell technology that enters the car market in the long term. However, for inner city and short distance transport, it is expected that electric cars, i.e. city cars, will enter the market in the short to medium term and gain a significant market share among the smaller car segments. Bioethanol, LPG and advanced plug-in hybrids remain as niche markets for different reasons. Bioethanol suffers from a shortage of fuel supply since it tends to be blended with gasoline rather than sold as a pure oil (or E85). LPG offers too little savings in terms of CO_2 and costs to be really attractive and advanced electric hybrids, i.e. featuring both an electric and a combustion engine, become too heavy and costly and furthermore achieve the highest fuel savings in urban traffic, where they will have to compete with pure electric cars.

The picture is similar for the 400 ppm scenario except that electric cars are even more successful due to more support policies and the higher cost of fossil fuels because of higher certificate prices, with the result that the numbers of fossil-fuelled cars drop over time.

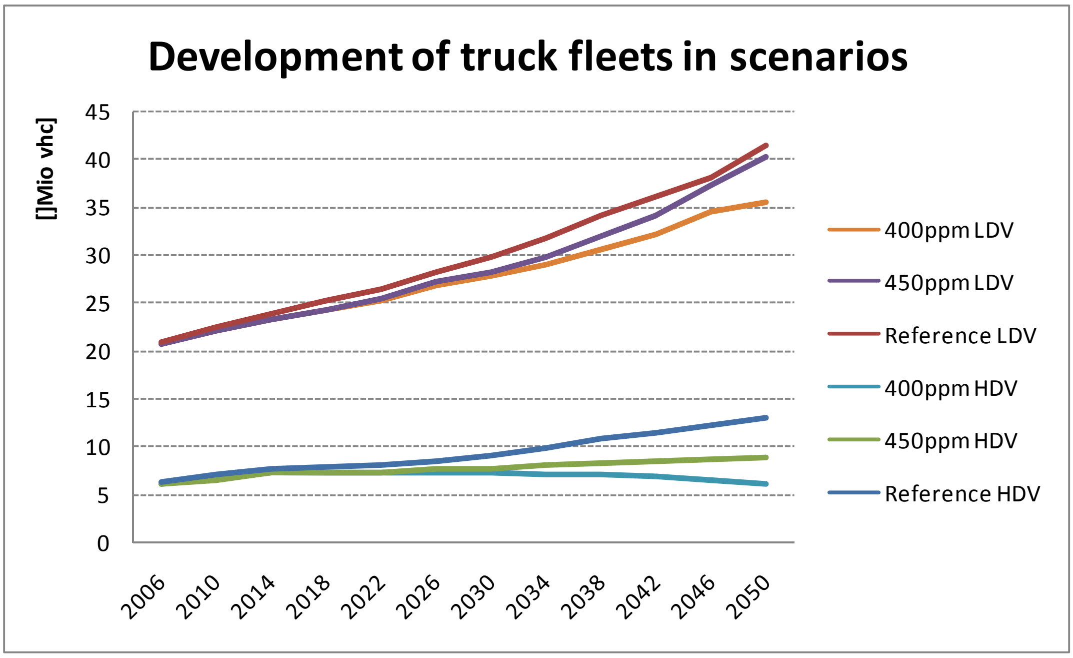


Source: Schade et al. (2009)

Figure 22: Structure of the car fleet in the 450 ppm and 400 ppm scenarios

In contrast to the car fleet, where the number of cars hardly changes across the scenarios, the development of the truck fleet (both LDVs and HDVs) is greatly affected by the policies in the scenarios. Figure 23 presents the vehicle stock of trucks in the Reference Scenario and in the two variants of the 2°C scenario. In the Reference Scenario, both truck types increase by about 100% until 2050 compared with 2006; with a slightly stronger rise in HDVs. In the 450 ppm scenario, road freight performance decreases slightly and a shift occurs from smaller HDVs towards electric LDVs, with the result that the HDV fleet is at a lower level than in the Reference Scenario with an increase of 45% in 2050. The LDV fleet is about the same in 2050.

In the 400 ppm scenario, there is a more marked reduction in freight performance and the modal shift towards rail and ships is reinforced by their improved competitiveness, so that the HDV fleet in 2050 is about the same as in 2006. LDVs still increase by 70% compared with 2006, which means the number of LDVs is 30% smaller than in the Reference Scenario.



