TRIAS

Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios

Outlook for Global Transport and Energy Demand

Deliverable 3

Version 1.1

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Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios

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Table of contents:

List of tables

List of figures

List of abbreviations

ASTRA	Assessment of Transport Strategies
AUT	Austria
BD	Biodiesel
BETOH	Bioethanol
BETOH Ligno	Bioethanol from Lignocellulosic Biomass
BIO	Bioethanol driven cars (E85 including flexi-fuel cars)
BLX	Belgium and Luxemburg
BLG	Bulgaria
BTL	Biomass To Liquids
CHE	Switzerland
CNG	Compressed natural gas
CO_2	Carbon dioxide
CYP	Cyprus
CZE	Czech Republic
DNK	Denmark
DPC1	Diesel cars with cubic capacity less than 2.0 litre
DPC2	Diesel cars with cubic capacity more than 2.0 litre
ELC	Electric current driver cars
EST	Estonia
ESP	Spain
EU	European Union
EU12	All new Member States acceded the EU in 2004 and 2007
EU12+2	All new Member States acceded the EU in 2004 and 2007 plus Norway and Switzerland
EU15	All members of the EU until 2003
EU25	All Member States of the EU despite Bulgaria and Romania acceded in 2007
EU27	All Member States of the EU in the year 2007
FIN	Finland
FC	Fuel cell
FRA	France
HUN	Hungary
G7	Group of Seven, meeting of finance ministers
Gbl	Giga barrel
GBR	Breat Britain/UK
GDP	Gross Domestic Product
GER	Germany
GHG	Greenhouse Gases
GPC1	Gasoline cars with cubic capacity less than 1.4 litre
GPC2	Gasoline cars with cubic capacity more than 1.4 and less than 2.0 litre
GPC3	Gasoline cars with cubic capacity more than 2.0 litre
GRC	Greece
GVA	Gross value-added
HYB	Hybrid cars, gasoline/diesel and electric
H2	Hydrogen
IRL	Ireland
ITA	Italy
LAT	Latvia
LPG	Liquefied petroleum gas
LTU	Lithuania

MLT	Malta
NACE	General industrial classification of economic activities within the European communities
NGV	Natural gas vehicle
NLD	The Netherlands
NOR	Norway
NO_x	Nitrogen oxide
NUTS	Nomenclature of Territorial Units of Statistics
OD	Origin/Destination
Pkm	Passenger-kilometre
PM	Particulate matter
POL	Poland
POP	Population
PRT	Portugal
ROM	Romania
RoW	Rest-of-the-World countries
SAM	Social accounting matrice
SEA	Strategic environmental assessment
SLO	Slovenia
SVK	Slovakia
SWE	Sweden
TFP	Total factor productivity
Tkm	Ton-kilometre
Vkm	Vehicle-kilometre
WP	Work package
VAT	Value-added tax
Yr	Year

1 Executive Summary

The main objective of the TRIAS project is to perform an integrated sustainability impact assessment of transport, technology and energy scenarios. In order to fulfil the requirements of an integrated sustainability impact assessment five models simulating economic, transport, environment, energy and technology systems were linked in TRIAS. Finally, the linked models are fed with technology scenarios as well as policies for transport and its energy supply. The following five models were integrated and prepared for the implementation of scenarios:

- POLES and BIOFUEL covering the energy sector,
- ASTRA for modelling national economies, sectoral foreign trade and transport on an aggregate level,
- VACLAV simulating detailed transport network impacts on NUTSIII level and
- Regio-SUSTAIN highlighting local environmental impacts for two selected European regions.

Figure 1 demonstrates the interaction between the five linked models and the main outputs and inputs exchanged between the models.

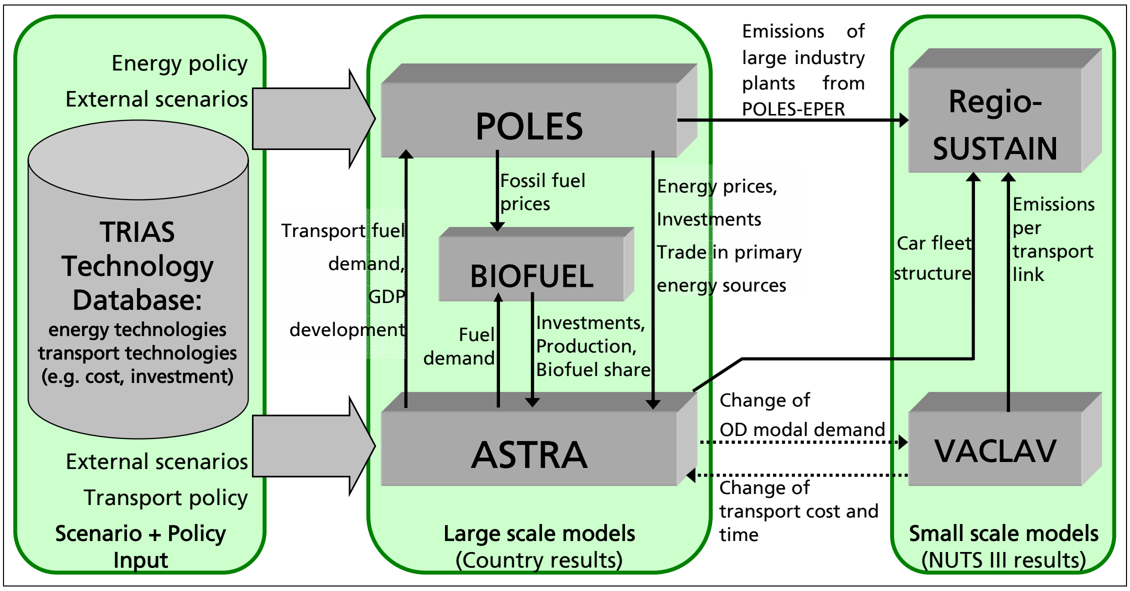

Figure 1: Linkage and interaction of models in TRIAS.

In the TRIAS project scenarios for technological evolution in the transport and energy sector but also for potential mega-trends shaping the next 30 to 45 years are developed and analysed. All scenarios are tested within the modelling framework of the five integrated models. The final impact assessment is carried out by selecting a number of representative indicators to demonstrate possible consequences of the scenarios as broad as possible. A condensed set of indicators is defined to make the results accessible for the public and decision-makers. These major tasks are assigned to five work packages. This report focuses the results achieved in WP3 and WP4 in which the energy and transport models are prepared to produce the TRIAS baseline scenario for each model.

In the context of WP3 and WP4 several new features like the integration of alternative transport technologies in the models, the update of data sources used for calibration and the extension of time horizon of model simulations until 2030 and 2050 were carried out. In addition to the development of interfaces linking the five models, significant effort has been invested into two originally not foreseen tasks:

- A new BIOFUEL model was developed and linked with the POLES model. In order to simulate biofuels scenarios this development was crucial for the TRIAS project.
- The ASTRA model was successfully split into modules in order to enable distributed software development. For this purpose, a tool, the so-called ASTRA-Merger, was developed to link the separate modules of ASTRA into one integrated model again.

Major model improvements for TRIAS

The main improvements for the BIOFUEL and the POLES-TRIAS model consist in the development of the BIOFUEL model itself and its linkages to the POLES-TRIAS model. With respect to the relevant biofuel pathways, the BIOFUEL model performs the calculation of production costs split by capital, operational and feedstock costs. In the next step, market prices of biofuels and of fossil fuels calculated by POLES-TRIAS are linked together. This enables to derive the level of production capacity and the production of biofuels, which are sold as blended fuel or as pure biofuel. Besides costs, production and consumption of biofuels, the BIOFUEL model derives also emissions in order to conduct a full assessment of policy instruments fostering biofuels as transport fuels.

Several important improvements of the ASTRA model were realised in WP4 of the TRIAS project. Regarding the simulation of technological scenarios the most important one was the revision of the vehicle fleet model. Six new alternative car technologies - CNG, LPG, hybrid, electric, bioethanol and hydrogen cars – were integrated in a new vehicle purchase model driven by specific costs and filling station infrastructure. This task was completed in adding the air emissions caused by alternative fuel cars with the help of specific emission factors in the environmental module. Feedback loops were implemented simulating the technological impacts in the macroeconomics and foreign trade model. Besides other significant innovations motorisation levels were integrated as driver of passenger modal split and transport cost calculations were disaggregated and revised.

The transport network model VACLAV has been extended to 2030 in regard of networks and demand matrices. The latter has been achieved by adding a link to the ASTRA model and using growth rate forecasts for passenger and freight demand. Furthermore detailed assignment information is provided back to ASTRA for selected years.

Regio-SUSTAIN has been developed to assess the impacts of traffic-related emissions on a regional scale. The model has been modified and applied to two case-study regions during the TRIAS project, namely the Ruhr area (Germany) and Andalusia (Spain). Boundaries for the two regions are based on the Nomenclature of Territorial Units of Statistics (NUTS). The outcome of Regio-SUSTAIN is two-fold: On the one hand side local immissions and on the other side the number of inhabitants affected by a special substance, such as NOx, PM or noise, can be computed. For the TRIAS project Regio-SUSTAIN has been expanded to point emissions from stationary facilities. Furthermore, new components have been added to the model for small-scale scenario analysis (e.g. demographic development, new vehicle emissions classes, elevation model).

Major developments in TRIAS baseline scenario

The TRIAS baseline scenario provides trajectories for the analysed indicators until 2050. The most suitable way to present a variety of indicators across different fields is to use indices, which we calculate relative to the base year 2000. Figure 2 shows the major results of the TRIAS baseline scenario that can be assigned to three different groups of indicators. The first group includes indicators that remain stable or only show very moderate growth until 2050. This includes population and employment, which both show a peak in the period 2025 to 2035 and then decline, but overall remain very close to the level of the year 2000. Transport energy demand, transport CO_2 emissions (life cycle perspective) and passenger performance, which are the other three indicators of this group, increase by up to 50% until 2050. The second group reveals a growth of about 200% until 2050. GDP and freight transport performance belong to this group, which indicates that the models do not foresee a decoupling between freight transport and GDP, but at least a relative decoupling between transport energy demand and GDP, which can be assigned to technological improvements including not only improved energy efficiency of individual technologies but also switches between different technologies. The last group in the figure represented by one indicator only reaches a growth of more than 300%. This includes exports, which reveals that the models expect a continuation of current globalisation trends leading to further specialisation of production in different world regions and hence growing transport activity between different locations of goods production.

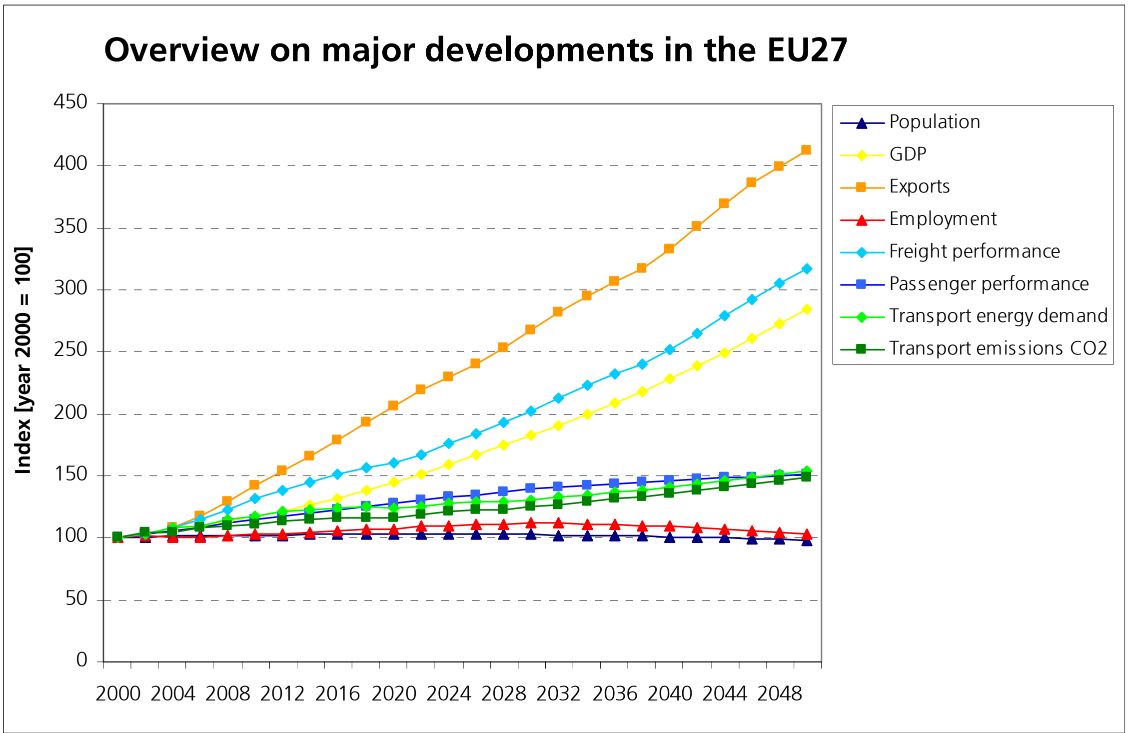

Figure 2: Major developments in the transport-energy-economic system of the EU27

Taking a closer look at indicators of the transport and energy system in Figure 3 one can observe that for both freight and passenger transport the volumes grow slower than the performance, which indicates that travel distances continue to grow, and in particular for passenger transport this is the most relevant driver of continued growth. Despite stabilisation of population the car fleet continues to grow significantly. One major reason is the catching-up of the new EU member states joining the EU in the years 2004 and 2007 in terms of car-ownership. Further in some countries income continues to grow strongly, which is one of the strongest drivers of car purchase, and finally it seems that ASTRA generating this indicator is more on the optimistic side of forecasts for this indicator.

Consumption and prices of the currently dominating fuels, gasoline and diesel, behave differently. For gasoline, we observe a strongly rising fuel price as well as a sharp reduction of demand reaching about -50% until 2030, which is due to both improved efficiency and fuel switch of cars. For diesel the fuel price increase is much more moderate. Efficiency improvements of trucks and buses, which consume a large share of diesel, remain lower then for cars such that together with the strong growth of freight transport diesel fuel demand doubles until 2050. In addition part of the fuel switch of cars is from gasoline cars to diesel cars, which also drives the growth of diesel fuel demand.

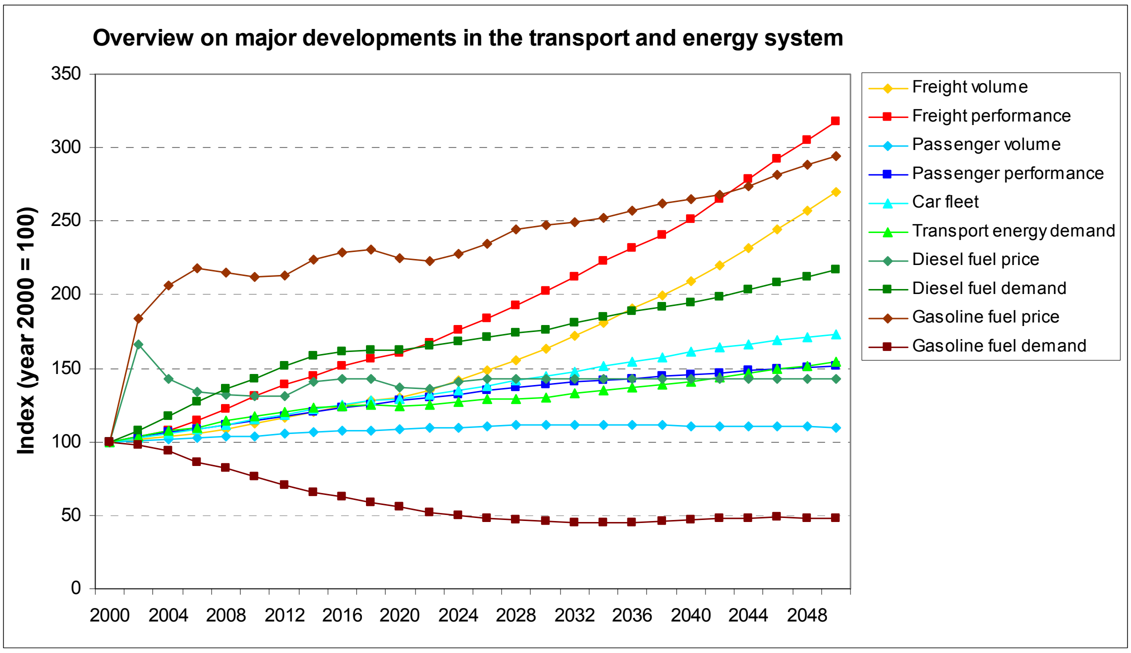

Figure 3: Major developments in the transport and energy system of the EU27

Figure 4 presents the development of shares of each car technology on total EU27 car fleet and clarifies the origin of increasing diesel fuel demand in EU27. The observed trend towards diesel continues until 2030 account of gasoline technology. Especially the CNG technology, which is promoted in several member states via initiatives, benefits from increasing diesel and gasoline prices until 2024. In the following predicted natural gas price growth by POLES-TRIAS leads to a strengthening of improved gasoline and alternative bioethanol technology. According to cognitions made in other projects the TRIAS baseline scenario per definition does not consider a successful diffusion of hydrogen cars into the EU27 markets until 2050. Regarding the moderate growth of passenger transport performance (see Figure 3) and the technological improvements of alternative car technologies the reader might wonder about the still increasing CO_2 transport emissions of 50% until 2050. Finally this trend seems to be realistic taking into account that freight transport performance is growing significantly until 2050 in EU27 and the fact that ASTRA does not consider alternative vehicle technologies to be integrated in truck fleets. This leads to a movement of the main polluter of CO_2 emissions from passenger to freight transport.

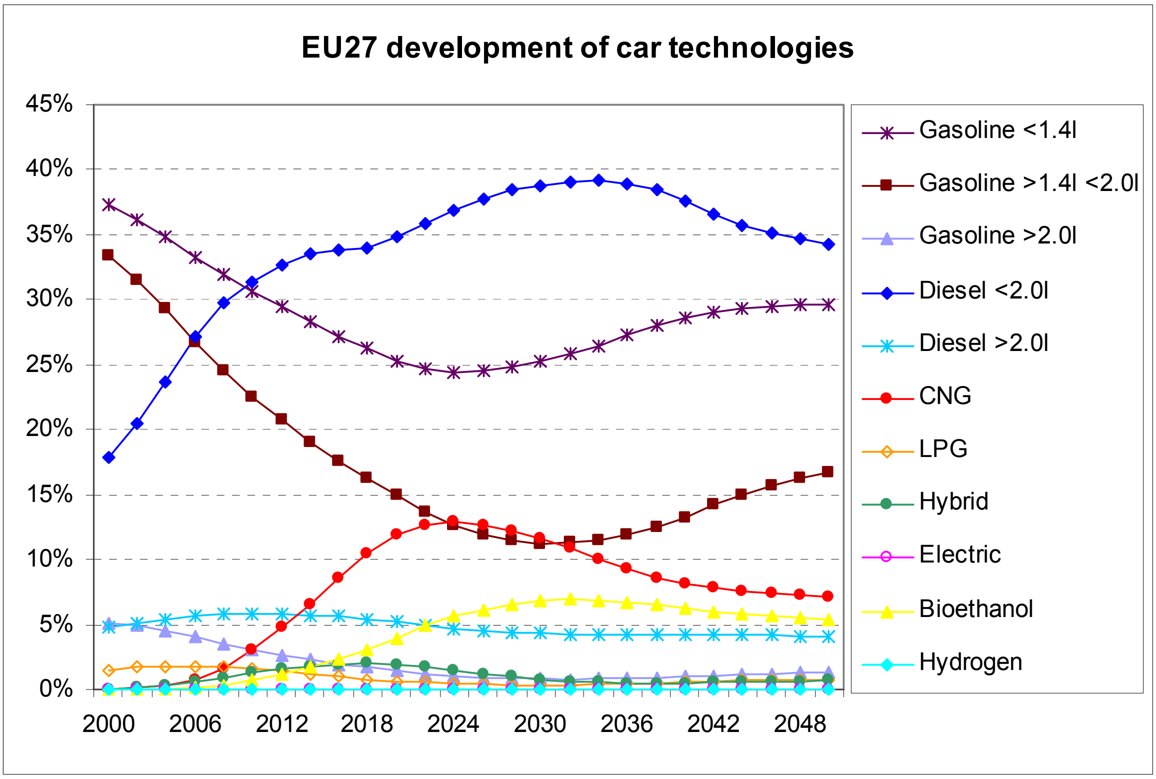

Figure 4: Share of passenger car technology in EU27

Besides results on national level the TRIAS project intended to zoom into representative European case study regions to get an idea of the impacts on regional level. Figure 5 displays the baseline results of the regional immission calculation with Regio-SUSTAIN for the transport sector for nitrogen oxides. The major motorways with the highest transport loads in the Ruhr area can be ascertained from the figures (the motorways A3 and A46). Both axis are mostly used for long distance traffic, especially HGVs coming from the Dutch ports with destinations in the South or East of Germany respectively Europe. The results are based on the assumption of a constant average wind field of 225° (South-East direction) with an average speed of 2.5 m/s. Expert interviews have shown that the assumptions are acceptable.

The absolute values of this figure represent indicators for the situation in the region, as the focus of TRIAS is on long-distance transport and energy pollutants only. Therefore, inner city traffic and pollutants from households go behind the objectives of the project but should be considered when analysing absolute values.