Source: Schade et al. (2009)

Figure 23: Impact on truck fleets in the 450 ppm and 400 ppm scenarios in EU27

MITIGATION INVESTMENTS IN THE TRANSPORT SECTOR

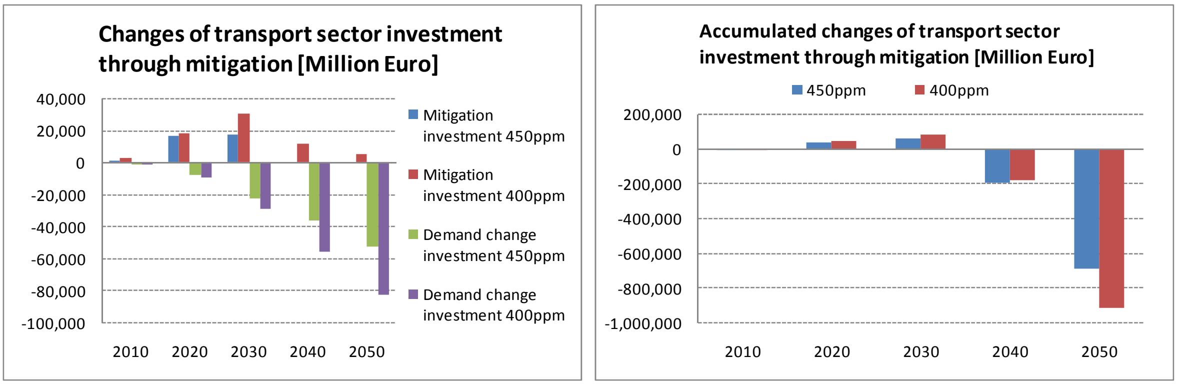
The mitigation policies in the transport sector are influenced by two factors: (1) implementing the policies requires additional investments, which increase the specific cost of transport activities (i.e. the transport cost per pkm or per tkm), and (2) the mitigation policies lead to demand changes and modal shifts which alter the investment patterns of the transport sector. Both investment changes are significant compared with the Reference Scenario and cannot be neglected.

Additional investments are considered for the development of vehicles with higher fuel efficiency, e.g. those required by the CO_2 emission limits for cars, LDVs and HDVs. For cars, the detailed cost increases are taken from TNO [2006] and are in the order of a few 100 euros to about 1500 euros added onto the purchase price. For LDVs and HDVs, the maximum cost increase is estimated to be 1500 and 5000 euros per vehicle, respectively, which corresponds to a vehicle price increase of about 5%. In addition to this, other additional costs have to be considered, for instance for the use of ultra-fluid lubricants which cost 10€ per filling and are required every two years for each car, for the binding use of low resistance tyres for trucks, which are assumed to cost 10% more than standard tyres and have a 10% shorter lifetime. About 2 billion euros additional investments in rail systems are also required each year in the EU27 to improve the competitiveness of passenger rail by adding 3000 km of high-speed lines (built over 30 years), provide better connections at stations and improve the attractiveness of stations. In addition, the competitiveness of freight rail has to be improved by adding 3000 km of dedicated freight rail track (built over 20 years), eliminating bottlenecks caused either by (1) competition between freight and passenger rail transport or (2) direct capacity limits for rail freight transport (e.g. in seaport-hinterland connections) and implementing additional, multi-modal terminals.

The impact of the demand changes have already been described in the previous section. The car fleet remains more or less the same with only about -1% reduction in the 2°C scenarios and a moderate downsizing of cars, but the EU27 truck fleet is significantly reduced by -10% in the 450 ppm scenario and -24% in the 400 ppm scenario in 2050. In particular, the changes in the truck fleet reduce the investments required for vehicles in the transport sector, although increased demand for rail transport requires increased investments in locomotives and engines. After 2030, a strong reduction of transport-related vehicle investment can be observed.

Figure 24 shows the investment increase by mitigation measure, the reduction of transport investment due to demand changes (left-hand side) and the accumulated changes in investment over time (right-hand side). It is clear that the mitigation investments in the 450 ppm scenario occur earlier (between 2015 and 2035, with a peak of €18 billion in 2022), while the peak in the 400 ppm scenario is around 2030 (peaking at €30 billion) and that significant mitigation investments are required to drive down the GHG emissions of transport after this point until 2050.

On the other hand, the adaptations of investment due to changes in transport demand increase continuously following the path of continuously increasing load factors and the modal shift away from roads. They reach a maximum in 2050 with about €-52 billion and €-82 billion in 450 ppm and 400 ppm scenarios, respectively. Looking at the accumulated balance of the investment changes in the 2°C scenarios (right-hand side of Figure 24), it is apparent that, until around 2033, additional mitigation investments are required in the transport sector (with a respective peak of €68 billion and €80 billion in the 450 ppm and the 400 ppm scenario). After this point, the accumulated investments in the transport sector are lower than in the Reference Scenario.



Source: Schade et al. (2009).

Figure 24: Impact of the 2°C scenarios on transport investment in EU27

Translating the mitigation investments for trucks into an average cost change per tkm, it appears that costs increase moderately during the first two decades by about 1 cent/tkm (or about +8%). In the long term, road freight transport costs actually decrease by about 3 cent/tkm due to energy and CO_2 efficiency improvements.

IMPACT OF POLICIES IN THE 2°C SCENARIOS

A model-based analysis performed with a simulation model like ASTRA enables simulations of scenarios to be run with and without selected measures (i.e. policies or technological changes). This feature is used to run simulations of the 450 ppm and 400 ppm scenarios in which a selected number of measures are excluded (switched-off) from the scenario. We call such a scenario a 'switch-off scenario'. The results of the 450 ppm switch-off scenarios can be compared with the full implementation of measures in the 450 ppm scenario to identify the impact of individual measures. It should be pointed out that the simulation could be done using a different approach, i.e. by taking the Reference Scenario and adding only one measure to identify its impact. However, the results would not be the same and it is more appropriate to apply the switch-off analysis as the measures then unfold their effects within the frame of interaction with the other measures of this scenario. Further, adding the impacts of all the switch-off analyses together and assuming that there are no synergies between the measures, one should reach the level of indicators (e.g. energy demand) in the Reference Scenario. This is not the case which demonstrates implicitly the existence of synergies between the measures. Accordingly, the switch-off analysis includes one category of impacts which is called synergies.

Since more than 20 measures have been implemented in the transport sector, measures were grouped together to produce a limited number of thematic packages in order to reduce the number of required simulations. The following packages were defined for the switch-off analysis in the 450 ppm scenario:

- 'Efficiency package switch-off' includes CO2 emission limits for cars, CO2 emission limits for LDVs, reactions of truck load factors to fuel cost increase (including CO2 prices of certificates), binding regulation of low resistance lubricants.
- 'Biofuels package switch-off' includes biofuels for road transport only as in the Reference Scenario; no biofuels at all for rail or air transport.
- 'Fuel switch package switch-off' includes electric car diffusion only as in the Reference Scenario, no hydrogen cars and no hydrogen filling station network, no electric LDVs.
- 'Demand shift package switch-off' includes no CO2 efficiency labelling of cars, no inclusion of transport into ETS, i.e. no CO2 costs aggregated into the cost parameters of any of the modes.

Since additional measures were implemented in the 400 ppm scenario, the packages in the switch-off analysis include those listed above plus:

- Efficiency package switch-off also includes no binding regulation for low resistance tyres for trucks, no special training for HDV truck drivers.
- Biofuels package switch-off also includes no increased quotas of biodiesel for road or of biofuel for air transport.
- Fuel switch package switch-off also includes no increased diffusion of electric cars, i.e. diffusion only as in the Reference Scenario.
- Demand shift switch-off package further includes no increased competitiveness of rail due to investment and organisational innovations and thus no modal shift of long distance freight and passenger transport to rail. No inclusion of the higher CO_2 cost in transport costs.

Figure 25 provides the results of the switch-off analysis for the total energy demand in the 450 ppm and 400 ppm scenarios. The lowest dark area represents the energy demand in the 450 ppm and 400 ppm scenario, respectively. Each switch-off element increases the energy demand towards the level of the Reference Scenario, which is represented by the upper curve of the topmost area (the synergies area). Looking at the 450 ppm scenario (left-hand side), one can observe two key features of the switch-off packages: (1) the order of magnitude in relation to each other, and (2) the time profile of package impacts.