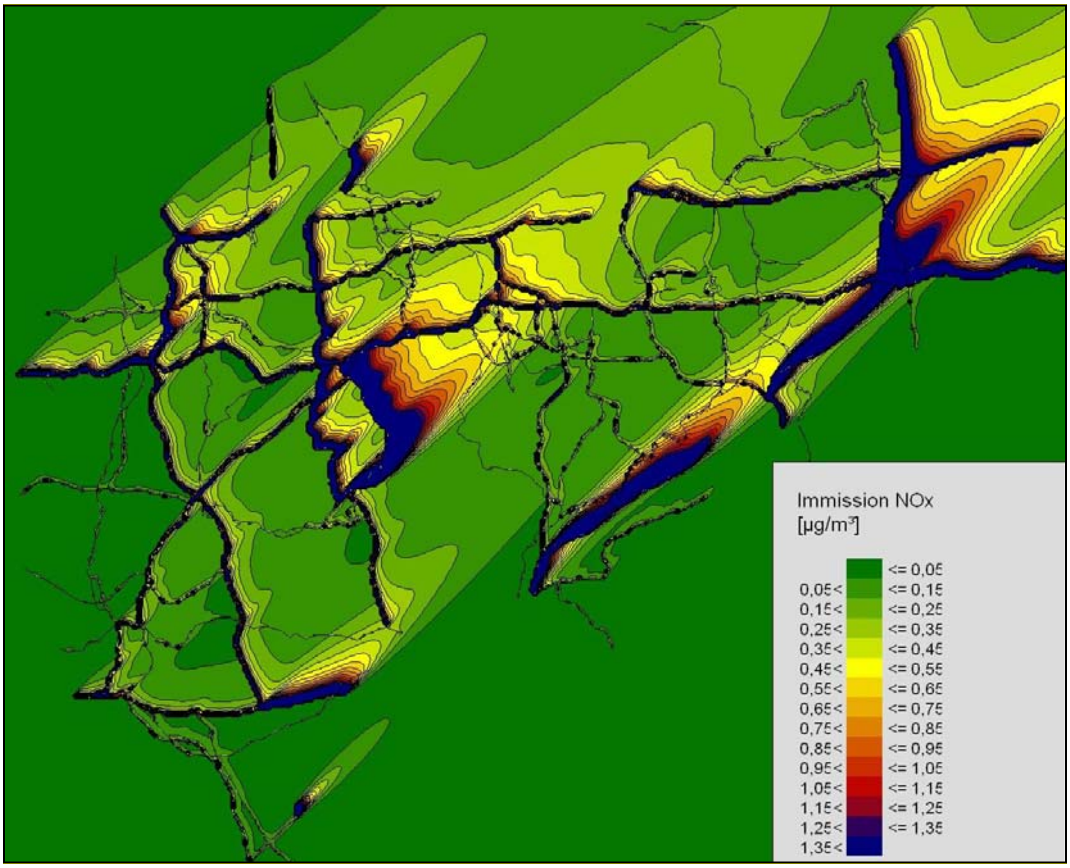

Figure 5: NOx immissions in the Ruhr area (Baseline scenario for 2000)

2 Project Setting

The TRIAS project is performing a "Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios". This means, the emerging fossil energy constraints, the potential technology lines for alternative fuels of transport and possible policies to foster fuel switch of transport are combined for the TRIAS analyses and their potential sustainability implications are assessed by the project team.

The project is co-funded by the European Commission DG Research and is undertaken by four partners, with Fraunhofer Institute Systems and Innovation Research (ISI), Karlsruhe, taking the lead and collaborating with the Institute for Economic Policy Research (IWW) at the University of Karlsruhe, TRT Trasporti e Territorio (TRT), Milan, and the Institute for Prospective Technological Studies (IPTS) of the European Commission DG JRC, Seville.

The strategic objectives of the TRIAS research project are

- Develop and test strategies to reduce greenhouse gas and noxious emissions from transport, based on the trilogy (trias) of transport, technology and energy scenarios.
- Build the assessment on an integrated model-based approach, looking at environmental, economic and social impacts (sustainability impact assessment).
- Consider the life-cycle implications of all strategies investigated.

The main scientific objective consists of the provision of a methodology for quantitative Sustainability Impact Assessment (also known as Strategic Sustainability Analysis) considering transport and energy sectors policies as well as scenario developments on the world scale, like the development of oil prices, the global GDP growth rates or the potential of new transport technologies on world scale.

The project provides quantified scenarios of the potential of conventional and alternative vehicle and fuel technologies until 2030 and - allowing for greater uncertainty - until 2050, based on an integrated modelling approach that combines the techno-economic analysis of transport technologies with the evaluation of environmental and socio-economic issues, as well as issues related to the autonomy and security of energy supply.

TRIAS uses a set of established forecasting models and is applying them in an interlinked manner to analyse the full picture of impacts induced by strategies including technology, transport and energy scenarios. Investigated scenarios are developed in TRIAS both by building on external sources like national or international studies as well as other European projects and by using the inherent trends of the four TRIAS models. The four applied models act at European scale (EU27) and include: POLES for energy modelling, ASTRA for transport and economic modelling as well as integrated sustainability assessment, VACLAV for detailed transport modelling and Regio-SUSTAIN for small scale analysis of environmental impacts, which is limited to two selected European regions. As the energy supply system in particular for fossil fuels is constituted as a world system the POLES model is also considering the global energy system.

2.1 Project Activities in General

The TRIAS project aspires to perform a Sustainability Impact Assessment of combined energy and transport policies and scenarios. In order to provide reasonable advice for policy-making, it is crucial to analyse the full picture of potential policies: in addition to the trajectory describing when a technology would first enter the market and how its market diffusion happens, an estimate of the required investments and the ways to finance these have to be part of the analysis.

Giving an example: large scale changes of the energy supply system for transport might be financed by charges collected from the transport users. Such charges would change the users travel decisions altering the competitiveness of the different modes, which would have to be reflected in a transport model to identify the full reactions to a policy. On the other hand, investment and changes of transport prices affect the economic system, with different sectors behaving in a different way. This requires using a sectoral economic model that is linked with the transport system. Further, cost changes of long distance transport and lower demand for fossil fuels would affect trade such that the applied model system should include a trade model.

The research objective of TRIAS is then to provide such a combination of models that can be fed with a broad range of technology scenarios as well as policies for transport and its energy supply. To fulfil this research objective, three major tasks are designed:

1. Identification and development of scenarios for technological evolution in the transport and energy sector but also for potential mega-trends shaping the next 30 to 45 years.

2. Preparation and integration of existing models to implement the scenarios: POLES and BIOFUEL covering the energy sector, ASTRA modelling transport on an aggregate level, the national economies and international trade with a detailed sectoral disaggregation, VACLAV to bring in the detailed transport network impacts on NUTS III level and Regio-SUSTAIN to calculate local environmental impacts for selected European regions. The interaction of these models is shown in Figure 6.

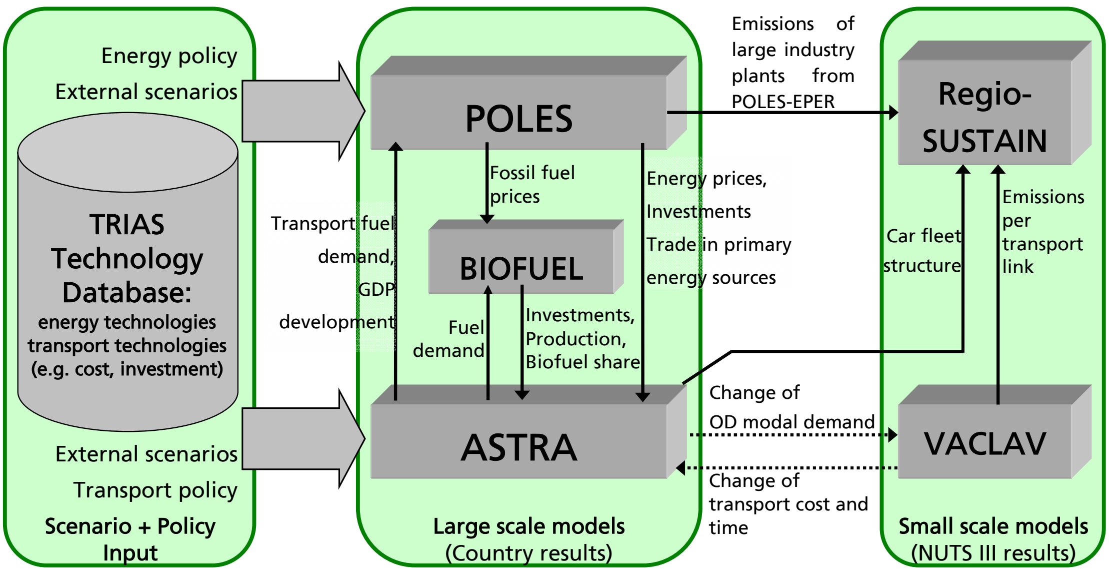

Figure 6: Linkage and interaction of models in TRIAS.

3. Sustainability Impact Assessment of the policies and scenarios. The scenarios are tested with the interlinked five models and from each model a number of indicators is selected to provide a picture of consequences of the scenarios as broad as possible. A condensed set of indicators is defined to make the results accessible for the public and decision-makers.

These three major tasks are organized in five technical work packages that are accompanied by a number of workshops, in particular two open forums where results of TRIAS and similar projects are discussed. The five work packages comprise:

- WP1 scenario screening of existing transport and energy scenarios;
- WP2 technology assessment and development of a technology, cost and investment database for biofuel and hydrogen technologies;
- WP3 energy modelling preparing the POLES and BIOFUEL models for TRIAS;
- WP4 transport and economic modelling preparing the ASTRA, VACLAV and Regio-SUSTAIN models for TRIAS;
- WP5 sustainability impact assessment analysing 10 different scenarios.

This deliverable presents the work undertaken and the results obtained in work packages WP3 and WP4 of TRIAS.

2.2 Project Activities in Workpackage 3 and Workpackage 4

The major objective of WP3 and WP4 is to prepare the models for their application in TRIAS and to produce the Baseline Scenario for each of the models. Preparing the models included to add new features e.g. representing the alternative transport technologies in the models, to update the data sources used for their calibration, to extend the time horizon of model simulations until 2030 and 2050 and to establish the linkages between the models.

Significant effort has been invested into two originally not foreseen tasks: first, this is the development of a new BIOFUEL model that is associated to the POLES model but could also be integrated into the ASTRA model in the course of further development. Second, the growth of the ASTRA model required to fully modularise it to enable distributed software development and to make use of software tools and operational practices that support such distributed software development. For this purpose, a complete software reengineering of ASTRA was undertaken and a tool, the so-called ASTRA-Merger, was developed to link the separate modules of ASTRA into one integrated model again.

Finally, a baseline scenario is developed using both external scenario assumptions and internal trends of the applied TRIAS models. Major external scenario assumptions come from the ADAM project (Adaptation and Mitigation Strategies, EC 6FP), which provided GDP growth trends until 2050 for the EU27 and the rest of the world. These trends were used as orientation for the GDP trends in ASTRA and POLES. Technology inputs were taken from the TRIAS Technology Database developed in work package WP2 of TRIAS.

3 Energy Modelling

3.1 Description of POLES-TRIAS and BIOFUEL Module

3.1.1 Outlook on the (POLES-TRIAS) Energy Model

The POLES model is a simulation model for the development of long-term (2050) energy supply and demand scenarios for the different regions of the world. It has to be stated that in the TRIAS project ASTRA and POLES are linked. Therefore, POLES runs with values that originate or are affected by other models. Hence, we name this model POLES-TRIAS. The development of the model intends to fulfil five main objectives:

- to reduce the uncertainties in future developments of world energy consumption and corresponding GHG emissions by the construction of baseline or reference scenarios;
- to provide elements for a global analysis of emission reduction strategies in an international perspective;
- to provide the key parameters of new energy technologies;
- to asses the marginal abatement costs for CO_2 emissions and simulations of emission trading system;
- to analyse the impacts of emission reduction strategies on the international energy markets.

The model structure corresponds to a hierarchical system of interconnected modules and articulates three level of analysis:

- international energy markets;
- regional energy balances;
- national energy demand, new technologies, electricity production, primary energy production systems and CO_2 sectoral emissions.

The main exogenous variables are the population and GDP, which was derived iteratively with ASTRA, for each country / region, the price of energy being endogenised in the international energy market modules. The dynamics of the model corresponds to a recursive simulation process, common to most applied models of the international energy markets, in which energy demand and supply in each national / regional module respond with different lag structures to international prices variations in the preceding periods. In each module, behavioural equations take into account the combination of price effects and of techno-economic constraints, time lags or trends.

The development of such a disaggregate model of the world energy system has been made possible by the availability of a complete International Energy Balance database (from 1971) provided by ENERDATA and completed by techno-economic data gathered and organised at IEPE. International economic databases for the key macro-economic variables used in the model have been provided by the CHELEM-CEPII database, in the framework of the LETS network of the JOULE II program.

In POLES-TRIAS, the world is divided into fourteen main regions: North America, Central America, South America, European Community (15 countries), Rest of Western Europe, Former Soviet Union, Central Europe, North Africa, Middle-East, Africa South of Sahara, South Asia, South East Asia, Continental Asia, Pacific OECD.

In most of these regions the larger countries are identified and treated, as concerns energy demand, with a detailed model. In the current version these countries are the G7 countries plus the countries of the rest of the European Union and five key developing countries: Mexico, Brazil, India, South Korea and China. The countries forming the rest of the 14 above-mentioned regions are dealt with more compact but homogeneous models.

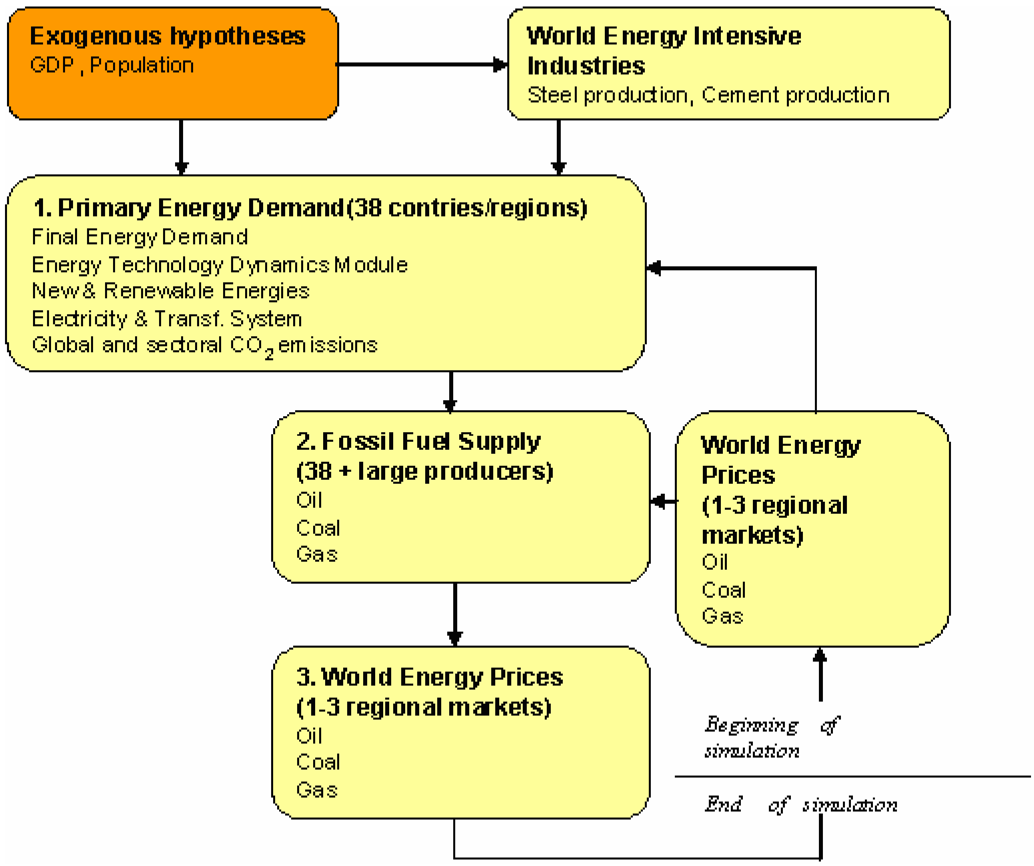

Figure 7: POLES-TRIAS five modules and simulation process.

Vertical integration

For each region, the model articulates four main modules dealing with:

- Final Energy Demand by main sectors;
- New and Renewable Energy technologies;
- The Electricity and conventional energy and Transformation System;
- The Primary Energy Supply.

As indicated in **Figure 7**, this structure allows for the simulation of a complete energy balance for each region.

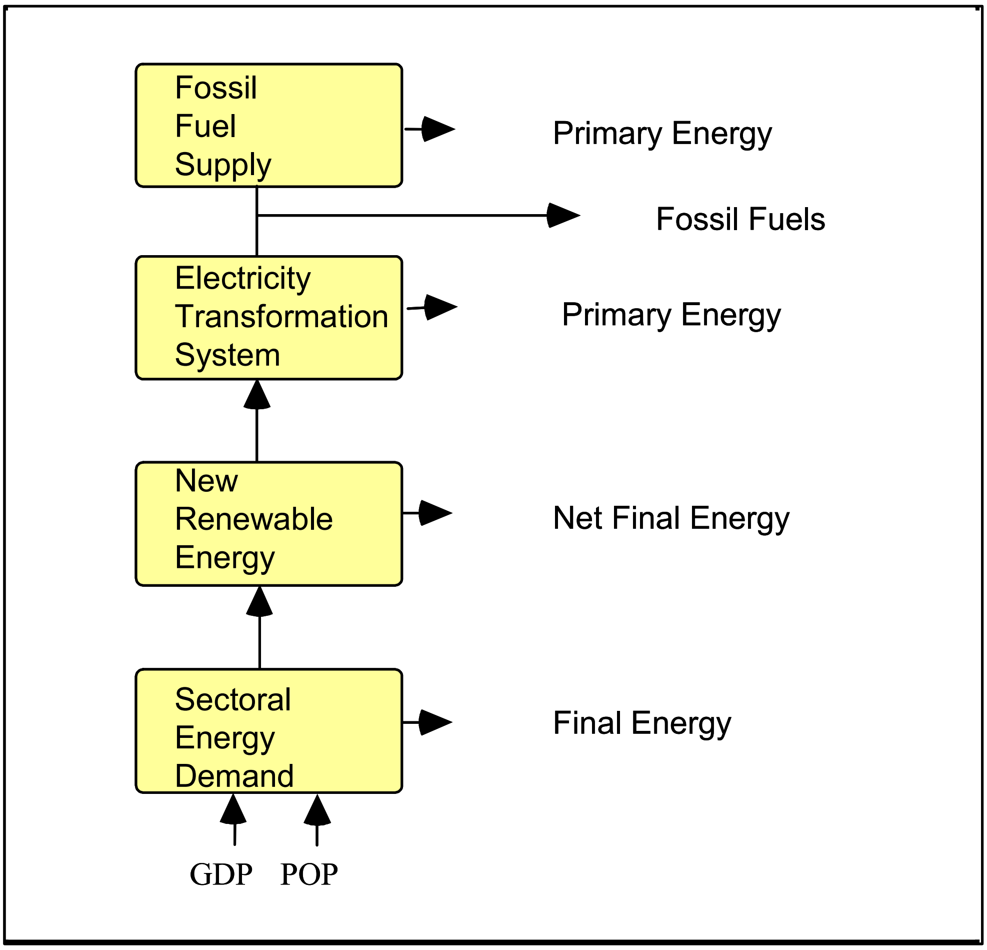

Figure 8: POLES-TRIAS five vertical integration

Horizontal integration

While the simulation of the different energy balances allows for the calculation of import demand / export capacities by region, the horizontal integration is ensured in the energy markets module of which the main inputs are the import demands and export capacities of the different regions. Only one world market is considered for the oil market (the "one great pool" concept), while three regional markets (America, Europe, Asia) are distinguished for coal and gas, in order to take into account for different cost, market and technical structures.

According to the principle of recursive simulation, the comparison of imports and exports capacities for each market allows for the determination of the variation of the price for the following period of the model. Combined with the different lag structure of demand and supply in the regional modules, this feature of the model allows for the simulation of under- or over-capacity situations, with the possibility of price shocks or counter-shocks similar to those that occurred on the oil market in the seventies and eighties.

In the final energy demand module, the consumption of energy is divided into 11 different sectors, which are homogenous from the point of view of prices, activity variables, consumer behaviour and technological change. This is applied in each main country or region. The Industry, Transport and Residential-Tertiary-Agriculture blocks respectively incorporate 4, 4 and 3 such sectors:

Table 1: POLES-TRIAS demand breakdown by main sectors

INDUSTRY	Steel Industry Chemical industry (+feedstock) Non metallic mineral industry Other industries (+non energy use)	STI CHI (CHF) NMM OIN (ONE)
TRANSPORT	Road transport Rail transport Air transport Other transports	ROT RAT ART OTT
RAS	Residential sector Service sector Agriculture	RES SER AGR

In each sector, the energy consumption is calculated separately for substitutable techs and for electricity, with a taking into account of specific energy consumption (electricity in electrical processes and coke for the other processes in the steel-making, feedstock in the chemical sector, electricity for heat and for specific uses in the Residential and Service sectors).

3.1.2 The BIOFUEL Model

The BIOFUEL model is based on a recursive year-by-year simulation of biofuel demand and supply until 2050. For each set of exogenously given parameters an equilibrium point is calculated 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 capacity. This equilibrium point is envisaged by market participants but not necessarily reached in each year.

Increasing production of biofuels and a subsequent rise in feedstock demand has an impact on the prices of biofuel feedstock, which in turn affects biofuel production through a feedback loop (Figure 9).

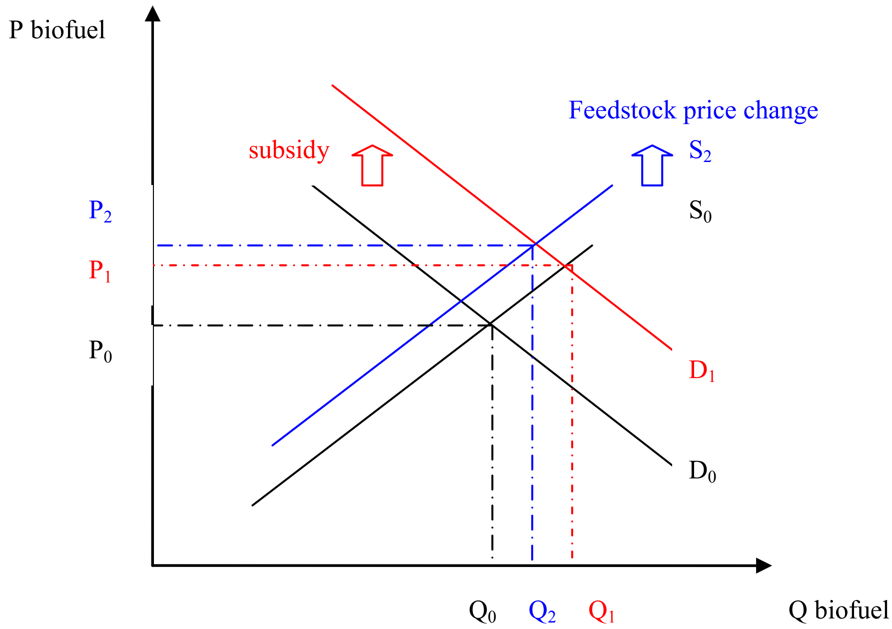

Figure 9: Biofuel supply and demand shifts

First, the equilibrium point for the consumption of biofuels is identified. Keeping the other factors constant, this would correspond to an equilibrium price for feedstock from each pathway. At that level, a certain amount of feedstock would be produced as a result of the agricultural market increasing or decreasing its supply compared to the reference case. The change in the supply of biofuel feedstock will affect the area of cultivated land for these feedstocks, the area for other products, as well as imports and exports of all related agricultural products. As a result, prices will change and strongly influence the costs of biofuel production as feedstock prices account for between around two thirds up to around 90% of total production costs for conventional biofuels.