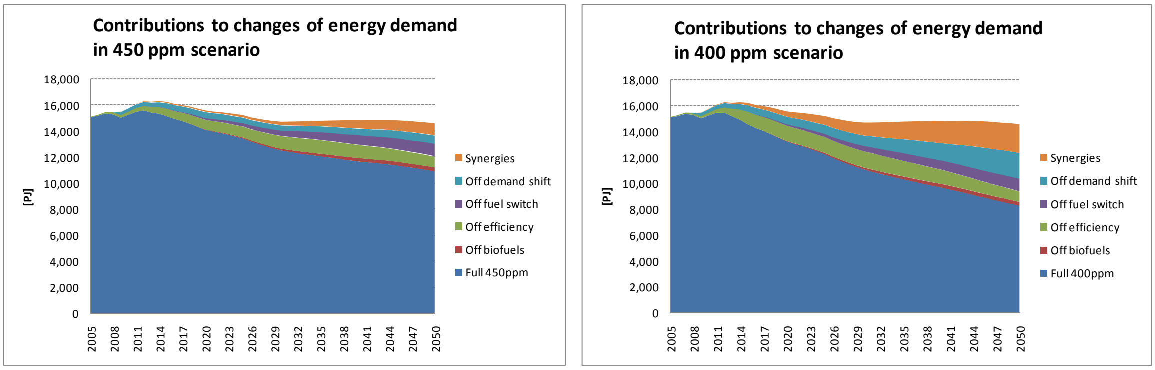
In the 450 ppm scenario, the most effective element is the efficiency package, i.e. in particular, the CO_2 emission limits for cars and light duty vehicles. Such a binding regulation is not only effective, but also provides the framework for a competitive market to develop efficient vehicles. In other words, (1) it provides certainty for the investment decisions of vehicle manufacturers (they can be certain they have to develop efficient cars and will not lose any R&D investments in efficiency improvements), and (2) the free-rider argument does not hold anymore, i.e. the argument that a manufacturer is not able to develop efficient cars even though they might want to because their competitors are continuing to sell high-powered, fast cars which would sell better than fuel-efficient ones (at least in the past).

In the medium to long run, the fuel-switch, i.e. the market penetration of electric cars and vans as well as hydrogen cars plays the second most important role. Here, it has to be taken into account that only moderate market penetration is achieved in this scenario and that the energy savings are proportional to the market shares gained by these new technologies. The demand shift plays a limited role as labelling only has a potential of 2-4% savings, and including the transport sector in the ETS with certificate prices of up to 80€/t CO_2 only increases the fuel cost for diesel or gasoline by about +10% and by about +20% for kerosene, because no other taxes are added here. Further, fuel costs play the largest role for air transport compared with the other modes. Accordingly, air transport experiences the highest impact of -5% reduction of passenger performance.

Biofuels only have a very limited effect on energy demand as they mainly replace one type of primary energy input (i.e. fossil fuels) by a similar type of input (i.e. bioethanol or biodiesel). A more important role can be observed for the synergies in the medium to long term. The causes of synergies are difficult to identify analytically. One reason may be that the modal shift is augmented by adding different policies, e.g. the diffusion of electric engines reduces energy demand and leads to a new modal split between modes as well as between car engines. This is also affected when the cost of CO_2 certificates are added onto fossil fuels, such that fewer gasoline and diesel cars are bought and more electric cars, which then further reduces the energy demand compared with the efficiency package switch-off and thus constitutes one of the reasons for synergies. In 2050, the synergies are nearly equally as important as the efficiency and the fuel switch packages.

Looking at the 400 ppm scenario, two major changes can be observed. The demand shift plays a much larger role than in the less ambitious 450 ppm scenario and in the long run actually delivers the largest contribution to energy saving. This has two explanations: First, investments in and organisational improvements of rail transport increase its competitiveness significantly. Second, the higher CO_2 price of up to 200 €/t CO_2 increases kerosene price by close to 50% such that, e.g. air transport suffers a loss of more than 20% of demand compared with the Reference Scenario.

A similar large contribution to the reductions is made by the synergies, which also enfold over the medium to long term. The contribution of the efficiency measures increases by about one third compared with the 450 ppm scenario.

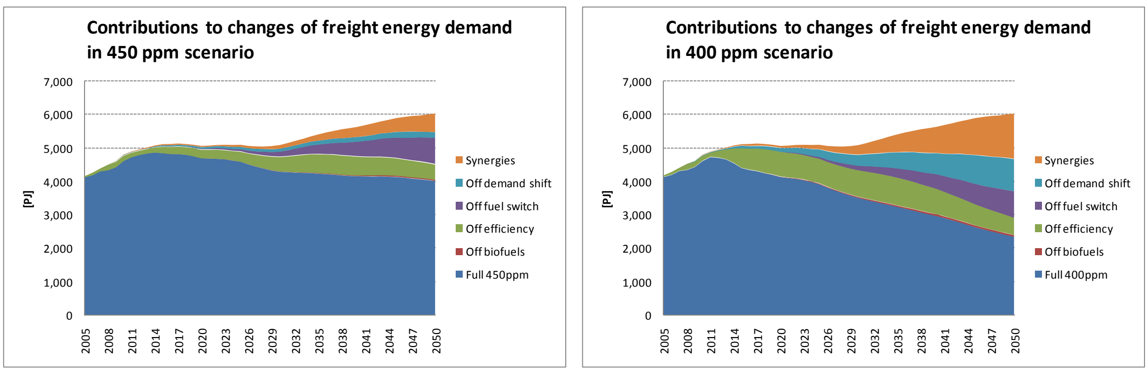


Source: Schade et al. (2009)

Figure 25: Switch-off impacts on energy demand in the 450 ppm and 400 ppm scenarios

Figure 26 shows the energy demand impacts for freight transport based on the approach explained above. First, it should be noted that the 450 ppm scenario enables to shift freight energy demand from a growth path to a stable path. In the 450 ppm scenario, again efficiency measures make the largest contribution. The impact of any other measure only unfolds in the medium to long term showing that fuel switching, i.e. the introduction of electric LDVs, plays a significant role, while demand shift and biofuels have almost no impact on energy demand of freight transport.

In the 400 ppm scenario, freight energy demand is also reduced by -43% compared with 2005, i.e. freight energy demand is also put on a declining path. This is achieved by increased efficiency measures which now also address HDV freight transport and thus nearly double the efficiency savings of freight transport in 2030 (medium term). In the long term, the modal shift towards rail freight and shipping plays an even larger role than efficiency measures, which was also observed for the whole transport sector above. This confirms once again that aligned push-pull strategies are needed to shape transport in a climate-friendly manner. In this case. the pull strategy is the improved competitiveness of rail and the push strategy comprises higher CO_2 prices and the higher relative energy demand per unit of truck transport compared with rail. Also, as observed above, synergies play a large role, particularly when demand shift measures already contribute a significant share of energy demand reductions.

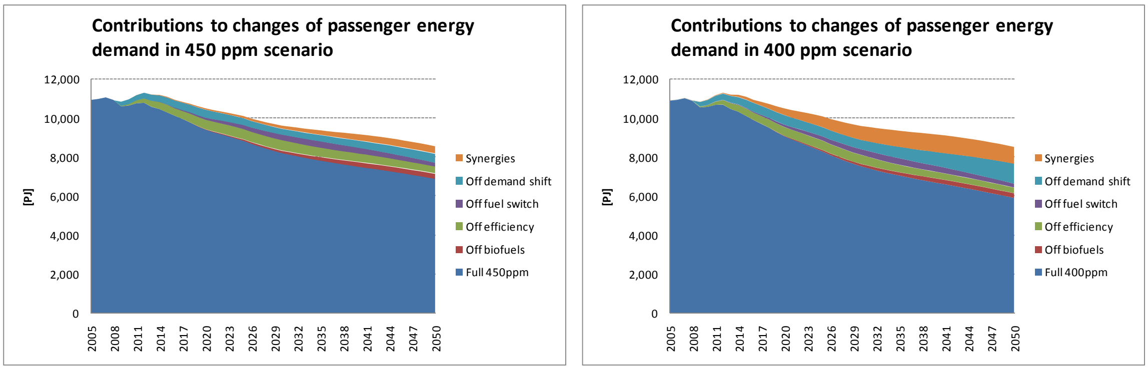


Source: Schade et al. (2009)

Figure 26: Switch-off impacts on freight energy demand in the 450 ppm and 400 ppm scenarios

Figure 27 presents the corresponding figures for the switch-off analysis of passenger transport. Since passenger transport in the Reference Scenario already includes efficiency gains that, together with a stable demand, generate a declining energy demand path, the further reductions of passenger energy demand are smaller than for freight. Efficiency and demand shift play the largest role in passenger transport. The demand shift reduces the share of air transport and to lesser extent also car transport and increases the shares of slow modes, train and bus transport.