The reaction of the agricultural markets thus influences the production costs of biofuels and, subsequently, the level of biofuel supply as shown schematically in Figure 9. This feedback is modelled through a number of econometrically estimated equations, which are based on information in the ESIM model simulation results and DG Agriculture. The assumed elasticities for wheat, sugar beet, rapeseed, sunflower and lignocellulosic feedstock are 0.1, 0.1, 0.25, 0.2, 0.04, respectively.

It needs to be noted that the resource limits are exclusively taken into account through the price effects, while upper physical limits for domestic biofuel feedstock supply were not considered. These necessitate a value judgement regarding e.g. the extent to which farmland with a high nature value can be used for bioenergy cropping and whether food/fodder crop cultivation shall be given higher priority than bioenergy production. The model delivers detailed outcomes for the types of biofuels considered – biodiesel or ethanol, first or second generation – with regard to production capacity and produced volumes, costs and well-to-wheel emissions of greenhouse gases. Historical values for biofuel production, consumption and production capacities are incorporated up to 2005.

The model focuses on the main production pathways of biofuels, namely biodiesel based on rapeseed and sunflower and ethanol based on wheat and sugar beet, as well as advanced 2nd generation pathways from lignocellulosic feedstock (i.e. ethanol and synthetic diesel BtL). For the 1st generation of biofuels the technical coefficients, costs and greenhouse gas emissions are based on the deliverable D2 of the TRIAS project, with additional information from the analysis carried out by the JEC study (JRC/EUCAR/CONCAWE 2006). Transportation costs in TRIAS amount up to 20% of total costs while in the JEC study transportation cost are only in the range of 5-6%. The lower transportation costs of the JEC study were taken into account. For the 2nd generation the biofuel prices of TRIAS D2 were taken. Furthermore, technological learning needs to be considered. However, this was only taken into account for 2nd generation biofuels as cost reductions in the production process of conventional biofuels are seen as limited and lie within the range of uncertainties. Important cost reductions for 2nd generation biofuels can be expected both in terms of the production process due to economies of scale and more mature technologies and in terms of the feedstock, as current crops are not yet optimised for their energy content. These effects can nevertheless be quantified only to a very limited extent. For the purpose of the TRIAS scenarios, a cost reduction of about 20% was assumed to occur until 2030 based on the TRIAS D2 values for 2010. As the cost reduction is dependent on the produced amount of biofuel the cost reduction varies between scenarios.

Figure 10 summarises the way the different factors interact. Impacts are traced in the various sectors. The chart is restricted to the EU domestic biofuel market. Regarding imports, biofuel prices are given as exogenous variables as well as their maximum penetration levels. Other main exogenous parameters include

- Selection of biofuel production pathways;
- Production costs and maturity factors (learning of new production technologies);
- Well-to-wheel emissions of greenhouse gases;
- Development of oil prices and subsequently the fossil fuel prices;
- Elasticities of the raw material prices;
- Transport fuel demand.

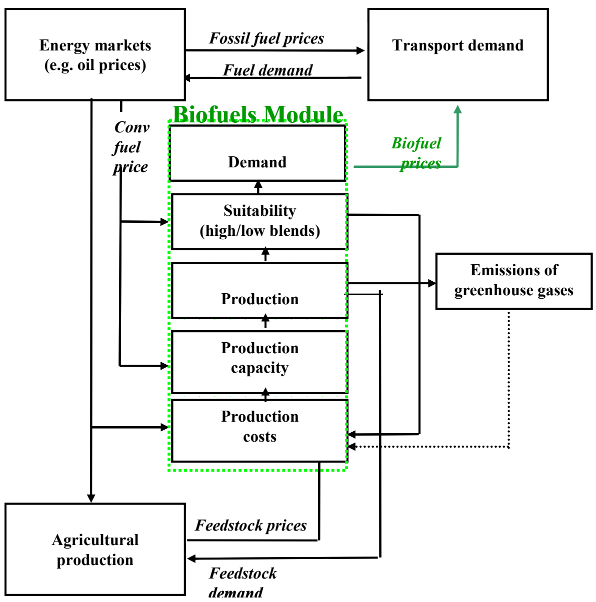

Figure 10: Interaction of factors affecting supply and demand of biofuels (Wiesenthal forthcoming)

The model determines the penetration of biofuels as a function of final price of biofuels relative to the pump price of fossil fuels. These are affected by the prices of oil and raw materials as well as the production costs that each alternative pathway entails (depending on capital costs, feedstock prices, load factors etc.)

The relation of biofuel production costs to fossil prices excluding taxes is considered as an incentive for investors to install additional production capacities, which in return leads to an increased amount of biofuels produced. The additional installed capacity per year depends on the distance to the equilibrium point (and thus the profit margin) and starts from historical values: the average annual growth rate of biodiesel and bioethanol capacity was about 44% and 69% over the period 2002 to 2006, respectively, and prospects for currently planned projects indicate that similar rates are likely to continue also for the coming two years.

The main factors that determine the equilibrium point via influencing the cost ratio of biofuels and fossil fuels are oil prices, distribution costs and feedstock prices:

Oil prices influence the level of biofuel deployment as they are directly linked to fossil fuel prices. On the other hand, they influence biofuel production costs for which energy costs account for up to 15%. Besides, there is a limited, yet not negligible impact of oil prices on the feedstock costs, which is taken from the JEC study (JRC/EUCAR/CONCAWE 2006).

Once the biofuel penetration exceeds a certain share and passes from low blends to higher blends or pure biofuels, additional costs occur due to distribution and blending and potentially adaptation of car engines.

Increasing production of biofuels and a subsequent rise in feedstock demand has an impact on the prices of biofuel feedstock, which in turn affects biofuel production through a feedback loop. First, the equilibrium point for the consumption of biofuels is identified. Keeping the other factors constant, this would correspond to an equilibrium price for feedstocks from each pathway. At that level, a certain amount of feedstock would be produced as a result of the agricultural market increasing or decreasing its supply compared to the reference case. The change in the supply of biofuel feedstock will affect the area of cultivated land for these feedstocks, the area for other products, as well as imports and exports of all related agricultural products. As a result, prices will change and strongly influence the costs of biofuel production as feedstock prices account for between around two thirds up to around 90% of total production costs for conventional biofuels. The reaction of the agricultural markets consequently influences the production costs of biofuels and, subsequently, the level of biofuel supply and demand. This feedback is modelled through a number of econometrically estimated equations, which are based on information in the ESIM model simulation results for the agricultural sector and DG Agriculture. It needs to be noted that the resource limits are exclusively taken into account through the price effects, while upper physical limits were not considered.

The following figure illustrates this effect: changes in feedstock prices are shown for a scenario that assumes a biofuel quota of 10% to be reached by 2020, relative to a scenario that assumes no further increase as of today.

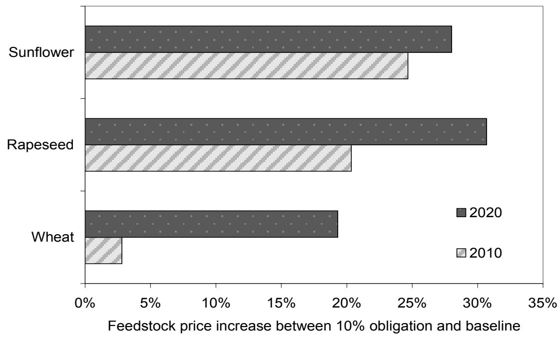

Figure 11: Change of feedstock prices (Wiesenthal forthcoming)

The simulation results demonstrate the high interdependence of biodiesel feedstock prices on biodiesel consumption. The feedback on ethanol feedstock prices remains limited, at least for 2010. Beyond 2010, the price increase for wheat can be explained by the much faster uptake of ethanol compared to biodiesel. The main reason behind the different reaction of the ethanol and biodiesel markets is the fact that the supply curves of the two markets differ considerably. There are large differences between biodiesel and bioethanol production in terms of the share of the consumption of agricultural commodities for biofuel production compared to the consumption of the same commodities for other uses, and the presence of global markets.

In the case of rapeseed, 58% of the total harvested volume was used for biodiesel production in 2006 (EC 2006). Total rapeseed consumption in the EU corresponds to one third of the world production and is three times the size of the net international trade. Rapeseed and rapeseed oil are therefore very responsive to changes in demand and an increase in biodiesel production leads to a steep increase in their prices. The use of sunflower for biofuels represents a quarter of the total EU market for sunflower, a smaller but still significant share. The repercussions of rapeseed and sunflower use for biofuels reach the food and animal feed industry that also use their oils and meals as input. The recent rise in demand because of biofuels has already now led to significant fluctuations in consumption, imports and prices of inputs and final products for the related sectors. Alternatives do exist, mainly soybean and soybean oil, coconut oil and palm oil, soybean meal and tapioca, but restrictions in international trade and biofuel quality requirements limit the options considerably.

On the contrary, only about 1.5 percent of the total EU-25 cereals production and some 5% of sugar beet production were used as feedstock for bioethanol in 2006. The impact of the increased demand for bioethanol on the prices of cereals and sugar will be more limited than for biodiesel. In addition, the reform of the Common Agricultural Policy (CAP) is expected to create negative pressure on sugarbeet prices and/or free additional agricultural land for production of cereals. Finally, it needs to be noted that unlike for biodiesel, there is already a global market with the EU consumption and trade representing only a small share of world production and international trade.

So far, capital grants to support investment in biofuel production plant facilities played only a limited role in promoting biofuels. This is mainly due to the relatively low investment costs compared to the operation and maintenance costs of first generation biofuels (see Figure 12). If, for example, a typical large biodiesel plant with investment costs of 15-20 Mio Euros was supported with 10 Mio Euros, this would affect the biodiesel production costs by mere 0.01 € per litre.

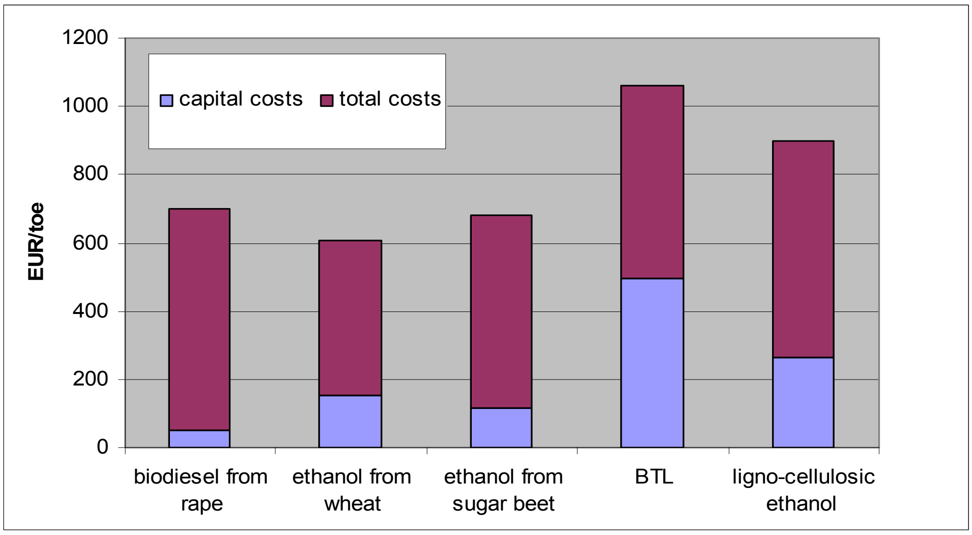

Figure 12: Investment and total costs for different biofuels

This may change drastically with advanced biofuels as the investment of the processing facilities make a higher share of the total production costs of biofuels. Here, the investment support can be used to steer the type of biofuels produced in order to e.g. accelerate the market introduction of advanced biofuels.

With this model structure, the development of biofuels deployment up to the equilibrium point can be calculated for various sets of exogenous assumptions. In particular, the impacts of different policy instruments on the deployment and mix of different biofuels and the economy can be simulated, which is the main focus of the TRIAS analysis. The main implementation measures examined in the TRIAS scenarios include the following:

- A carbon permit price or carbon tax increasing from 0 (2010) to 30 €/t CO_2 in 2030 and remains of this value till 2050. The value of 30 €/t CO_2 is derived from a climate change scenario that assumes a 21% domestic reduction of GHG emissions in the EU by 2020 (EC 2007).
- Subsidies for investments in new capacity. This is analysed as a possible measure in order to accelerate the deployment of advanced biofuel production technologies, which may be desired due to their larger GHG emission benefits or potential.
- Quotas (obligation) differentiated according Member States for fuel suppliers to sell a certain share of total sales as biofuels.

To determine the levels of the quota of the biofuel shares a clustering of Member States was conducted (Figure 13). The TRIAS biofuel scenarios were also looked at on a Member State base, which will be described in the following. For that purpose, Member States were grouped into clusters according to their potential in producing biofuel feedstock and their interest in increasing biofuel consumption (Bekiaris 2007, Wiesenthal forthcoming).

So far, the European biofuel market is carried by a limited number of Member States. In 2005, only 4 (Spain, Sweden, Germany, France) and 3 Member States (Germany, France, Italy) produced 80 % of the total EU ethanol and biodiesel production, respectively. In terms of biofuel consumption, only Germany and Sweden achieved a market share of 2% or above of total transport fuels by 2005. A number of other Member States are only recently implementing national biofuel policies that will allow them achieving their national biofuel targets.

Despite the converging markets, it is likely to assume that the speed of the market deployment of biofuel and the eventual levels reached will continue to differ among Member States. This will certainly depend on a Member States interest in either producing the biofuel feedstock and/or the consumption of biofuels, depending on a number of country-specific factors.

Having in mind the main drivers for setting up a biofuels policy, the overall economic strength of a country combined with energy demand in transport and the importance of the agricultural sector were seen as the most relevant characteristics of a country with regard to biofuels. Even though all of these factors influence a country's interest in promoting biofuels together with additional factors such as collaboration of the domestic car manufacturers or a country's interest in pushing innovative biofuel technologies, a rough distinction can be made between the interest in increasing cultivation of biofuel feedstock and consumption of biofuels.

Biofuel Consumption can be translated as the potential interest of a country to support the use of biofuels domestically in order to reduce its oil dependency or for environmental reasons (such as the reduction of greenhouse gases). There are examples of countries that cannot produce excessive feedstock for biofuels production, but their energy demand and dependency on energy – and specifically oil - imports is such that it is advisable to support consumption of biofuels. Typical example of such a country is Germany, which, in spite of the fact that it cannot cover all its needs in biodiesel, also needs to import from other countries to satisfy the domestic demand.

Feedstock Production on the other hand is the potential interest of a country to support feedstock production for biofuels. Again there are cases of countries that have great potential for cultivation of feedstock and an important agricultural sector although their potential interest in biofuel consumption may not be that advanced. Typical examples of such countries are the Eastern European block members.

The indicator-based exercise results in the clustering of Member States as shown in Figure 13. From the perspective of feedstock production, particularly Lithuania, Denmark, Poland, Hungary and France can be classified as countries with an elevated interest in agricultural production. As such, they are candidates for being interested in increasing domestic production of biofuels. Nevertheless, this also depends on the competitiveness of conventional agricultural products, which determines whether there is a need for the agricultural sector to switch to alternative products. On the other hand, Member States that combine the economic capability (high GDP) with high transport energy demand and related oil import dependency as well as elevated CO2 emissions are likely to have a greater interest in increasing biofuels consumption. According to this indicator, most of the pre-2004 EU-15 Member States could have an elevated interest in increasing the consumption of biofuels, led by Luxembourg and followed by Germany, Ireland and France.

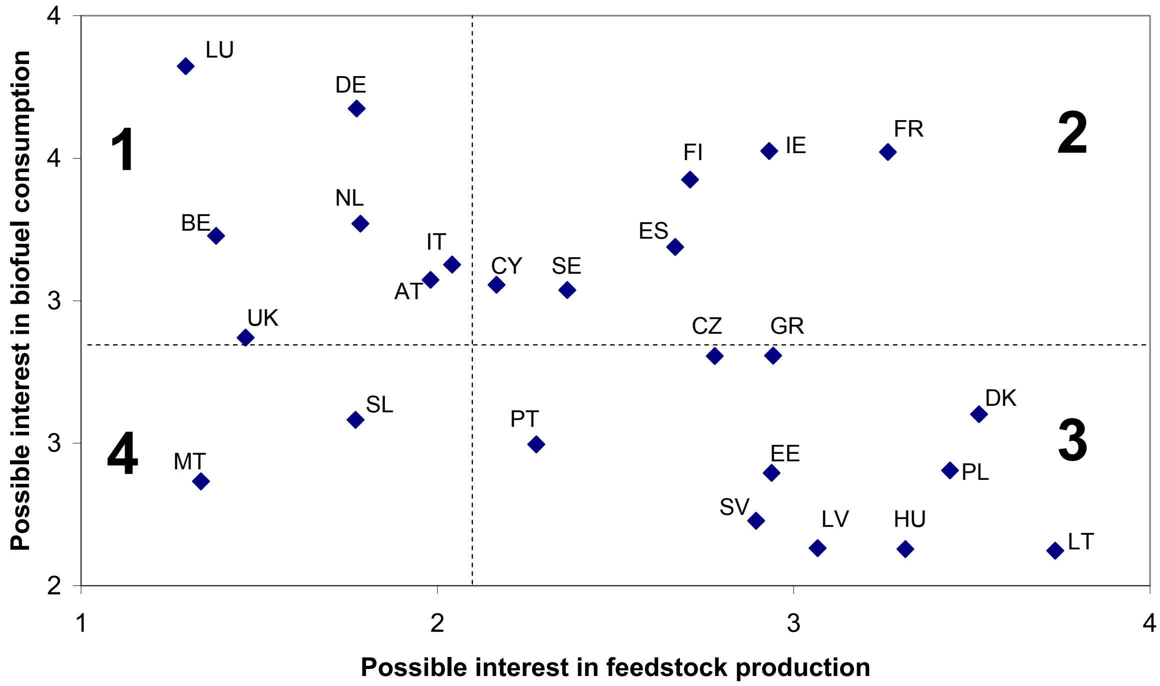

Figure 13: Member States interest to support biofuel consumption vs. interest to support feedstock production

Not surprisingly most of the new Member States show a large potential of biofuel production, particularly in relation to their transport fuel demand (Figure 13). They would not only be self-sufficient so as to meet the 2010 biofuel target without any imports, but have a considerable export potential. The export potential is further stressed by the fact that they may lack the finance to support the creation of large domestic biofuel consumption. Some countries have started to create a biofuel policy (e.g. Czech Republic, Poland and Slovakia). However, biofuels are often rather exported than used domestically.

Luxembourg, Germany, Belgium, the Netherlands, Italy, Austria and United Kingdom are countries with a relatively high economic strength but with a limited potential in arable land. These countries have limited means to produce domestic feedstock, but may be interested to import feedstock. The option of importing biofuels is supported by the factor that these Member States (except for Luxembourg) host important harbours.

There are only few Member States that combine a high production potential with an elevated interest in the consumption of biofuels. These comprise mainly France, Ireland and Finland, and to a lesser extent Spain, Sweden and Cyprus.

Most of these Member States have implemented an ambitious biofuel policy, with the exception of Finland, Ireland and Denmark that considers the use of biomass for heat and power production a favourable option compared with biofuels. France has been the leading player on biofuels in Europe in the 1990s, driven by the strong agricultural and industrial sectors. From 2000 biofuel share on the market was controlled by an accreditation (quota) system, which stabilized the market, but also prevented growth. The market was limited to a few big industrial players. French government has now announced ambitious plans for the coming years, aiming for 10% biofuels by 2015. Germany is now leading the European market, driven by strong agricultural and industrial sector backing and a very favourable legislation for biofuels (up to the end of 2006). Spain has become the leading Member State in ethanol production. The Swedish success story is mostly driven by local initiatives, supported by local and national governments (McCormick et. al. 2006). Even though Sweden imports large amounts of ethanol, there are plans to use the large potential of woody biomass for producing lignocellulosic ethanol in the future. Austria was a very active player on biodiesel, but the very favourable legislation in neighbouring Germany has resulted in an almost complete export of produced biodiesel to Germany. With its obligation system from 2005, Austria is getting back on track.

On that basis, it was assumed that Member States will ultimately achieve different biofuel consumption shares by 2020. Furthermore, their import shares will vary, depending on the interest in protecting domestic agriculture. Please note that this clustering is based on socio-economic indicators and does not provide an indication on the political commitment to biofuels or the support of stakeholders!

Table 2: Country clusters and model assumptions

Clu ster	Characteristics	Target by 2020	Import lev-els (from outside EU)
1	Rather limited means to produce domestic feedstock, but interest in increasing the consumption of biofuels → imports	5.75%	40%
2	Fairly high potential for producing feedstock, and relatively high interest in consuming biofuels	5.75%	15%
3	Large potential in producing biofuels combined with a limited interest in increasing biofuels	2.35%	0%
4	Neither a large interest nor a high potential for promoting biofuels	2.35%	40%

Table 2 shows the different levels of the quota and the expected import share of a country. E.g. France as it belongs to group 2 is assumed to establish a quota of 5.75% share of biofuels of total fuel demand in the base scenario. Due to their high potential for producing feedstock an import level of only 15% is assumed. The quota defines only the minimum share, so that depending on the price relation between biofuels and fossil fuels the biofuel share can be higher than 5.75%.