In the 400 ppm scenario, the demand shift becomes even more relevant as air transport has to bear the highest cost impacts of the CO_2 certificate prices and rail transport benefits from infrastructure and organizational improvements and increases its competitiveness and thus its modal share. Again, synergies are important as is a higher significance of the demand shift in generating energy reductions.



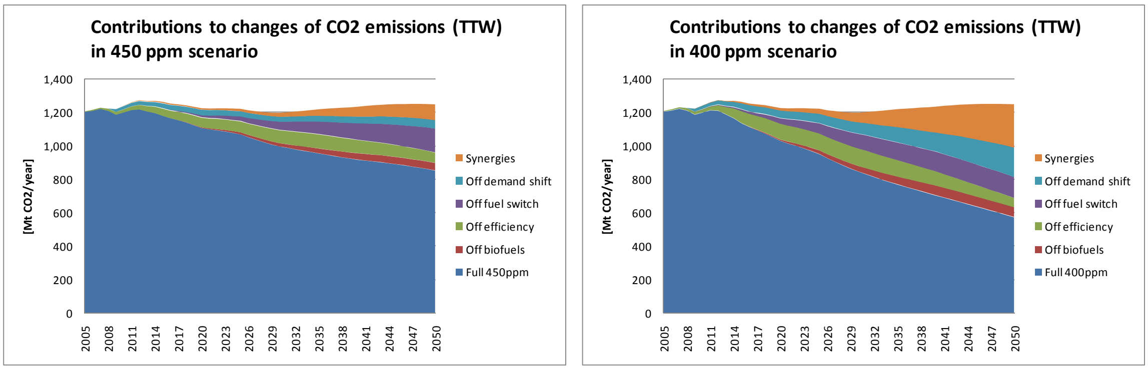
Source: Schade et al. (2009)

Figure 27: Switch-off impacts on passenger energy demand in the 450 ppm and 400 ppm scenarios

Figure 28 presents the results of the switch-off analysis for the transport CO_2 emissions. In general, they confirm the results of the energy-related analysis above. Two major differences concern the fact (1) that biofuels actually contribute to CO_2 savings, and (2) that the fuel switch plays a larger role than it does for energy demand.

In both cases, one should mention the specifications under which the CO_2 emissions were calculated in the ASTRA model. The CO_2 emission savings are not estimated considering different pathways for their production, but are considered as average savings of CO_2 per unit of fuel. This average saving starts at about 50% and rises to 65% in 2050 for bioethanol, which is optimistic for the first decade and rather pessimistic for the medium- to long-term future, which could see the use of second (e.g. straw and use of residues and whole plants) and even third generation biofuels (e.g. algae fed by CO_2) so that the CO_2 savings from biofuels could be even higher in the medium and long run than shown in the figures.

In the case of fuel switching, one has to note that the figures show the tank-to-wheel emissions (TTW). That is, for electricity and hydrogen, the CO_2 emissions are calculated as zero. ASTRA also estimates the upstream emissions (well-to-tank) of these fuels. The figures show that about two thirds of the area shown constitute actual CO_2 savings for fuel switching, while about one third is generated upstream.



Source: Schade et al. (2009)

Figure 28: Switch-off impacts on transport CO_2 emissions in the 450 ppm and 400 ppm scenarios

BRIEF COMPARISON WITH OTHER SCENARIOS

Though a few years ago many experts had denied that significant reductions of GHG from the transport sector can be achieved there are also a number of other studies that developed scenarios for transport until 2050, which achieve reductions in similar orders than we have presented in our analysis i.e. between -30% and -70%.

One example are the scenarios from the International Energy Agency from 2009 as well [IEA 2009]. Though these scenarios are global in nature they indicate also some numbers for OECD-Europe. In particular, it seems that the 450 ppm scenario corresponds to the IEA Blue Map scenario, which focuses on efficiency and new technologies but not on travel demand changes, while the 400 ppm scenario is closer to the concept of the IEA Blue Map Shift scenario, which includes efficiency, new technologies and modal shift.