3.2 Basic assumptions of POLES-TRIAS

POLES-TRIAS provides an image of the energy scene to 2050 as resulting from the continuation of on-going trends and structural changes in the world economy. This projection has been developed with the POLES-TRIAS model. The Base scenario of POLES-TRIAS is quite similar to the Reference scenario being developed in the *World Energy Technology Outlook–2050* or *WETO-H_2 study*[1]. Main differences occur due to changes in GDP (which is calculated iteratively in combination with ASTRA) and due to a lower supply and demand for hydrogen in the Base scenario of POLES-TRIAS. From the identification of the drivers and constraints in the energy system, the model allows to describe the pathways for energy development, fuel supply, greenhouse gas emissions, international and end-user prices, from today to 2050.

The approach combines a high degree of detail in the key components of the energy systems and a strong economic consistency, as all changes in these key components are largely determined by relative price changes at sectoral level. As explained in the previous section, the model identifies 46 regions of the world, with 22 energy demand sectors and about 40 energy technologies – now including generic "very low energy" end-use technologies, such as:

- Carbon capture and storage options as add-ons to plants burning fossil fuel to make electricity or hydrogen
- Distributed electricity production, with or without cogeneration, from fossil fuel, renewable energy or hydrogen
- Low and very low energy buildings with significantly improved thermal performances (meaning a reduction by a factor of 2 to 4 from the consumption of present buildings in each region); these can even be "positive energy buildings" when photovoltaic systems are integrated into the design

The main exogenous inputs to the Baseline projection relate to: world population and economic growth as the main drivers of energy demand; oil and gas resources as critical constraints on supply and the future costs and performances of energy technology that define the feasible solutions. In all cases, the projected trends extrapolate existing structural changes; this in no way implies, as is illustrated below, a uniform development of the world economic and energy system.

An important aspect of the projections performed with the POLES-TRIAS model is that they rely on a framework of permanent competition between technologies with dynamically changing attributes. The expected cost and performance data for each critical technology are gathered and examined in a customised database that organises and standardises the information in a manner appropriate to the task.

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1 http://ec.europa.eu/research/energy/pdf/weto-h2_en.pdf

Critical Assumptions

Population

World population is expected to grow at a decreasing rate to 8.9 billions in 2050. After 2030, the population in several regions of the world decreases – including Europe and China.

Economic growth

The rate of economic growth in industrialised regions converges to 2.3%/yr in the very long run. Growth in Asian emerging economies falls significantly after 2010, while conversely it accelerates in Africa and the Middle East. As a result, global economic growth is expected progressively to slow from 4.0%/yr in the 2001-2010 period to 2.8%/yr between 2010 and 2030 and then 2.5%/yr until 2050. Total world GDP in 2050 is more than three times the present GDP.

World fossil fuel resources

Nowadays, the availability of oil and gas resources in the next decades is increasingly questioned. The accumulated production of oil to date is 900 Gbl. The assumption in this study is that there remain almost 1 100 Gbl of identified reserves and slightly more than 600 Gbl of resources that have not yet been identified. Higher recovery rates through technological progress are expected to extend the Ultimate Recoverable Resource base from 2700 Gbl today to 3500 Gbl in 2050.

Energy Supply and Prices

The world oil production increases from around 30 Giga barrel in 2006 to around 44 Giga barrels in 2034 before remains at that level until the end of the period (2050). About similar trend can be expected to occur in the world natural gas supply, which will increase from around 2.8 Gtoe in 2006 to reach around 4 Gtoe in the early 2030 and stays on that level until 2050. As consequences, the average natural gas and gasoline prices (without VAT) in EU-27 are expected to increase by around 40% between 2006 and 2050. Diesel price will also increase but in a much slower rate.

The electricity production in EU-27 is expected to increase steadily by about 3.3% per year from 2006 to 2050. In 45 year-period the average electricity price in EU-27 is expected to increase by mere 4%.

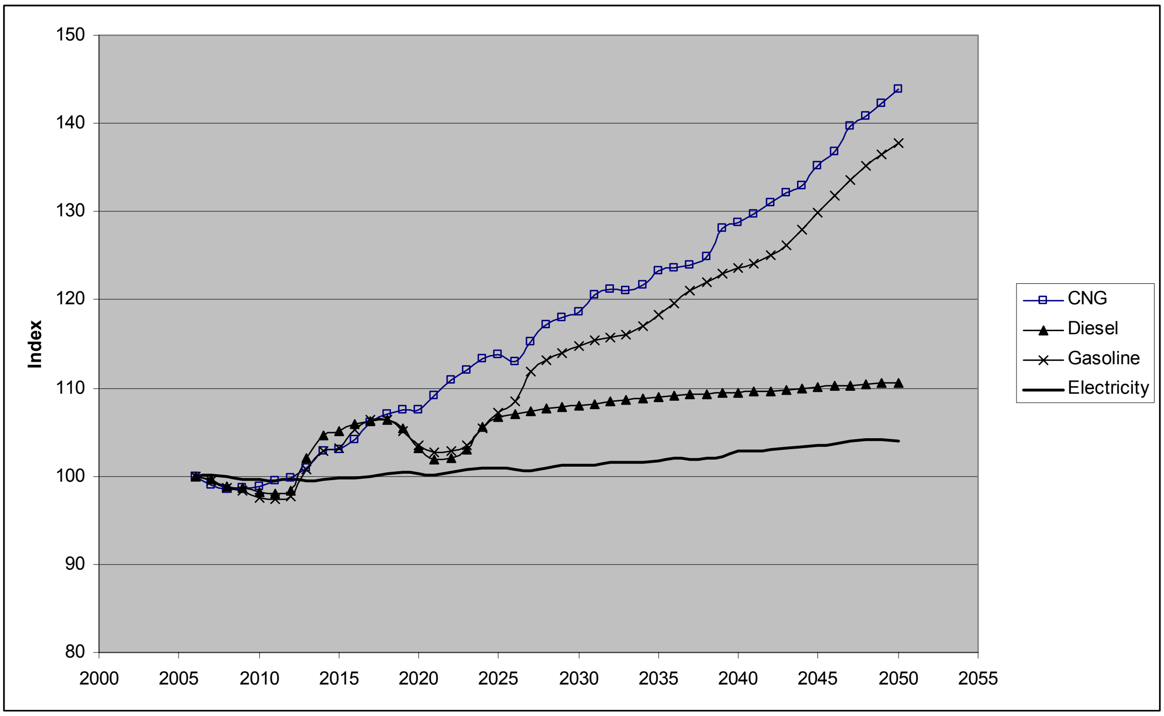


Figure 14: Evolution of fuel price without VAT in EU-27

Energy technologies

Technology development will be critical in the shaping the future energy system. A thorough examination of the technical possibilities for the next 50 years suggests new portfolios of energy technologies will challenge conventional ones based on fossil and renewable sources with electricity as a main carrier. It is indispensable to explore the role in future energy systems of carbon capture and storage, options for producing and using hydrogen, diversified distributed electricity systems and end-use technologies with very low energy and/or very low emissions. Projections of the economic, physical and environmental performance of the new energy technology portfolios have been organised in a database known as TECHPOL, which was developed in the framework of the FP6 SAPIENTIA and CASCADE-MINTS projects and also in the French CNRS Energy Programme.

Climate policies

The Baseline case represents the situation without climate change policy. No carbon tax is applied in this scenario.

Access to oil and gas resources

The geo-politics of the international energy markets are a vital consideration for sound long-term energy projections; a sound representation of the economic behaviour without these influences is not sufficient. The Reference projection accounts for some of these aspects by partially constraining the development of oil production capacity in the Middle East.

3.3 Linkage with ASTRA

The task of linking the TRIAS models to perform quantitative techno-economic and socio-economic analysis of transport and energy policies constitutes one of the main tasks in TRIAS. On the macro-level of analysis the obvious combination of models is between POLES and ASTRA, where POLES-TRIAS covers the energy field with supply of energy resources on world level, energy demand and development of energy prices with an exogenously given economic development while ASTRA covers the transport field with infrastructure supply and transport demand as well as an economic model that endogenously forecasts economic development under varying policy conditions. For ASTRA the energy prices for gasoline, diesel as well as other fuels (e.g. biofuels) are exogenous inputs. The first and obvious linkage between the models accounts for replacing the exogenous input by results from the other model such that ASTRA receives fuel prices from POLES-TRIAS and POLES-TRIAS receives GDP development from ASTRA. Furthermore there exists some overlap between the models e.g. POLES-TRIAS and ASTRA both include transport energy demand components as well as models for trade in energy resources. In these cases the results from the more sophisticated model are used, which would be ASTRA for transport energy demand and POLES for trade flows of energy resources. Furthermore, POLES includes bottom-up calculations of investments into energy technologies. In the TRIAS scenarios such investments are transferred to ASTRA in so far they constituted additional investments that was stimulated and financed by the policy e.g. by revenues from a carbon tax on fuels.

In addition, even if ASTRA and POLES models have different features and deal with a different set of variables, they both simulate the demographic trends for the EU countries and such trends play a role in the outcomes of the simulations. Therefore, it is necessary that also these trends are similar across the models such that both models have been calibrated according to the same demographic development forecast until 2050, provided by the European commission.

Figure 15 and Figure 16 show how the population and the GDP are forecasted to develop until the year 2050 in the EU27 (divided into EU15 and EU12 member states group) according to the ASTRA and POLES models. The forecasts in the figures are drawn from their baseline, calibrated for the TRIAS project.

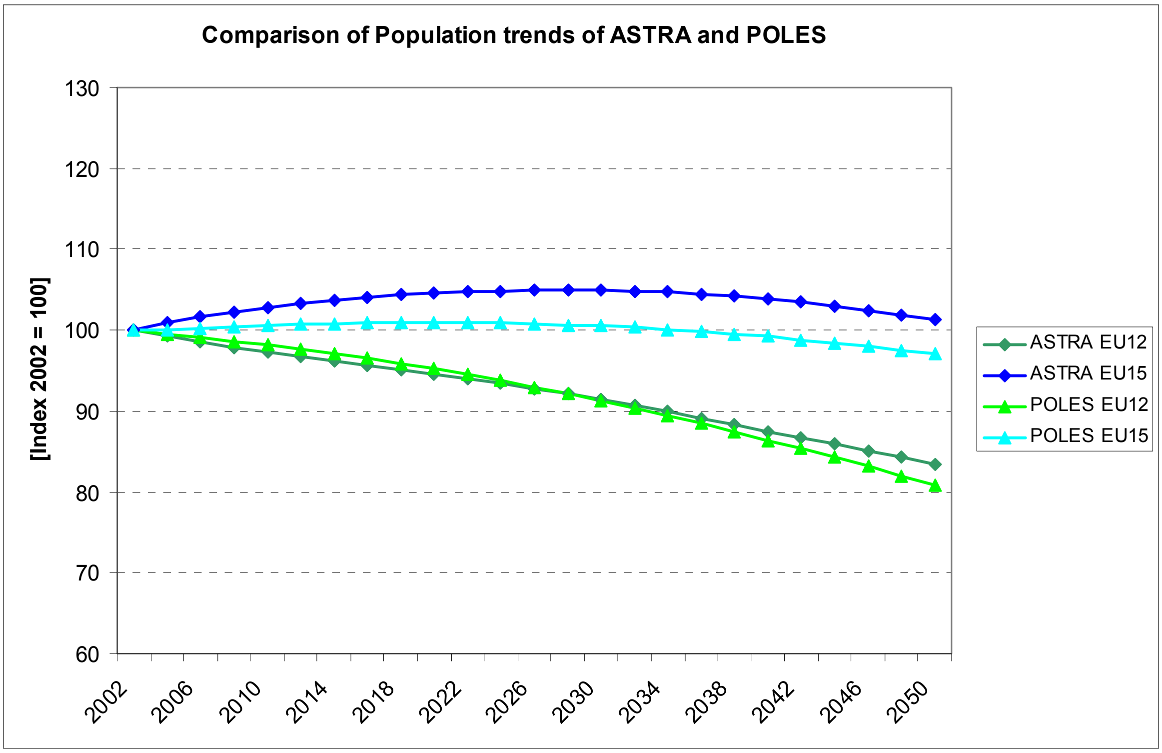


Figure 15: Population trend in ASTRA and POLES-TRIAS models

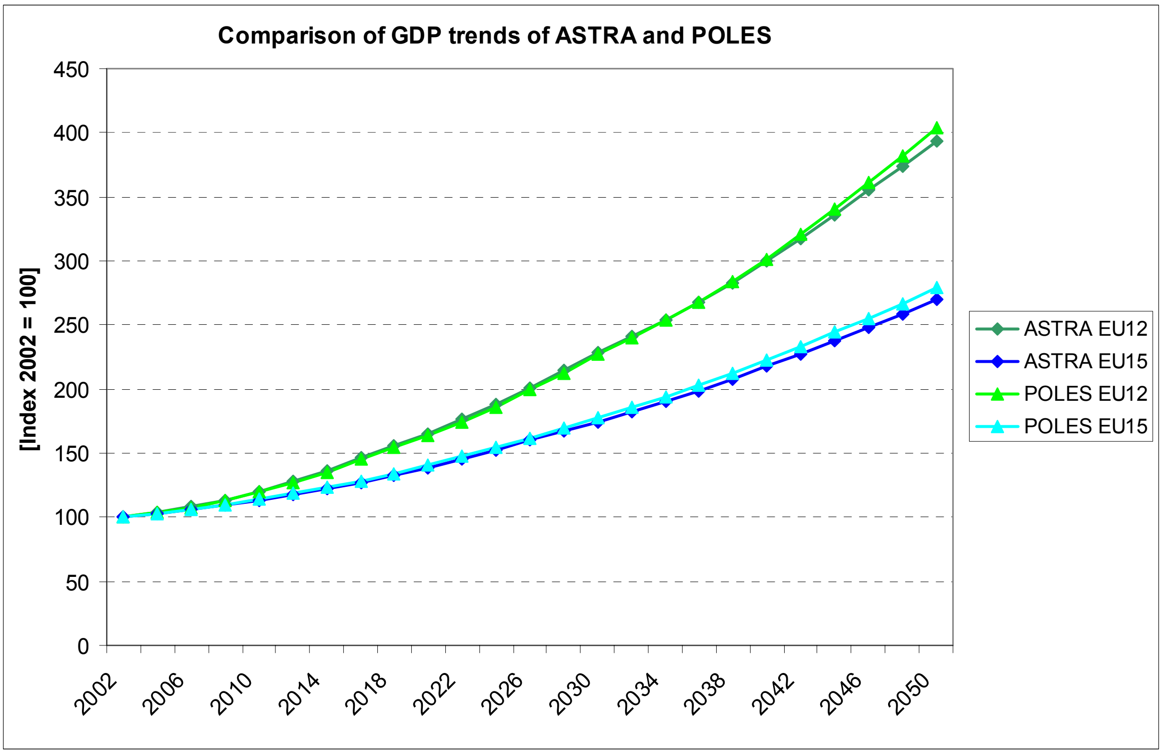


Figure 16: GDP trend in ASTRA and POLES-TRIAS model (ADAM trend)

One of the primary variables in the data exchange between POLES-TRIAS and ASTRA is oil price, which drives the cost of all fossil fuels and also of alternative technologies. However, even if there were a clear correlation between oil price and fuels price, it would not be correct to assume that the hypothesis concerning the former could be applied as such to the latter. Actually, historical trends show that fuel price is generally less volatile than oil price. For instance, the crude oil price has grown by about 120% in the last 6 years (from an average of 16.5 $/Barrel in 1999 to an average of 37.5 $/Barrel in 2004), while gasoline price in the same period has grown significantly less (e.g. of about 35% in Italy, of about 40% in Germany, etc.).

It was the energy market POLES-TRIAS model, which took care of the simulation of the fuels price development as a consequence of the oil price hypothesis assumed in the scenarios. And since one crucial variable affecting the development of fuels price is transport demand, this was provided to POLES-TRIAS form the ASTRA model. Transport demand affects prices but also the reverse is true, so there is a feedback relation to take into account. For that reason, the interactions between POLES-TRIAS and ASTRA for simulating the scenarios has been obtained working interactively with the models in a feedback process.

Taking transport cost, as generalised costs, and transport demand, as vehicles-kms, from the ASTRA model, POLES-TRIAS has computed the fleet evolution and fuels price development. In turn, the fuels (resource) price forecast by POLES-TRIAS has been used in ASTRA to revise the transport demand forecast, which is again fed into POLES.

The loop transport demand – fuels price impact – impact on transport demand – impact on fuels price between the three models has requested several iterations (Figure 17) before reaching the equilibrium. The calculation of the baseline was started by ASTRA passing its relevant data to POLES, which then handed over its results to the BIOFUEL model. From both models, results were given back to ASTRA where the next step was started. For all nine scenarios POLES-TRIAS started the calculation, giving results to the BIOFUEL model and ASTRA, and BIOFUEL gave its results to ASTRA as well. ASTRA started the baseline calculation because it calculated the GDP needed by POLES. On the other hand, POLES-TRIAS started the scenario calculations based on the final ASTRA baseline results because in POLES-TRIAS and BIOFUEL, the politic measures were implemented. These were carbon tax levels and subsidies for new fuel technologies. Figure 17 summarises which variables are exchanged and how ASTRA, POLES-TRIAS and BIOFUEL are linked.

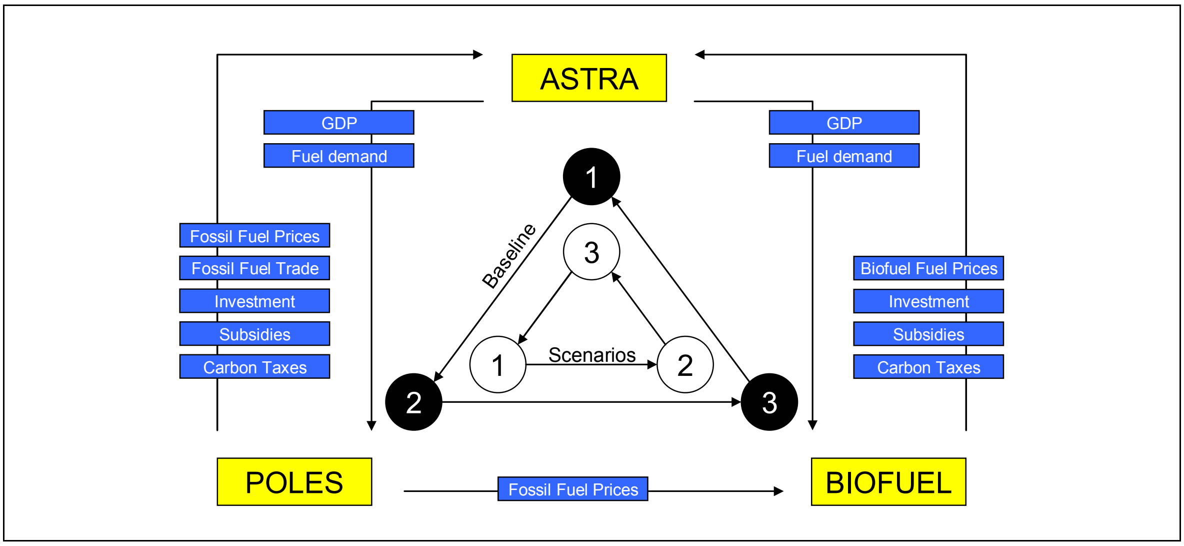


Figure 17: Data exchange between ASTRA, POLES-TRIAS and BIOFUEL models

4 Economic, Transport and Environmental Modelling

This section describes the three models used in TRIAS to analyse the transport system, the environmental impacts of transport and the economic impacts of the scenarios and policies tested in TRIAS. The three models include VACLAV, Regio-SUSTAIN and ASTRA. VACLAV is a transport network model covering the whole EU as well as the relevant long distance transport modes: road, rail, inland waterway, shipping and air transport. Regio-SUSTAIN enables to calculate immission concentrations on a local scale such that the model in TRIAS will be applied for two selected regions of Europe. ASTRA is an integrated transport – economy - environment model, which in TRIAS in particular is used to estimate the indirect economic impacts of transport and energy policies. The three models, their improvements and their application are explained in the following sections.

4.1 The ASTRA Model

ASTRA stands for Assessment of Transport Strategies. The model is developed since 1997 with the purpose of strategic assessment of policies in an integrated way i.e. by considering the feedback loops between the transport system and the economic system. The most detailed description of ASTRA is provided by Schade (2005). The following sections give an overview on ASTRA taking into account extensions made for the TRIAS project.

The most important as well as resource consuming improvement, though not visible in the technical capabilities of ASTRA, is the fact that ASTRA is physically modularised in TRIAS. So far, ASTRA was only conceptually modularised, which means that all former modules of ASTRA were implemented within one physical software file. In TRIAS physical modularisation is implemented, which required both software reengineering of the existing modules and the development of a software that links separate ASTRA modules into one software file again, because the applied Vensim System Dynamics software is working only with one physical file. The big advantage of modularisation justifying the efforts is that a physically modularised ASTRA can be developed further applying the knowledge and organisation processes of professional distributed software development i.e. the separate modules can be improved and tested separately by independent developer teams and a repository supports version controlling and change management of the ASTRA modules.

4.1.1 Description of ASTRA

This section provides a description of the ASTRA model starting with the basic modelling concept and an overview of the whole model framework. The overview is followed by a description of important feedback loops of the full model and two sections describing the classification structures of ASTRA: spatial differentiation and sectoral classification.

Concept of ASTRA

The approach for the original development of ASTRA was to build an integrative coded model that is implemented with the System Dynamics standard software Vensim. If available ASTRA draws on existing models of different scientific disciplines. Otherwise models are newly developed. Core models that spin off for ASTRA are the European transport model STREAMS and its updated version SCENES (ME&P 2000), the macroeconomic system dynamics model ESCOT (SCHADE/ROTHENGATTER/SCHADE 2002) and a set of environmental models that have been developed for purposes of Strategic Environmental Assessment (SEA) of the German federal cross-modal transport infrastructure plan (BVWP) (IWW et al. 1998, GÜHNEMANN 2000). Major completions and extensions of ASTRA have been achieved in the TIPMAC project and the related dissertation of Wolfgang Schade, which constituted so far the most comprehensive description of ASTRA (SCHADE 2005).

From each of the three above models the major feedback loops were analysed and selected for implementation in ASTRA. Since two out of the three models were not developed with System Dynamics this required reformulation and adaptation of their equations such that the final outcome looked rather different to the originating model. But the spirit of the identified feedbacks was maintained. One reason why system dynamics was chosen as methodology is founded in the flexibility to incorporate elements of different modelling approaches. In that sense, to model ASTRA various techniques from other modelling approaches outside system dynamics are borrowed. This includes econometrics to estimate functional relationships between variables for which all relevant data is available. It incorporates input-output analysis to reflect sectoral relationships of economies. It even covers equilibrium approaches as these are frequently used in transport modelling. Obviously these have to be adapted as in some cases there are fundamental differences in approaches e.g. an equilibrium concept in its pure form is diametrically opposed to the approach of system dynamics that can be called a disequilibrium approach from the viewpoint of neo-classical economics.

Finally, the problems of analysing and visualising the model are of key importance to build, to communicate and to control large-scale models. In this respect system dynamics and its tools offer powerful capabilities that are intensively used for verification and validation of ASTRA.

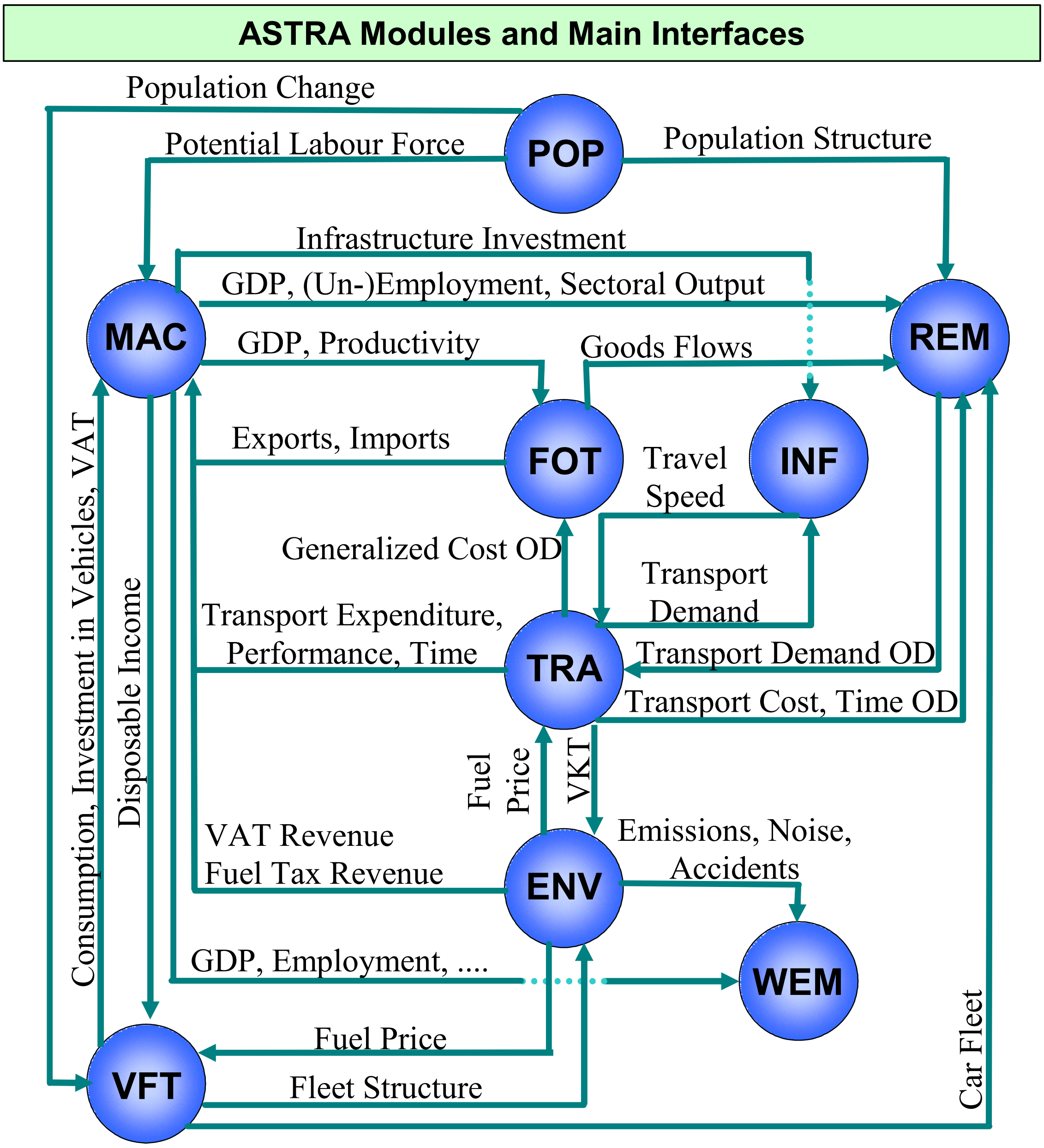
Overview on ASTRA

The ASTRA model consists of nine modules that are all implemented within one Vensim system dynamics software file. One scenario simulation between 1990 and 2050 with 2-yearly saving intervals of the selected result indicators generates about 800 Mega-Byte of output data for the EU29 countries. The model comprises close to 30 million objects in Vensim. Objects could be variables, which is equal to equations, constants or data input. More than 1 million objects are level variables and hence are dynamic variables. Two major types of level variables can be distinguished: delay variables and accumulating variables of which the former stand for the greater share of level variables in the model. About 12.000 time series are used to calibrate ASTRA for the period 1990 until 2000. Variables are grouped into the following nine modules:

- Population module (POP),

- Macro-economic module (MAC),
- Regional economic module (REM),
- Foreign trade module (FOT),
- Infrastructure module (INF),
- Transport module (TRA),
- Environment module (ENV),
- Vehicle fleet module (VFT) and
- Welfare measurement module (WEM).

An overview on the nine modules and their main interfaces is presented in Figure 18. The aggregate level of the figure provides the only exhaustive presentation of ASTRA. Going to one further level of detail with the description would already be outside what could be presented within one figure or one comprehensive set of equations. To cope with this difficulty the following explanations are zooming top-down into the details of the model necessarily having some overlap in the descriptions from the upper levels to the more detailed levels to pick-up the thread at each level of description again.



Abbreviations:

POP = Population Module
MAC = Macroeconomics Module
REM = Regional Economics Module
FOT = Foreign Trade Module
INF = Infrastructure Module
TRA = Transport Module
ENV = Environment Module
VFT = Vehicle Fleet Module
WEM = Welfare Measurement Module

Figure 18: Overview on the structure of the nine ASTRA modules

The Population Module (POP) provides the population development for the 29 European countries[2] with one-year age cohorts. The model depends on fertility rates, death rates and immigration of the EU29 countries. Based on the age structure, given by the one-year-age cohorts, important information is provided for other modules like the number of persons in

2 For simplicity reasons we are speaking of 29 European countries, though this includes Norway and Switzerland and Belgium and Luxemburg are aggregated into one region.

the working age or the number of persons in age classes that permit to acquire a driving licence. POP is calibrated to EUROSTAT population predictions.

The MAC provides the national economic framework, which imbeds the other modules. The MAC could not be categorised explicitly into one economic category of models for instance a neo-classical model. Instead it incorporates neo-classical elements like production functions. Keynesian elements are considered like the dependency of investments on consumption, which are extended by some further influences on investments like exports or government debt. Further elements of endogenous growth theory are incorporated like the implementation of endogenous technical progress (e.g. depending on sectoral investment) as one important driver for the overall economic development.

Six major elements constitute the functionality of the macroeconomics module. The first is the sectoral interchange model that reflects the economic interactions between 25 economic sectors of the national economies. Demand-supply interactions are considered by the second and third element. The second element, the demand side model depicts the four major components of final demand: consumption, investments, exports-imports and the government consumption. The supply side model reflects influences of three production factors: capital stock, labour and natural resources as well as the influence of technological progress that is modelled as total factor productivity. Endogenised total factor productivity depends on investments, freight transport times and labour productivity changes. The fourth element of MAC is constituted by the employment model that is based on value-added as output from input-output table calculations and labour productivity. Employment is differentiated into full-time equivalent employment and total employment to be able to reflect the growing importance of part-time employment. In combination with the population module unemployment was estimated. The fifth element of MAC describes government behaviour. As far as possible government revenues and expenditures are differentiated into categories that can be modelled endogenously by ASTRA and one category covering other revenues or other expenditures. Categories that are endogenised comprise VAT and fuel tax revenues, direct taxes, import taxes, social contributions and revenues of transport charges on the revenue side as well as unemployment payments, transfers to retired and children, transport investments, interest payments for government debt and government consumption on the expenditure side.

Sixth and final of the elements constituting the MAC are the micro-macro bridges. These link micro- and meso-level models, for instance the transport module or the vehicle fleet module to components of the macroeconomics module. That means, that expenditures for bus transport or rail transport of one origin-destination pair (OD) become part of final demand of the economic sector for inland transport within the sectoral interchange model. The macroeconomics module provides several important outputs to other modules. The most important one is, for sure, Gross Domestic Product (GDP). This is for instance required to calculate sectoral trade flows between the European countries. Other examples are employment and unemployment representing two influencing factors for passenger transport generation. Sectoral production value is driving national freight transport generation. Disposable income exerting a major influence on car purchase affecting finally the vehicle fleet module and even passenger transport emissions.

The Regional Economic Module (REM) mainly calculates the generation and spatial distribution of freight transport volume and passenger trips. The number of passenger trips is driven by employment situation, car-ownership development and number of people in different age classes. Trip generation is performed individually for each of the 71 zones of the ASTRA model. Distribution splits trips of each zone into three distance categories of trips within the zone and two distance categories crossing the zonal borders and generating OD-trip matrices with 71x71 elements for three trip purposes. Freight transport is driven by two mechanisms: Firstly, national transport depends on sectoral production value of the 15 goods producing sectors where the monetary output of the input-output table calculations are transferred into volume of tons by means of value-to-volume ratios. For freight distribution and the further calculations in the transport module the 15 goods sectors are aggregated into three goods categories. Secondly, international freight transport i.e. freight transport flows that are crossing national borders are generated from monetary Intra-European trade flows of the 15 goods producing sectors. Again transfer into volume of tons is performed by applying value-to-volume ratios that are different from the ones applied for national transport. In that sense the export model provides generation and distribution of international transport flows within one step on the base of monetary flows.

The Foreign Trade Module (FOT) is divided into two parts: trade between the EU29 European countries (INTRA-EU model) and trade between the EU29 European countries and the rest-of-the world (RoW) that is divided into nine regions (EU-RoW model with Oceania, China, East Asia, India, Japan, Latin America, North America, Turkey, Rest-of-the-World). Both models are differentiated into bilateral relationships by country pair by sector. The INTRA-EU trade model depends on three endogenous and one exogenous factor. World GDP growth exerts an exogenous influence on trade. Endogenous influences are provided by GDP growth of the importing country of each country pair relation, by relative change of sectoral labour productivity between the countries and by averaged generalised cost of passenger and freight transport between the countries. The latter is chosen to represent an accessibility indicator for transport between the countries. The EU-RoW trade model is mainly driven by relative productivity between the European countries and the rest-of-the-world regions. Productivity changes together with GDP growth of the importing RoW-country and world GDP growth drive the export-import relationships between the countries. Since, transport cost and time are not modelled for transport relations outside EU29 transport is not considered in the EU-RoW model. The resulting sectoral export-import flows of the two trade models are fed back into the macroeconomics module as part of final demand and national final use respectively. Secondly, the INTRA-EU model provides the input for international freight generation and distribution within the REM module.

The Infrastructure Module (INF) provides the network capacity for the different transport modes. Infrastructure investments derived both from the economic development provided by the MAC and from infrastructure investment policies alter the infrastructure capacity. Using speed flow curves for the different infrastructure types and aggregate transport demand the changes of average travel speeds over time are estimated and transferred to the TRA where they affect the modal choice.

The major input of the Transport Module (TRA) constitutes the demand for passenger and freight transport that is provided by the REM in form of OD-matrices. Using transport cost and transport time matrices the transport module performs the modal-split for five passenger modes and three freight modes. The cost and time matrices depend on influencing factors like infrastructure capacity and travel speeds both coming from the INF module, structure of vehicle fleets, transport charges, fuel price or fuel tax changes. Depending on the modal choices, transport expenditures are calculated and provided to the macroeconomics module. Changes in transport times are also transferred to the macroeconomics module such that they can influence total factor productivity. Considering load factors and occupancy rates respectively, vehicle-km are calculated.

Major outputs of the TRA provided to the Environment Module (ENV) are the vehicle-kilometres-travelled (VKT) per mode and per distance band and traffic situation respectively. Based on these traffic flows and the information from the vehicle fleet model on the national composition of the vehicle fleets and hence on the emission factors, the environmental module calculates the emissions from transport. Besides emissions, fuel consumption and, based on this, fuel tax revenues from transport are estimated by the ENV. Traffic flows and accident rates for each mode form the input to calculate the number of accidents in the European countries. Expenditures for fuel, revenues from fuel taxes and value-added-tax (VAT) on fuel consumption are transferred to the macroeconomics module and provide input to the economic sectors producing fuel products and to the government model.

The Vehicle Fleet Module (VFT) describes the vehicle fleet composition for all road modes. Vehicle fleets are differentiated into different age classes based on one-year-age cohorts and into different emission standard categories. The car vehicle fleet is developing according to income changes, development of population, fuel prices, fuel taxes, maintenance and purchase cost of vehicles, mileage and the density of filling stations for the different type of fuels. Vehicle fleet composition of buses, light-duty vehicles and heavy-duty vehicles mainly depends on travelled kilometres and the development of average annual mileages per vehicle of these modes. The purchase of vehicles is translated into value terms and forms an input of the economic sectors in the MAC that cover the vehicle production.

Finally, in the Welfare Measurement Module (WEM) major macro-economic, environmental and social indicators can be compared and analysed. Also different assessment schemes that combine indicators into aggregated welfare indicators for instance an investment multiplier are provided in the WEM. In some cases, e.g. to undertake a CBA, the functionality is separated into further tools to avoid excessive growth of the core ASTRA model by including the assessment scheme directly within the model.

Important Feedback Loops of ASTRA

The feedback loop concept constitutes the most important concept of system dynamics, which is the underlying modelling methodology of ASTRA. Starting from a causal analysis structured by the relations of the system to be modelled a feedback structure inherent to the system is developed. A feedback loop is identified when a sequence of relations of which the first relation commenced at the system component X reaches the component X again. Usually the sequence of relations leading from X via other system components back to X again incorporates a time structure i.e. commencing at X and feeding back to X would not happen at the same point of time. In fact, feedback loops are the most important structures of complex systems. STERMAN (2000 p.13) puts it this way: "*All systems, no matter how complex, consist of networks of positive and negative feedbacks, and all dynamics arise from the interaction of these loops with one another.*"

Feedback loops can be distinguished into two categories: negative feedback loops and positive feedback loops (Bossel 1994, Sterman 2000):

- *Negative feedback* loops are target-seeking. They tend to counteract any disturbance and lead systems towards a stable state. Control of the temperature in a room with a thermostat constitutes one example of a negative feedback loop. If temperature differs from the envisaged temperature (= target), heating will be activated until the difference between actual and envisaged temperature approaches zero.
- *Positive feedback* loops are present if the change of a system component leads to changes in other components that finally strengthen the original process. Positive feedback introduces an accelerating process of growth or decline. A system consisting only of positive feedbacks tends to explode or to implode. The well-known stylised fact of dependency between wages and prices provides an example for a positive feedback. Higher wages lead to inflation. Inflation leads to higher prices and higher prices result in claims for higher wages such that the inflation-spiral moves. This example reveals that *positive* does not at all mean favourable in connection with feedback loops.

Since, analysis of the feedback loops of a system enable to describe and understand the functionality of a system it is used in the following to deepen the explanation of ASTRA. Seven of the most relevant feedback loops are presented by causal loop diagrams. The diagrams cover:

- Consumption feedback loop,
- Investment feedback loop,
- Employment feedback loop,
- Government feedback loop,
- Export feedback loop,
- Freight transport feedback loop and
- Passenger transport feedback loop.

However, it remains impossible to present all influences affecting each loop such that in some cases interactions e.g. between the different feedback loops are explained in the text or in further literature (SCHADE 2005).

First, the consumption feedback loop is presented in Figure 19. The basic loop presents a positive feedback such that growth in consumption is generating growth in GDP and income leading to further growth in consumption in the next time period. However, negative influences from other parts of the model could break the inherent growth tendency of this loop. These could either stem from decreases of other elements of final demand, e.g. reduced investment, government consumption or exports (circle 1), or from the combined influences of sectoral shifts induced by changes in the transport system (circle 2) and the tax system (circle 3). The former would shift private consumption expenditures between sectors and could shrink consumption because of tax differentials between transport consumption and non-transport consumption while the latter would reduce disposable income available for consumption decreasing finally the consumption expenditures.

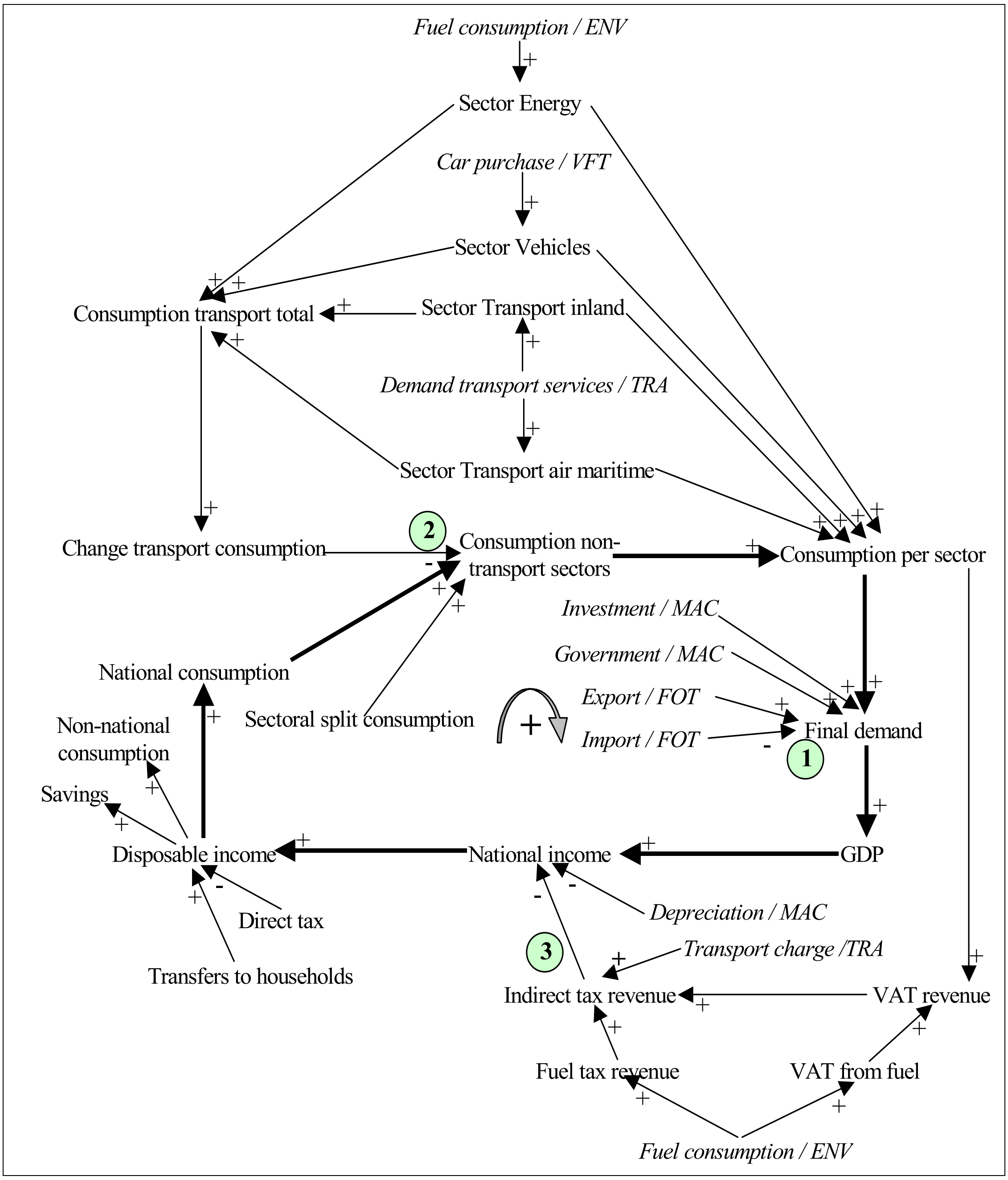


Figure 19: The consumption feedback loop in ASTRA and its impacts from transport

Investments are also affected by a major positive loop as investment increase capital stock and total factor productivity (TFP) of an economy leading to growing potential output and GDP that drives income and consumption feeding back to an increase of investments (Figure 20). However, this loop could also be influenced by other interfering loops that would break the growth tendency. Increasing government debt could lead to crowding out tendencies that provide a negative impact on investment (circle 1). Exports e.g. influenced by growing transport cost could decrease reducing investments (circle 2). Changes in transport demand e.g. modal-shifts due to policies that would shift demand from modes with high investment needs to modes with low investment needs per unit of demand would reduce investments (circle 3). Different growth rates between the supply side (potential output) of an economy and the demand side (final demand) change the utilisation of capacity. In case of demand growing slower than supply utilisation would be reduced affecting also the investment decisions. Finally that would also decrease investments (circle 4).