A scenario that even goes further comes from the Netherlands Environmental Assessment Agency [PBL 2009]. In this scenario, despite expecting higher transport demand growth rates than we foresee the reductions achieved in Europe would be -80% GHG emissions of transport until 2050 compared with 1990. This is achieved by faster and stronger penetration of electric vehicles and hydrogen fuel cell vehicles into the passenger car fleet than we modelled and by stronger influences on transport demand i.e. reduction of volumes and modal-shift towards rail transport. However, the general structure of the scenario is very similar: passenger surface transport is reducing GHG emissions most, followed by freight transport and air transport only ends at the levels of 1990. The strongest effect is expected from low-carbon fuels followed by efficiency improvements and then by volume/mode shift.

CONCLUSIONS

Including transport in the EU-ETS is not sufficient to transform it into a low carbon and climate-friendly activity. The time scales of market-based choices (one to four years), to which an ETS system belongs, are too short to introduce the required changes of technologies, organisations and behaviour and the time lag between adapted choices and their impacts on GHG emissions is often too large so that new choices have to be anticipated years or even decades before they become effective in reducing the GHG emissions of transport.

Thus besides including transport in the EU-ETS, a package of transport-focussed policy measures has to be implemented, including regulation, taxation, R&D support and information campaigns. One main issue is that policy-makers have to make it very clear to decision-makers in companies and households that climate protection policies in the transport sector are not a short-term policy fashion, but will be pursued forcefully and over the medium and long term.

The 2°C scenario results of implementing 22 different measures for transport have shown that transport energy demand can be reduced by -27% and -45% in the 450 ppm and the 400 ppm scenarios, respectively, until 2050 compared with 2005 and that this can feasibly be done with still moderate policy packages. In terms of transport CO_2 emissions reductions until 2050, this is equivalent to CO_2 reductions of -30% and -52% compared with 2005.

The impact analysis of the different measures' contributions to reductions has revealed that, in the short to medium term (3 to 20 years), energy efficiency measures contribute the largest reductions. In particular, CO_2 emission limits for cars and light duty vehicles play a large role in reducing the energy demand and CO_2 emissions of transport. As a side-effect, they also reduce the dependency on fossil fuels, which could already become an important issue within this time horizon due to growing scarcity and sharply increasing oil prices.

In the medium- to long-term perspective (20 to 40 years), two other measures play a larger role. These are the fuel switch (i.e. the introduction of electric vehicles and hydrogen fuel cell vehicles into transport) and the demand shift (i.e. improved logistics and competitiveness of rail as well as including transport in an ETS system with CO_2 certificate prices well above 100 €/t CO_2). Both need strong political support, the former via the support of R&D and early market diffusion (e.g. feebates) and the latter by supporting the creation of an interoperable European rail network featuring a backbone of high-speed rail for passenger and dedicated freight links at bottlenecks together with improvements of intermodal logistics as well as including transport in a global CO_2 ETS system.

Considering that the emerging policy objective is to reduce GHG emissions by -80% by 2050, it seems that our estimated reductions of transport emissions would still fall short compared with what is needed for climate protection. However, there are both some supporting trends of CO_2 reductions not fully operationalized in our analysis and other additional policies that could be realised to achieve the climate policy target. As a first trend, re-urbanisation should be mentioned. Cities are becoming greener with many attractions in terms of culture, education, childcare and healthcare services so that a growing number of people will move back into cities from the suburbs or even rural areas. Since cities are able to offer more carbon lean transport than suburbs or rural areas, this trend will help to reduce CO_2 emissions from transport. Of course, this also needs support in the sense that cities have to promote multi-modality, i.e. increased use of bikes, bike- and car-sharing systems, the latter ideally based on a fleet of highly efficient conventional or electric city cars and both combined with a comfortable and reliable public transport system. It must be possible to use all of these transport options with just one mobility card. If necessary, e.g. to fund the set-up of such a system and to add a push measure, city tolls should be considered to reflect the scarcity of infrastructure and urban space as well as clean urban air.

In addition, a number of soft factors also play a role. One example is the advertising strategies of European car manufacturers who tend to invest more in advertising fast, powerful cars than they do in adverts for fuel-efficient small and midsize cars [DENA 2009]. If this past trend also reflects the future development strategy of European car manufacturers, they run the risk of losing the market segment of fuel-efficient cars to Asian manufacturers, who have clearly defined the small, efficient and still affordable car as their main development goal. Given the constraints of limited fossil fuel resources and the need for climate protection, this represents precisely the car market segment with the largest demand growth in the future.

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