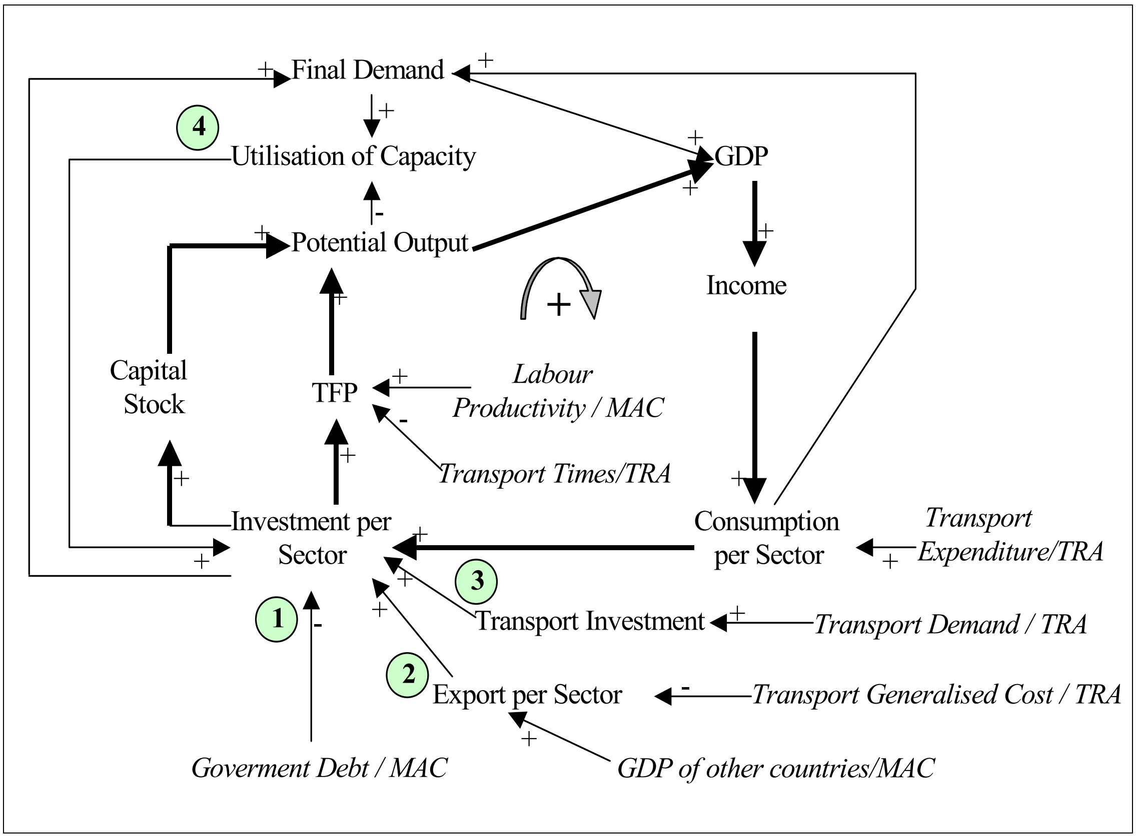


Figure 20: The investment feedback loop in ASTRA and its impacts from transport

The employment feedback loop in principle would also constitute a positive loop with growing employment increasing labour supply, potential output and GDP. This kicks-off the well-known sequence of growing consumption and increasing investments that both drive final use. The problem of this general analysis starts with the input-output tables since the absolute increase of final use might incorporate shifts between sectors. In general, increasing final use and feeding that through the input-output table gross-value added (GVA) should grow (circle 1). However, depending on the structure of coefficients in the IO-table and the sectoral shifts in principle it could happen that GVA is not increasing. In the latter case that would have a negative influence on employment while in the standard case GVA and employment should be affected positively. The main loop can be affected by increases in transport cost that would usually reduce GVA and employment (circle 2). Sectoral shifts play also an important role when it comes to the calculation of total factor productivity (TFP). If sectoral shifts of GVA occurred from more productive to less productive sectors the final impact on TFP could be negative despite a growth in total GVA (circle 3). Finally, a second feedback loop should be mentioned. Increase in employment decreases unemployment. At very low levels of unemployment employers will tend to increase productivity due to the labour shortage. Increased productivity in turn reduces employment, which in total makes this a negative feedback loop (circle 4).

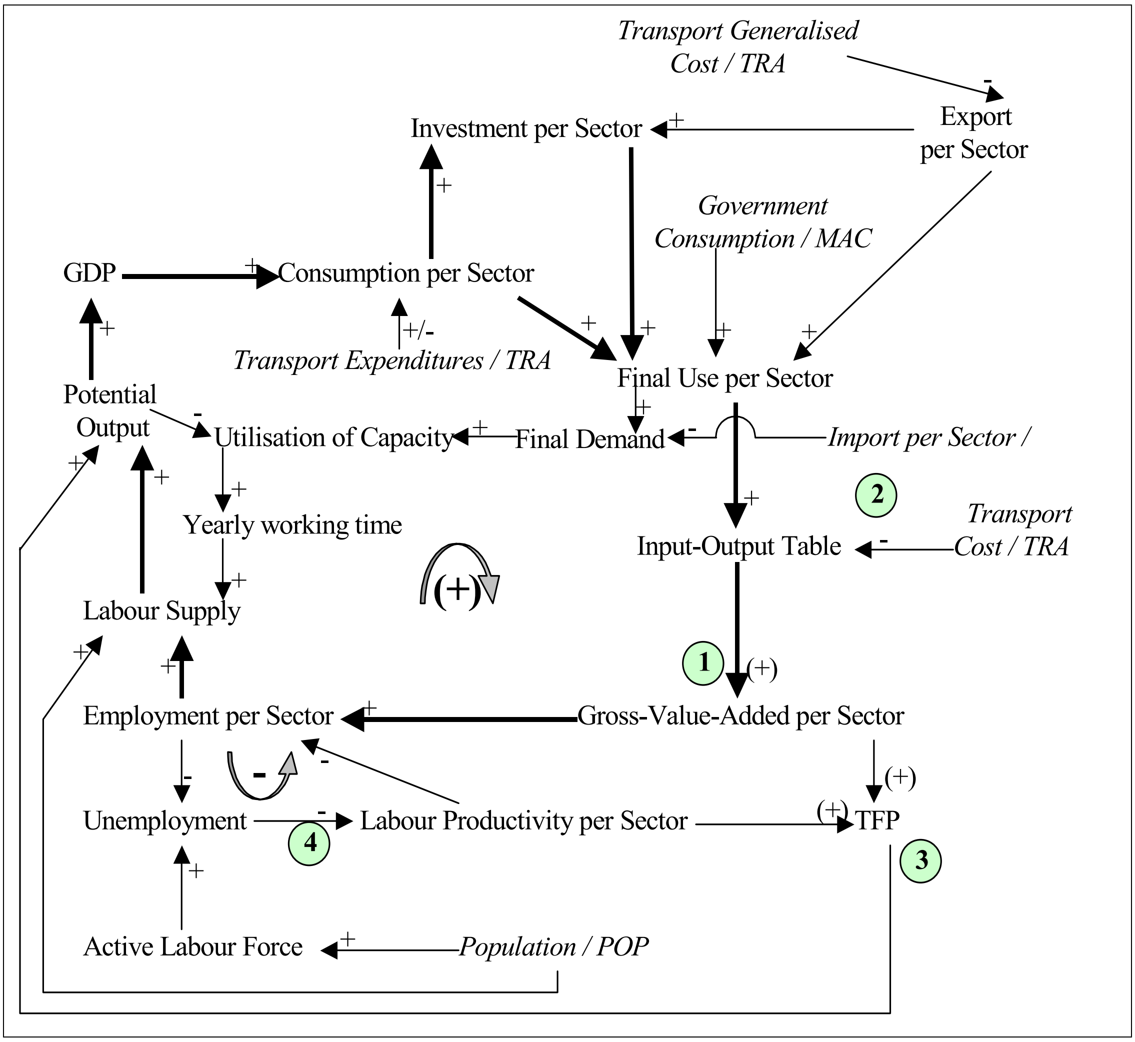


Figure 21: The employment feedback loop in ASTRA and its impacts from transport

The government feedback loop seems to be most difficult to describe since the government experiences many influences as the large number of influencing arrows to government revenues (circle 1) and government expenditures (circle 2) reveal. However, the impacts it exerts are mainly all policy measures e.g. adjusting its expenditure level by adapting the transfers to retired, children or unemployed. To adjust these automatically, e.g. in case of negative budget balance and high government debt, would be an option to close feedback loops. Experimental versions of these feedbacks are implemented in ASTRA but with the argument that these are all policy measures outside transport policy they are not used such that the only feedback remains the negative impact of high government debt on investment decisions. A reduction of government debt would increase investments in case crowding out prevailed leading to higher GDP and consumption. This would exert a positive impact on revenues from direct and indirect taxes leading to growth of government revenues and a more positive government balance, which in turn would reduce government debt. And that is where we commenced the loop such that this also constitutes a positive i.e. reinforcing loop. Another important loop is the one e.g. the German government struggles with. Starting with a high government debt large interest payments are payable leading to increased government expenditures and a potentially negative budget balance that in turn increases the debt. Again this constitutes a positive feedback loop as it reinforces the original stimulus (circle 3).

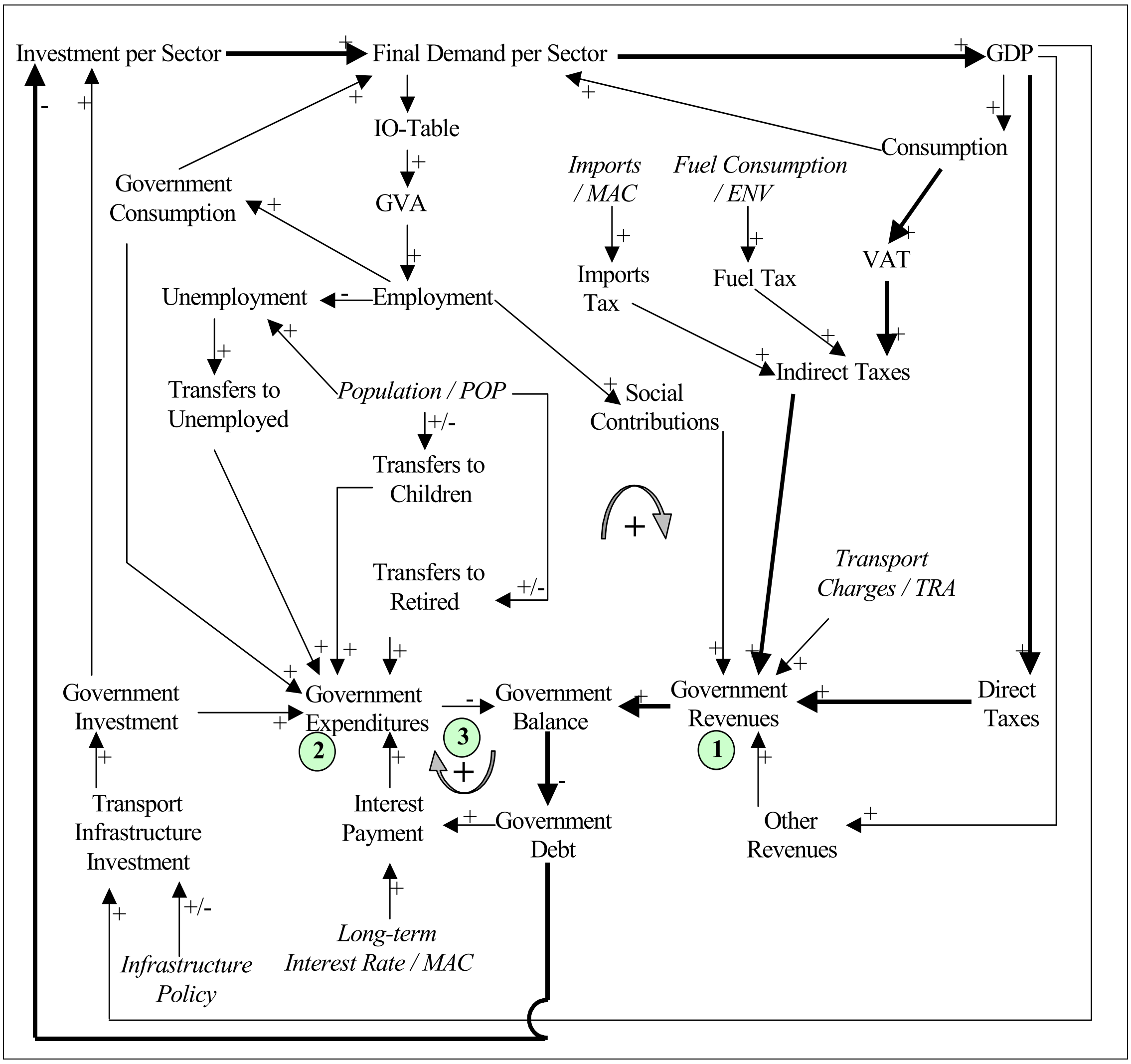


Figure 22: The government feedback loop in ASTRA and its impacts from transport

The export loop in Figure 23 resembles very much the Heckscher-Ohlin model of trade between two countries (HECKSCHER 1919). Country A is importing goods from country B, which appear as exports on the demand side of country B and increase GDP of B. Hence, country B increases imports, which in turn leads to growing exports of country A finally increasing the GDP of country A. The basic loop is reinforcing. However, one of its major influences is constituted by sectoral relative labour productivity between the two countries (circle 1). If country A becomes more productive than B it will increase its exports to B and vice versa, while B will loose exports such that the loop set-up by mutual growth of GDP could be broken by reduced GDP of country B. This impact could be different for any of the 25 sectors of ASTRA.

A further influence on exports stems from transport. The quality of transport connections between countries A and B can be expressed by the generalised cost of transport, which are an aggregate of transport cost and monetised travel time as transport decisions not only depend on cost but also on time conditions (ORTUZAR/WILLUMSEN 1998)[3]. Increased generalised cost would then shrink exports or at least lower export growth, which in turn leads to declining imports probably in both countries (circle 2). Figure 23 indicates merely an influence from

3 In fact, further relevant conditions might exist e.g. reliability of transport, safety requirements. But these could not be reflected in ASTRA, yet.

freight transport, but also changes of passenger transport could affect trade flows, considering exports of service sectors like tourism as part of the catering sector in ASTRA or the transport service sectors themselves.

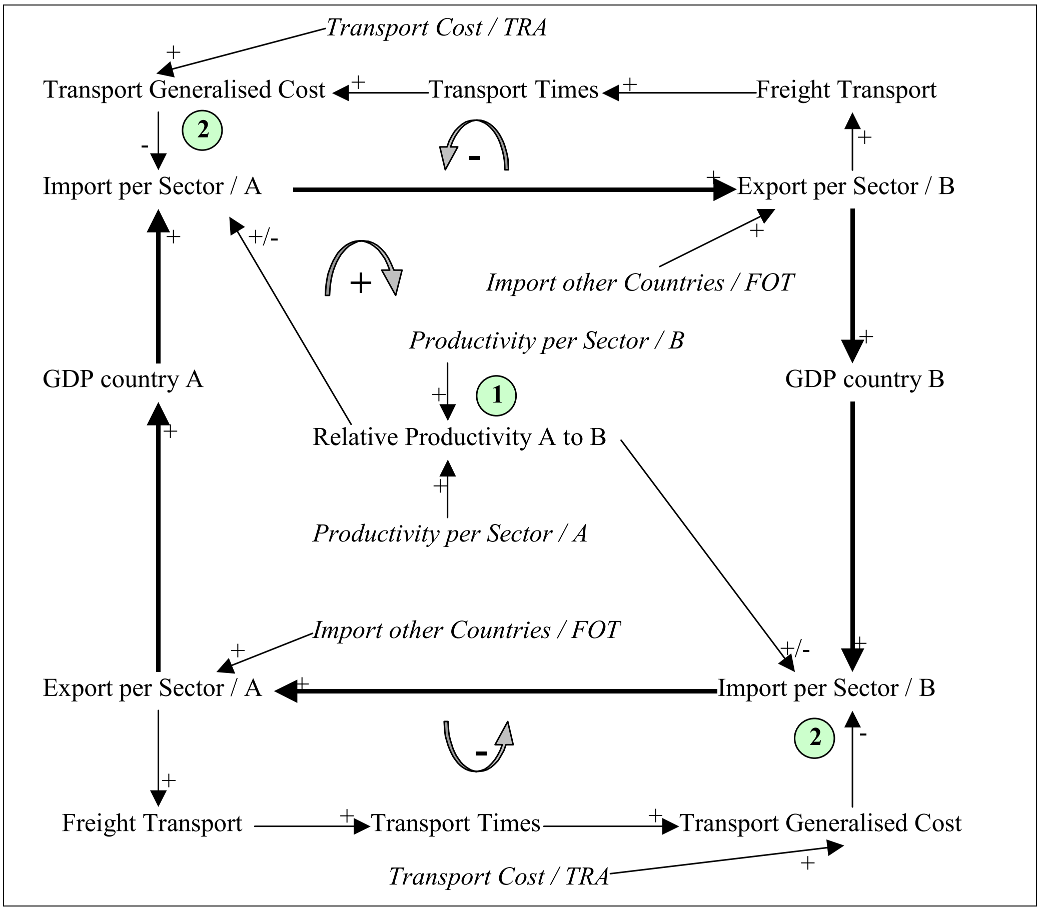


Figure 23: The export feedback loop in ASTRA and its impacts from transport

The most obvious feedback loop of freight transport starting at freight modal-split includes investments per sector that increase final use and output per sector (Figure 24). Domestic output per sector drives the freight volume that does not cross the national border while the trade flows generate the freight volume that crosses national borders. Freight flows are distributed onto the 71 potential destination zones though in this case not all destinations will increase their flows in the same shares due to the difference in generalised cost changes and transport characteristics. Finally, freight modal-split is performed but again increased demand on a selected origin-destination (OD) pair is not spread evenly on the different modes and the loop is closed by demand per mode. Additional to the direct link from final use to output per sector there is the link via the input-output table where output of intermediates per sector is calculated and then forms part of total output per sector (circle 1). In principle, this first feedback loop is positive though results depend to some extent on the structure of the modal-shifts that might strengthen a mode with lower investment needs such that the loop could then be reversed.

The second loop again starts at freight modal-split but is then continued via changes in freight transport times that in general tend to increase with increasing demand for a mode, though this should not necessarily be the case e.g. if economies of scale generate time savings in the logistic chain. Increasing transport times exert a negative impact on total factor productivity (TFP) arguing that freight transport constitutes an important element of today's production processes (circle 2). Decreasing TFP slows down growth of GDP and consumption leading to reduced final use. The remainder of this loop looks the same as for the previous loop but opposite to that loop this freight-times-TFP loop belongs to the negative or dampening category. Finally, one should also have in mind that passenger transport is interfering with this loop as it also may influence freight transport times due to the usage of the same transport network e.g. for cars and trucks (circle 3).

A further loop to mention accounts for the interaction between modal-split decisions and destination choice, which is indicated by the circles number 4. As already discussed modal-choice affects the freight transport times, but aggregate transport times for all modes serving an OD-pair influence the destination choice. Altered destination choice again leads to a new situation for modal-split and the loop commences again. However, these modal-choice and destination choice decisions work on different time scales where modal-choice can be an immediate or very short-run decision while destination choice would be affective on medium term e.g. as it depends on setting-up new trade contacts or new business locations.

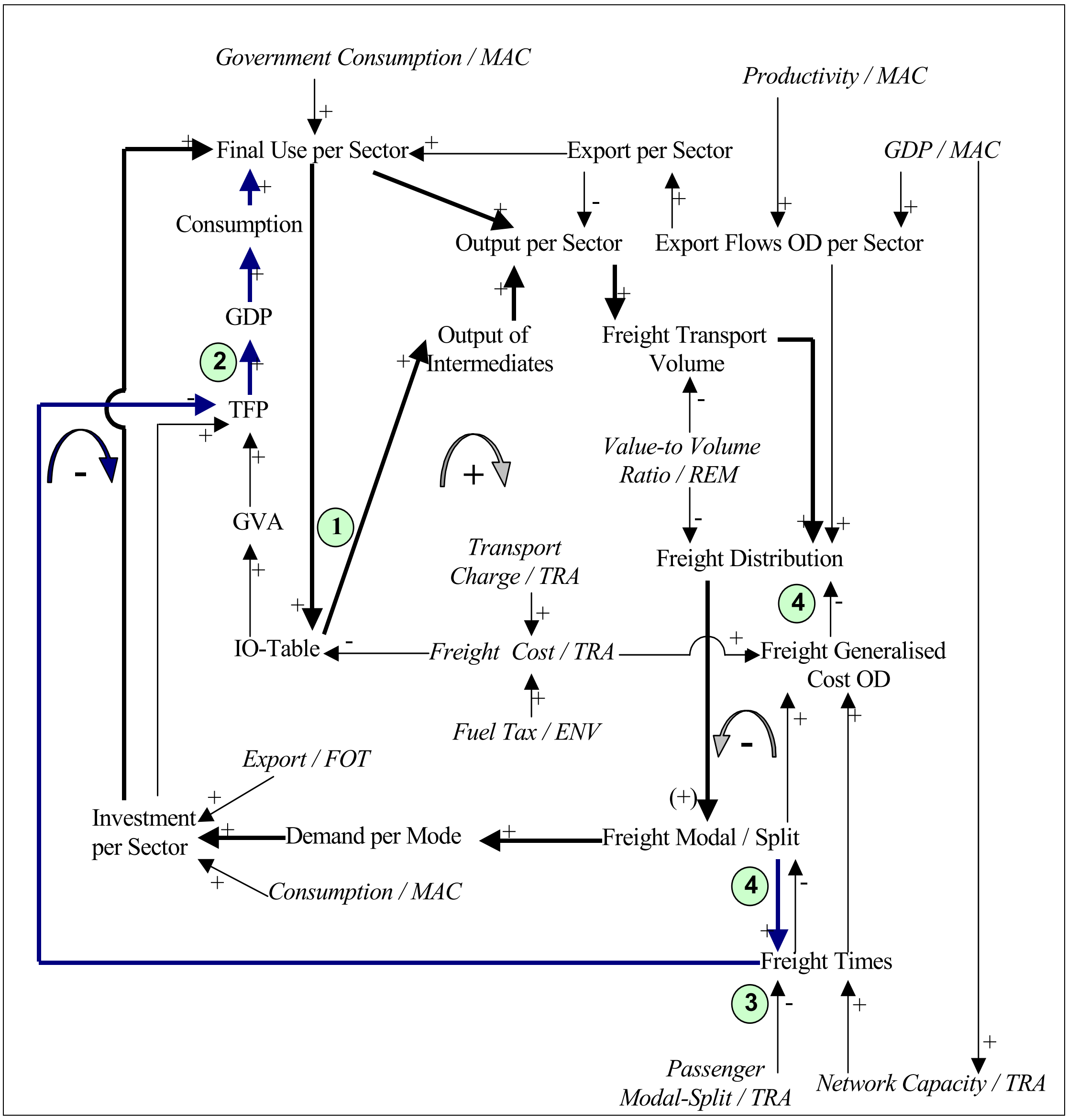


Figure 24: The freight transport feedback loops in ASTRA

Starting the analysis of the passenger transport feedback loops at passenger modal-split the first effect following an increase of demand for a mode generates increased expenditures for using this mode (Figure 25). Only expenditures for private trips become part of private consumption, which provides two effects: first, a shift between sectors of consumption, and second either a decrease or increase of consumption since there is a tax differential between transport and non-transport consumption. Hence, the outcome of this link remains unclear why it is indicated by "+/-". Assuming a positive or commutated effect with increased consumption a further increase of final demand and GDP follows generating also higher incomes. Linking income growth with population development allows for the calculation of income per adult, which if increasing will drive car purchase. The latter leads to larger car fleets and increased car-ownership shifting some persons into person groups with higher car availability. The composition of person groups in the population determines passenger transport such that a larger number of persons with high car availability would increase average trip rates leading to growth of passenger volumes. Finally, the growing volume is distributed onto the different destinations that on average also increase their demand and in the last step the OD-pair based demand has to be split onto the modes such that the loop is closed. The overall impact of this loop could not clearly be identified since the link between passenger expenditures and sectoral consumption is ambiguous (circle 1) such that it could act either as a positive (reinforcing) or a negative (dampening) loop.

A second loop that runs in parallel to the first one in the beginning links growing demand for a mode with increasing investment, which leads to growth of final demand (circle 2). The remainder of the loop is the same as the first loop. However, this loop acts clearly enforcing as all causal relationships show a positive sign. It should be pointed out that in both loops a second influence of the economic model plays a role in passenger transport generation, which is employment. Growing employment also alters the composition of the person groups such that e.g. more business trips are made (circle 3).

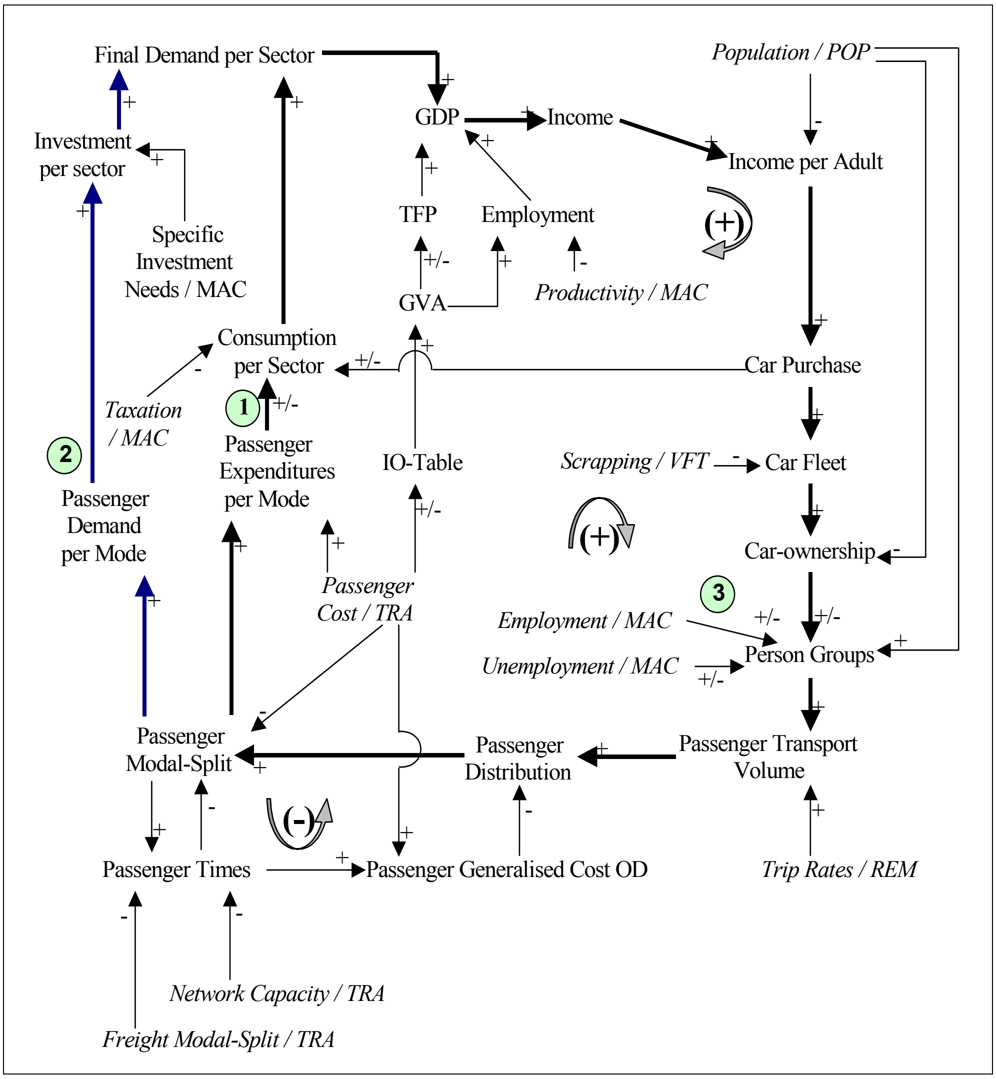


Figure 25: The passenger transport feedback loops in ASTRA

4.1.2 Important Structural Categorisations Applied in ASTRA

The following two sections explain the spatial representation and the classification of economic sectors used in ASTRA.

Spatial Differentiation in ASTRA

Representation of space is one of the most important issues for transport modelling that is best tackled by using detailed spatial zoning systems in which zones are connected by a detailed link-based multi-modal transport network. On the other hand system dynamics modelling is not capable of handling a full transport network neither would computing capabilities be sufficient to calculate European transport network equilibrium with system dynamics software. Hence, defining a spatial differentiation that balances the requirements of these two constraints provided one of the most relevant tasks in ASTRA. The problem is solved by defining four different categories for spatial representation that are selectively applied according to the needs of each module. The four categories are:

- Countries: current EU27 member states plus Norway and Switzerland are treated separately as countries with the exception of Belgium and Luxemburg that form one region such that this category consists of 28 entities.
- Functional zones: the 271 NUTS II zones of the EU27+2 countries are grouped into four different zone types per country for EU15 and two different zone types for the other countries according to their population density and settlement patterns. As not all zones exist in every country this amounts in total to 71 entities.
- Passenger distance bands: passenger transport originating in a certain zone is divided into five different categories of trip distances. Trips belonging to the three shorter distance categories remain within the zone itself, while the two longer distance categories may both cross borders of the zone and borders of the countries.
- Freight distance bands: freight transport originating in a certain zone is divided into four different categories of trip distances. Tons transported belonging to the shortest distance category remain within the zone itself. Tons transported in the second distance category may cross borders of the zones but not of the country. Tons transported within the two longer distance categories may both cross borders of the zones and borders of the countries.

The specific application of spatial categories in the nine modules of ASTRA is shown in Table 3.

Table 3: Summary of spatial categorisations used in different modules of ASTRA

Spatial category	POP	MAC	FOT	REM	INF	TRA	VFT	ENV	WEM
Countries	X	X	X	X	X	X	X	X	X
Functional zones			(x)	X	X	X	(x)	(x)	
Passenger distance bands			(x)	X	(X)	X		X	
Freight distance bands			(x)	X	(X)	X		X	

Legend: X = category fully applied in module; (x) = only limited use of category e.g. only within interface to module

Using the country level for the set-up of the top-level spatial category is obvious for two reasons. Firstly, administrative and statistical structures are defined at least on the base of differentiating countries such that to fulfil the needs of each model for input or calibration data the country level remains most important. Additionally some data e.g. input-output tables are only available on country level. Secondly, policy analysis on European scale requires the provision of conclusions at least on the distribution of policy impacts between the countries.

The second level of spatial categorisation results from a balanced judgement of factors like data availability, transport model requirements, soft- and hardware capabilities. To a large extent data differentiated into detailed spatial categories for all European countries is provided by EUROSTAT on NUTS II level, though availability on NUTS-III level from EUROSTAT or even on lower levels from national statistical offices is increasing. NUTS-II level consists of 271 zones for the EU27+2 countries. Using NUTS-II in a system dynamics model seems not to be feasible due to combined soft- and hardware restrictions as already the OD-matrices would have more than 70.000 elements, a number that would even increase when it comes to consider different modes and trip purposes, also. Furthermore it is not the idea of system dynamics to model every detail but to consider representative structures that shape the behaviour of the system under analysis. Taking transport as the system requiring the most sophisticated level of spatial differentiation in ASTRA a categorisation should be developed that reduces the number of spatial entities by clustering NUTS-II zones into groups that are homogenous with respect to their transport mechanisms. These groups of zones are called functional zones. For the purpose of grouping zones population density and the relative position of a zone within all zones of one country are selected as criteria. Firstly, population density seems to be reasonable as it determines most relevant transport characteristics e.g. high density zones can be expected to have competitive public transport by tram or metro, while low density areas are more bound to car usage. On average train connections between two high density areas should be better than between two lower density areas and so on. It seems that a differentiation into four functional zones would provide the minimum required information to cope with the needs of transport modelling. Hence, the following categorisation of functional zones is set-up listed in order of decreasing population density:

- Metropolitan Areas (**MPA**);
- High Density Areas (**HDA**);
- Medium Density Areas (**MDA**);
- Low Density Areas (**LDA**).

Secondly, taking population density as the only and the same criteria for all countries would lead to some countries that would show representatives only in one or two of the categories of zones, which means to loose potential differentiation as the matrices in ASTRA then would include many empty cells. Hence, the relative position within a country determines the further criteria for grouping zones such that e.g. for a country that would have exactly four NUTS-II zones each zone would belong to a different category of functional zone and the assignment would fit to a ranking of their zonal population densities.

Following these two criteria all EU15 countries besides Ireland and Denmark would show representatives in all categories. In Ireland only three functional zones are present while in Denmark only two are considered, leading in total to the number of 53 functional zones for EU15. For the EU12 member states plus Norway and Switzerland a slightly different approach was taken. The six smaller countries Slovenia, Malta, Cyprus, Estonia, Latvia and Lithuania were not differentiated into zones at all due to their limited size. For the other countries always a split into two zones is applied using gdp/capita as the main criteria. This led to the fact that always the capitals plus at maximum one further prosperous neighbouring zone were grouped into the same zone (MPA) while the other zones were grouped into the other zone (MDA).

The classification of NUTS-II zones into the functional zones of the ASTRA model is obtained following population density data and gdp per capita data of NUTS-II zones drawn from the

SCENES database (SCENES 2000) or the EUROSTAT Yearbook of Regions (EUROSTAT 2002). Considering in countries with large numbers of zones that the medium density areas are well represented the categorisation of NUTS-II zones leads to the structure of functional zones presented in Table 4. The table shows for the EU15 countries the thresholds used to define functional zones per country. Population density is expressed in persons per square km and GDP per capita in EURO/1999 per inhabitant per year.

Table 4: Summary of categorisation of NUTS II zones into functional zones in ASTRA for EU27+2

Type of Zone	Metropolitan Areas (MPA)		High Density Areas (HDA)		Medium Density Areas (MDA)		Low Density Areas (LDA)	
Country	**Population density**	**#**	**Population density**	**#**	**Population density**	**#**	**Population density**	**#**
EU15 countries								
Austria	> 300	1	100 – 300	2	60 – 100	3	< 60	2
Belgium-Luxembourg	> 1000	1	400 – 1000	4	200 – 400	4	< 200	2
Denmark	> 300	0	100 – 300	1	60 – 100	1	< 60	0
Finland	> 150	1	20 – 150	1	10 – 20	2	< 10	2
France	> 500	1	100 – 500	6	60 – 100	9	< 60	6
Germany	> 1000	4	300 – 1000	8	150 – 300	16	< 150	12
Greece	> 500	1	75 – 500	2	50 – 75	4	< 50	6
Ireland	> 250	0	100 – 250	1	40 – 100	1	< 40	1
Italy	> 300	3	175 – 300	4	75 – 175	8	< 75	5
Netherlands	> 700	1	500 – 700	2	150 – 500	6	< 150	3
Portugal	> 250	1	100 – 250	1	60 – 100	2	< 60	1
Spain	> 500	1	100 – 500	5	60 – 100	4	< 60	6
Sweden	> 250	1	50 – 250	2	15 – 50	2	< 15	3
UK	> 1000	6	300 – 1000	12	150 – 300	8	< 150	1
Total number of zones		*21*		*51*		*70*		*60*
EU10+2 countries	**GDP/cap**	**#**			**GDP/cap**	**#**		
Bulgaria	*> 1700*	*1*			*< 1350*	*5*		
Cyprus					*n.a.*	*1*		
Czech Republic	*> 9500*	*1*			*< 4500*	*7*		
Estonia					*n.a.*	*1*		
Hungary	*> 5900*	*1*			*< 4500*	*6*		
Lithuania					*n.a.*	*1*		
Latvia					*n.a.*	*1*		
Malta					*n.a.*	*1*		
Poland	*> 4800*	*1*			*< 3700*	*15*		
Romania	*> 1800*	*1*			*<1500*	*7*		
Slovenia					*n.a.*	*1*		
Slovakia	*> 6200*	*1*			*< 3000*	*3*		
Norway 1)	*> 151000*	*1*			*< 114000*	*6*		
Switzerland 2)	*> 37000*	*2*			*< 32500*	*5*		

1) regional turnover per capita 2) regional income per capita

It should be pointed out that out of the 71 functional zones 31 represent exactly one single NUTS II zone, such that at least results for OD-pairs between these 31 zones could be directly compared with other transport models based on NUTS II zoning.

Figure 26 presents the location of NUTS-II zones and functional zones in EU15 countries as well as the functional zones structure of the EU10+2 countries.

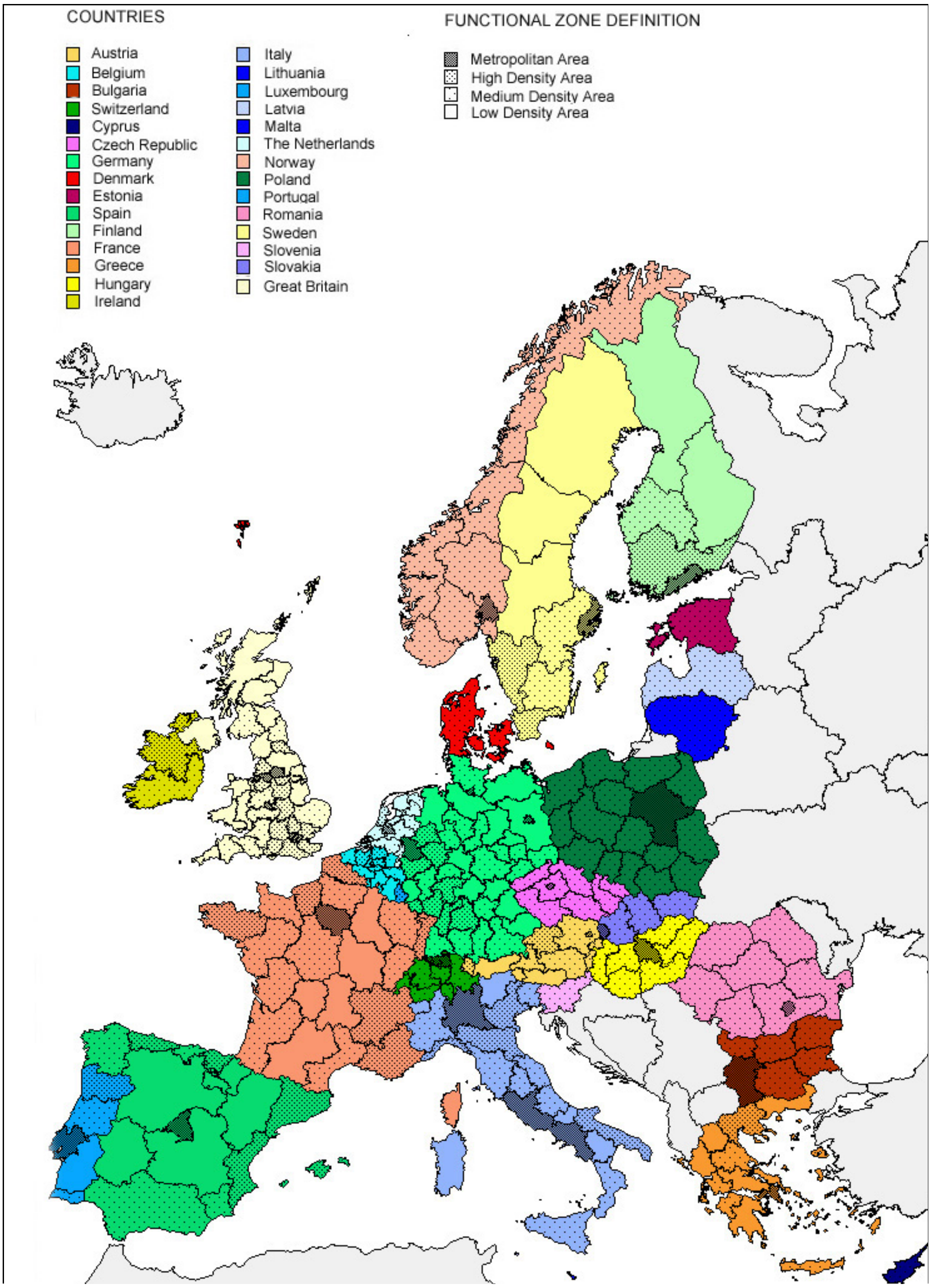


Figure 26: Overview on spatial differentiation in ASTRA

The final two elements for spatial representation in ASTRA are the passenger and freight distance bands. For both it is aspired to define distance categories with similar or even homogenous transport characteristics for all trips belonging to the distance band, while between the distance bands characteristics should differ. The major difference between distance bands clearly is the average transport distance as it provides the distinctive attribute of each distance band. Furthermore distance bands vary in the availability of different modes e.g. slow modes like walking or cycling are only used for very short trip distances. They differ with respect to existence of trip purposes e.g. tourism trips are present only for the longer distances. Finally, transport characteristics like cost per km, travel times, occupancy or load factors vary between the different distance bands. In the first instance distance bands seem to be non-spatial. In fact they are part of spatial representation in ASTRA as the concept defines that transport belonging to shorter distance bands remains within the border of the functional zone where it is originating. The category with the second longest transport distance covers transport between neighbouring countries e.g. passenger transport demand in this distance band originating from Italy could only reach destinations within Italy and in Austria or France. In the case of freight transport it could also reach the second nearest countries if the direct neighbouring country is one of the smaller EU27+2 countries. Only in the longest distance band any destination could be reached from every origin zone.

The relevant distance thresholds for beginning and ending of each distance band are derived from results of the European transport network model SCENES (ME&P 2000, IWW et al. 2000). For passenger transport the following distance bands are distinguished:

- Local distance band (LC): personal or business trips with distances between 0 and 3.2 km.
- Very short distance band (VS): personal or business trips with distances between 3.2 and 8 km.
- Short distance band (ST): personal or business trips with distances between 8 and 40 km.
- Medium distance band (MD): personal, business or tourism trips with distances between 40 and 160 km.
- Long distance band (LG): business or tourism trips with distances over 160 km.

Since the characteristics between passenger and freight transport, e.g. of what would be a short trip or a long trip, are rather different for freight transport a different set of distance bands consisting of four categories is defined.

- Local distance band (LOC): tons transported over distances of less than 50 km.
- Regional distance band (REG): tons transported over distances between 50 and 150 km.
- Medium distance band (MED): tons transported over distances between 150 and 700 km.
- Long distance band (LGD): tons transported over distances of 700 km.

Since each distance band might follow different rules concerning the destinations that could be reached by transport within this distance band, Table 5 presents an overview for all the distance bands.

Table 5: Destinations reached by transport in each distance band

	Remain within country of origin		Reach destinations in other countries	
	Remain in the same zone	Cross borders of zones	Reach neighbouring countries only	Reach all countries all zones
Passenger transport				
Local DB (LC)	X			
Very short DB (VS)	X			
Short DB (ST)	X			
Medium DB (MD)	X	X	X	
Long DB (LG)		X		X
Freight transport				
Local DB (LOC)	X			
Regional DB (REG)	X	X		
Medium DB (MED)		X	X	
Long DB (LGD)		X		X

Sectoral Differentiation in ASTRA

Sectoral disaggregation in ASTRA is based on the concept of NACE-CLIO sectoral coding system, where NACE stands for the *General industrial classification of economic activities within the European communities* and CLIO for *Classification and nomenclature of input-output*. Both are used in EUROSTAT statistics, though the CLIO system is especially designed to generate harmonised input-output tables for the EU25 countries since each country used its own national system e.g. in Germany with 59 sectors (STABA 1997) or in the United Kingdom with 102 sectors (CSO 1992).[4]

The NACE system corresponds to international classifications like ISIC (International Standard Industrial Classification), such that also data following these categorisations could be used, and is available as NACE with 17, 25 or 44 sectors. Three main reasons suggest using the NACE-CLIO version with 25 sectors (see Table 6): firstly, in ASTRA the use of harmonised input-output tables for the EU25 countries is of significant importance to reflect the economic interactions that are induced in all sectors of the national economies by influences of policies in those sectors that are directly related to transport demand. EUROSTAT provides such tables for the EU15 countries for 1995 (EUROSTAT 1998). For the EU10+2 countries the harmonised input-output-tables for 1997 were derived from the Social Accounting Matrices (SAMs), which were established for the IASON project (Banse 2000). Secondly, the split into 25 sectors offers five sectors that are directly related to transport demand changes and that would be affected by transport policies. These sectors are sector 2 *Fuel and power products* influenced by private expenditures for fuel; sector 10 *Transport equipment* affected by private car purchase and investments in any other kind of vehicles; sector 16 *Building and construction* driven among others by investments in transport facilities (e.g. container terminals or sta-

4 In recent years there are attempts to standardise the system of input-output tables by international bodies like UN or EUROSTAT e.g. with ESA the European System of National Accounts.

tions) and transport networks; sector 19 *Inland transport services* influenced by expenditures for bus, rail, road freight transport and inland waterway transport; sector 20 *Maritime and air transport services* affected by ocean ship transport and air transport. Thirdly, among the 25 sectors are already 9 service sectors, which enable the model to take account of the ever increasing importance of services for the European economies.

Table 6: 25 economic sectors used in ASTRA derived from the NACE-CLIO systematics

Nr	Sector Name	Goods sectors	Service sectors	Market sectors	Directly transport demand dependent
1	Agriculture, forestry and fishery products	X		X	
2	Fuel and power products	X		X	X
3	Ferrous and non-ferrous ores and metals	X		X	
4	Non-metallic mineral products	X		X	
5	Chemical products	X		X	
6	Metal products except machinery	X		X	
7	Agricultural and industrial machinery	X		X	
8	Office and data processing machines	X		X	
9	Electrical goods	X		X	
10	Transport equipment	X		X	X
11	Food, beverages, tobacco	X		X	
12	Textiles and clothing, leather and footwear	X		X	
13	Paper and printing products	X		X	
14	Rubber and plastic products	X		X	
15	Other manufacturing products	X		X	
16	Building and construction			X	X
17	Recovery, repair services, wholesale, retail		X	X	
18	Lodging and catering services		X	X	
19	Inland transport services		X	X	X
20	Maritime and air transport services		X	X	X
21	Auxiliary transport services		X	X	
22	Communication services		X	X	
23	Services of credit and insurance institutions		X	X	
24	Other market services		X	X	
25	Non-market services		X		

Table 6 presents the list of the 25 NACE-CLIO sectors. It is indicated which sectors belong to goods sectors that e.g. generate freight transport flows and which sectors are considered for services. Together goods and service sectors are used e.g. at a sectoral level to model trade relationships of the EU15 countries. The five sectors that are directly influenced by changes of transport demand are also marked. It should be noted that both via the exchange of intermediate products from other sectors to these five sectors and via transport cost changes affecting the supply of intermediate products from the five sectors to all other sectors also **all** sectors will be influenced by changes in the transport system that might emerge on a level as detailed as a single OD-pair.

4.1.3 ASTRA Model Improvements

This section concentrates on the technical improvements developed and implemented in the nine ASTRA modules. One task that is not reported specifically for each module concerns the extension of the simulation horizon until 2050 from 2030. This required for exogenous variables to specify a development after 2030. The ASTRA merger and the related software re-engineering, which constitute a tremendous improvement of ASTRA in terms of software development, are described in the separate section 4.1.5.

4.1.3.1 Population Module

The previous ASTRA population module (POP) is characterised as a sophisticated one-year-age cohort model. Hence there was no need to improve the structure of the POP module for the TRIAS project. Nevertheless the POP module was recalibrated for the TRIAS project. In order to synchronize the ASTRA demographic forecasts with recent EUROSTAT baseline projections (February 2006) until 2050 the calibration period has been prolonged from 1990 to 2050. Factors like country-specific death rates, migration balance and immigration age cohorts were calibrated with the Vensim™ optimiser. Finally the calibration provided good quality results with less than 1% deviation to EUROSTAT baseline projections at maximum.

4.1.3.2 Macroeconomics Module

Improvements of the macroeconomic module (MAC) of ASTRA have not been a key task in TRIAS. Hence, improvements were limited to three areas:

- Re-calibration of the endogenous GDP development such that development after 2050 becomes comparable with other forecasts, in particular of the European project ADAM.
- Implementation of structure of fuel prices for alternative fuels that enables first to distinguish the different elements of the fuel price (resource price, fuel tax, carbon tax and VAT on fuel), and second to link with POLES and the BIOFUEL model that calculate the fuel prices in TRIAS.
- Implementation of shifted and additional types of investments that result from the different policies. This includes investments into biofuel production plants and hydrogen production plants that were provided by POLES and BIOFUEL, shift of investments due to the development and introduction of hydrogen fuel cell vehicles into the car fleet and of R&D- and manufacturing plant investments due to enforced CO2 emission standards.

Implementation of fuel prices and fuel taxes

Gasoline, diesel and kerosene fuel prices in ASTRA were already implemented with a structure distinguishing the pure fuel price, the fuel taxes and the VAT on fuel, while for other fuels only simplified aggregate prices were used. Hence, in a first step the three-part structure was implemented for compressed natural gas (CNG), liquefied petroleum gas (LPG), hydrogen, bioethanol (first and second generation), biodiesel (first and second generation) and electricity, and an exogenous trend for the ASTRA model was implemented. In a second step for all fuels besides kerosene a link was implemented to the POLES and BIOFUEL model, where POLES provides the inputs for gasoline, diesel, CNG, LPG, hydrogen and electricity and BIOFUEL the inputs for biodiesel and bioethanol. A switch was implemented enabling to run ASTRA stand-alone with its own implemented prices or linked to POLES and BIOFUEL.

All fuels were linked with a number of models of ASTRA where fuel prices or taxes play a role. This includes the transport cost and modal choice (TRA), vehicle purchase decisions (VFT), transport consumption expenditures (MAC) and tax revenues (MAC).

Considering investments into biofuel plants

The BIOFUEL model calculates the additional investments needed to build biofuel production plants in order to satisfy the demand calculated by ASTRA and the BIOFUEL model itself. These investments are transferred to ASTRA and become part of final demand. Since they are provided as aggregate numbers they have to be split onto the ASTRA sectors to be considered properly in the investment model. The applied sectoral shares to split onto ASTRA sectors are shown in Table 7.

Table 7: Split of aggregate biofuel plant investments onto ASTRA sectors

Sector	Share [%]	Sector	Share [%]
Minerals	35	Trade	7
Metal Products	7	Transport Inland	2
Industrial Machines	20	Other Market Services	5
Electronics	15	Non Market Services	1
Construction	8	Total	100

Source: EC Impact Assessment on Renewable Energies

Considering investments into hydrogen plants

Based on the fuel demand for hydrogen for Europe coming from ASTRA the POLES model analyses which pathways for hydrogen production will be used. Two outcomes of this analysis are transferred to ASTRA: hydrogen fuel cost (see above) and required investments into hydrogen production plants and hydrogen infrastructure. The investments are provided as aggregate numbers and hence have to be split onto the ASTRA sectors to become part of the investment model of ASTRA. The applied sectoral shares to split onto ASTRA sectors are shown in Table 8.

Table 8: Split of aggregate hydrogen plant investments onto ASTRA sectors

Sector	Metal products	Machinery	Electronics	Construction
Share [%]	10	50	20	20

Source: ASTRA implementation for MATISSE project

Concerning hydrogen cars TRIAS follows the conclusion of the HyWays project that the first hydrogen cars have to be subsidised to bring them into the market. Hence, in the first ten years when hydrogen cars enter the market the related subsidies are calculated and the subsidies become part of government expenditures and of national income.

Considering the shift of consumption and investments due to fuel cells in cars

Cars equipped with hydrogen fuel cells have to be manufactured differently then cars with internal combustion engines. The former require less moving parts and a higher contribution of electronics and chemicals sectors for the production of the fuel cells and their drive train. This means the demand for hydrogen fuel cell cars from private consumers and businesses affects other sectors then if these customers would buy cars with combustion engines. In the ASTRA model this is taken into account by extracting the share of car purchase cost that is related to the engine (34%) and distributing part of this demand onto the electronics sector (40% of drive train cost) and chemicals sector (30% of drive train cost). The remaining 30% of the drive train cost are still supplied by the vehicles sector. This split of demand is implemented for both the demand of private consumers that becomes part of sectoral consumption in ASTRA and the demand of businesses for cars that becomes part of sectoral investments.

Considering investments to reduce CO2 emissions of cars

ASTRA has incorporated CO_2 emission factors for EURO 1 to EURO 7 type of cars. After 2025 a further exogenous reduction trend of CO_2 emission factors is assumed for baseline scenario (-35% from 2025 until 2050, see also section 4.1.4.7). This trend is also reflected in the car prices. Policies that require more ambitious reduction efforts lead to lower emission factors, to additional investments into R&D and fuel consumption and emissions and upgraded manufacturing plants and hence to higher car prices. This is reflected in ASTRA by calculating the additional turnover from car purchase compared to the baseline and by assigning these revenues to additional investments onto the two sectors other-market-services (60% of additional investments) and machinery (30%). This approach ensures both that the technical improvements do not fall from haven like manna, that additional investments appear in the economic framework and that the budget constraint is considered, which is implemented as part of the ASTRA consumption model i.e. when consumers spend more money for transport purposes they have less to spent for other sectors of the economy.

4.1.3.3 Foreign Trade Module

The foreign trade module (FOT) was extended to consider the change of imports of fossil fuels that would occur due to the policies. Two versions are implemented that affect the imports of the energy sector of the EU29 countries from the rest-of-the-world in monetary terms:

- ASTRA includes an endogenous import model for the energy sector, which is calibrated to OECD and EUROSTAT statistics. Based on the expenditures for gasoline, diesel, CNG and LPG without any taxes the changes of expenditures for fossil fuels are calculated for each EU29 country. Assuming that none of these countries is able or willing to change significantly its domestic production or its imports from other EU countries, such changes of fossil fuel consumption would affect the imports from the rest-of-the-world. For instance, when less fossil fuel is used for transport due to shift to alternative fuels that would reduce the imports of the energy sector and hence would generate a positive stimulus on the demand side of the economy.
- In the linkage with POLES the approach is implemented differently. POLES includes a world energy trade model and receives from ASTRA the changed transport fuel demand including the fossil fuel types. Based on this information POLES provides the fossil fuel imports to ASTRA, which are then feeding into the imports of the energy sector.

4.1.3.4 Transport Module

The transport module has been subjected to many modelling tasks in order to contribute to the development and improvement of the ASTRA model. In particular, the following activities have been completed:

Transport passenger:

- revision of modal split algorithm in order to take into account car ownership;
- update of passenger data stocks;
- implementation of new transport costs;
- re-calibration of the module according to last data and trend available.

Transport freight:

- introduction of road feeder mode for rail and ship;
- including selected OD pair from EU12 to EU15 countries (and vice-versa) in the MED distance band;
- update of freight data stocks;
- implementation of new transport costs;
- re-calibration of the module according to last data and trend available.

Transport Passenger Sub-Module (TRA pass)

Revision of modal split algorithm to take into account car ownership

This task consisted in testing and calibrating the addition of a specific car-ownership parameter in the modal split function. The expected role of this parameter is to increase the share of car when motorisation rate increases (other things – times, costs, modal constants – being equal).

The car-ownership effect on modal split has been tested introducing in the generalised cost used for modal split an additional term depending on car ownership yearly growth rate development during the time simulation period. The additional term, representing this effect, multiply the "original" generalised cost, so its value is between 0 and 1: as the independent variable of this function is the index of the car ownership yearly growth rate, the additional term has been included as a lookup depending on this variable, in order to reflect the changes occurred every year. Different lookups for local and medium-long distances have been used, with a lower effect for the latter, as well as for EU15 and EU12 countries. The effect of the new term is to slightly reduce the generalized cost of car on all O/D pairs as the car-ownership of the origin country increases (on the contrary, in case the car ownership rate is negative the value of the variable is higher than 1, so the original generalized cost is slightly increased). At local level, the lookup is also differentiated by functional zone of origin (the effect is stronger in sparsely regions and lower in metropolitan area).

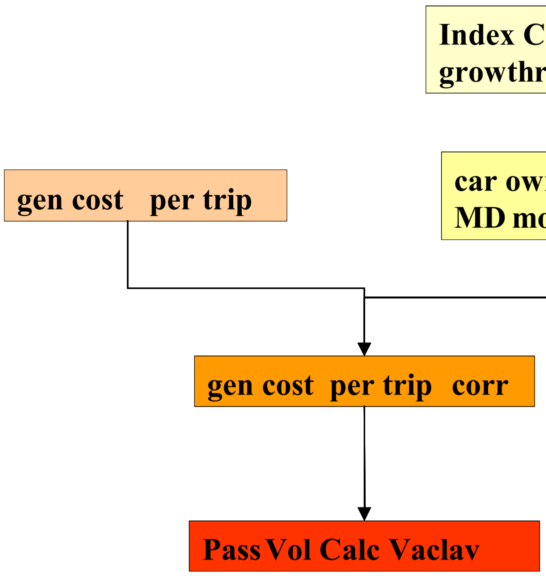


Figure 27: Structure of the car-ownership effect on modal split

Passenger Data Stocks Update

The data for the stocks which are used as starting point for the ASTRA model runs has been completely re-estimated using more updated information (where available). Data concerning passenger in terms passenger and passenger*km has been selected from the SCENES data (version 2005, for the White Paper Assessment project). The SCENES model produces data for passenger concerning:

- passengers traffic (Million pass/year) by O/D pair, purpose and mode;
- passengers average distance (km) by O/D pair, purpose and mode;

The terms *O/D pair, purpose, flow and mode*, used above are to be intended with the meaning used in ASTRA. The correspondence between the ASTRA concept and the SCENES elements is described in the following paragraph.

Three trip purposes are considered in ASTRA for the passenger demand, which correspond to the SCENES flows as explained in the following table.

Table 9: Conversion between SCENES flows and ASTRA purposes

ASTRA Purpose	SCENES flow
Business	20-21-26-27-28
Personal	18-19-29-30-31-32
Tourism	22-23-24-25

The modes used in ASTRA for passengers in terms of the SCENES ones is explained in the following table.

Table 10: Conversion between SCENES modes and ASTRA modes

ASTRA passenger mode	SCENES mode
Slow	11
Car	1 – 12
Bus/coach	2
Train	3 – 4 – 13
Air	5 – 16 – 17

The main issue in the extraction of SCENES data is the classification of O/D pairs. Modes, flows and purposes can be readily obtained according by aggregation of the SCENES variables, O/D pairs are more difficult to deal with.

The problem is that traffic from a given origin (defined as country + functional zone) and a given destination (defined as country + functional zone) is to be further divided into the different distance bands to yield the complete O/D definition. If the output of the SCENES model is aggregated just on the basis of the functional classification of each zone (e.g. by defining High Density Areas of Italy, of France, etc.) the total amount of demand for each O/D is derived, without any reference to the distance other than the average distance.

In order to extract the data and recognise the different groups of demand, the SCENES O/D pairs have been extracted and classified according to the ASTRA criteria "country origin, functional zone origin, country destination, functional zone destination, distance band", where the distance band has been assigned on the basis of the average distance calculated.

Once that the data has been converted into a format consistent with ASTRA definition, the resulting matrix has been used to calculate the passenger traffic by OD pair, flow and mode (in terms of pass/year and pass*km/year) and to compare the aggregated results with Eurostat total pkm per country in 2000 (Transport in figures 2005).

As some discrepancies have been detected, some adjustments have been produced in order to reflect Eurostat aggregated data. The new corrected matrix has been used to recalculate the passenger traffic by OD pair, flow and mode, with the results that the aggregated comparison with Eurostat total pkm per country in 2000 was acceptable.

Table 11: Comparison between data stock and Eurostat total pkm per country in 1990 and 2000

Country	**Observed pkm (Eurostat, elab TRT)**		**Data stocks (SCENES, elab. TRT)**		**Difference (%)**	
	1990	**2000**	**1990**	**2000**	**1990**	**2000**
Austria	84 677	108 555	83 786	107 044	-1%	-1%
Belgium&Luxembourg	115 896	141 733	112 314	137 317	-3%	-3%
Denmark	65 792	80 395	62 038	75 698	-6%	-6%
Spain	258 377	438 394	264 932	448 307	3%	2%
Finland	67 354	73 387	58 637	63 828	-13%	-13%
France	719 022	850 760	713 820	843 480	-1%	-1%
Great Britain	705 657	787 096	661 966	739 839	-6%	-6%
Germany	847 602	1 027 721	811 457	981 305	-4%	-5%
Greece	81 542	123 759	80 848	123 066	-1%	-1%
Ireland	25 217	33 806	26 164	34 811	4%	3%
Italy	670 469	900 773	666 226	891 434	-1%	-1%
The Netherlands	167 007	175 109	182 664	190 852	9%	9%
Portugal	62 409	111 445	59 957	104 934	-4%	-6%
Sweden	111 944	124 649	103 293	114 399	-8%	-8%
Bulgaria	39 293	26 162	37 045	24 918	-6%	-5%
Switzerland	102 354	124 792	92 155	113 669	-10%	-9%
Cyprus	8 131	10 152	6 663	8 438	-18%	-17%
Czech Republic	76 256	90 581	68 582	81 867	-10%	-10%
Estonia	11 368	12 148	9 907	10 497	-13%	-14%
Hungary	78 639	76 645	69 875	68 139	-11%	-11%
Latvia	13 699	12 407	11 773	10 590	-14%	-15%
Lithuania	18 614	19 066	16 004	17 187	-14%	-10%
Malta	3 141	3 894	2 754	3 503	-12%	-10%
Norway	59 382	73 724	58 589	73 634	-1%	0%
Poland	172 733	202 856	152 769	181 021	-12%	-11%
Romania	59 234	28 831	60 847	28 453	3%	-1%
Slovenia	15 830	17 693	15 459	18 767	-2%	6%
Slovakia	32 857	35 619	31 407	33 784	-4%	-5%
Total	**4 674 496**	**5 712 152**	**4 521 935**	**5 530 781**	**-3%**	**-3%**

Implementation of New Transport Modes Costs

For most of the modes of transport, a new, more detailed, structure of costs has been implemented. Values to fill in the new variables have been estimated from different sources.

The revision of transport cost has mainly involved all the passenger modes: car, train, bus (local and long distance) and – in a different way – air transport. For all modes (except air passenger) the structure of the calculation is similar and is designed to produce as main output the average cost per Pass*km of every mode. This result is used in the mode split algorithm and other intermediate outputs like taxation unitary revenues.

The new structure implemented is exactly the same for all EU25 countries. This means that also where in the original version of the model a different structure was used for EU15 and NMS, now the cost is computed in the same way and with the same level of detail.

In general, the new cost structure and the new data implemented came up with final costs that in many cases are quite different from the original ones. Therefore, a recalibration of the mode split modules has been required.

Private Car Costs

The costs are divided into five main categories, according to common specifications found in literature. Taxes, that influence investment and fuel, are kept separated to be used in other parts of the model. Therefore, for instance, fuel cost per vkm is actually the result of three components: pure fuel price, excises and VAT on fuel (the same structure already existing in ASTRA).

The calculation structure (see Figure 28) produces two kinds of costs: the perceived one (to be used in the modal choice) and the total one (representing consumed resources plus taxes).

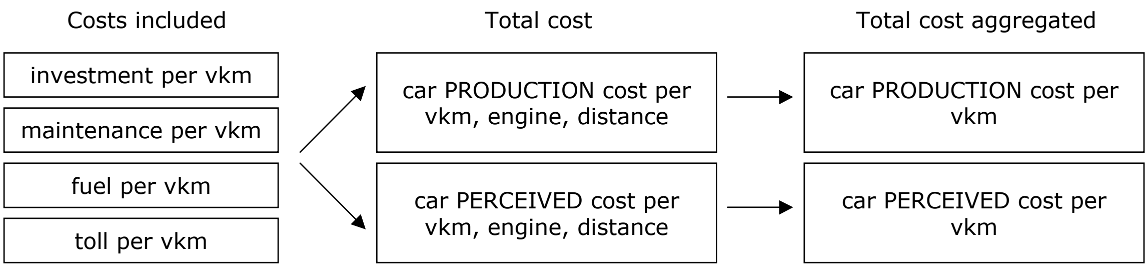


Figure 28: Car cost split

The costs are fully split, depending on fuel and emission class and then weighted with fleet for obtaining the final indicator. Actually, tolls are not computed within the cost per vkm, but are included later in the transport module at the O/D pair level.

For the cost estimation data is fully available for Italy (Italian Automobile Club publishes an annual collection of fully split costs: ACI, 2006). Some information is available for UK, too (AA Trust, 2006). For all other countries the Maintenance costs, Investment costs, Insurance costs derive from Italian ones with the application of the same proportion found for trucks. For instance, the hypothesis is that the proportion between Italian and German cost of tires is the same for trucks and cars.

Taxation levels, both for purchase and periodic taxes, are available for some countries (Denmark, Netherlands, Ireland, Greece, Finland, Italy, Austria, Germany, Great Britain). The sources of such data are TIS, 2002 and OECD/EEA, 2006.

The costs data used are reported in the following table.

Table 12: Data found for car costs.

Country	Purchase	PurchaseTaxes	Yearly taxes	Insurance	Maintenance
	[€/vehicle]	[€/vehicle]	[€/year]	[€/year]	[€/km]
ITA	16 845	171	170	1 349	0.075
AUT	17 695	1 388	212	650	0.065
FRA	16 334			1 080	0.068
GER	16 334	100	360	1 160	0.062
POL	13 952			474	0.043
SLO	15 313			846	0.052
ESP	16 504			707	0.052
HUN	16 504			402	0.046
GBR	17 525	171	278	638	0.049
DNK		15 659	463		
NLD		4 625	307		
IRL		4 423	306		
GRC		2 667	133		
FIN		7 503	186		

* including VAT
Sources: ACI (2006), AA Trust (2006), OECD/EEA (2006), TIS (2002)

In order to use available data to estimate costs for all countries, equivalence tables have been defined. Table 13 reports the two tables, one used for taxation and the other for remaining cost components.

Table 13: Equivalence table for private car costs

Country	Equivalent to (taxation)	Equivalent to (other costs)
AUT	AUT	AUT
BLX	NLD	GER
DNK	DNK	GER
ESP	ITA	ESP
FIN	FIN	GER
FRA	GER	FRA
GBR	GBR	GBR
GER	GER	GER
GRC	GRC	ESP
IRL	IRL	GBR
ITA	ITA	ITA
NLD	NLD	GER
PRT	GRC	ESP
SWE	FIN	GER
BLG	GRC	HUN
CHE	AUT	ITA
CYP	GRC	ESP
CZE	GRC	HUN
EST	GRC	POL
HUN	GRC	HUN
LAT	GRC	POL
LTU	GRC	POL
MLT	GRC	ESP
NOR	FIN	GER
POL	GRC	POL
ROM	GRC	HUN
SLO	GRC	SLO
SVK	GRC	HUN

Local Bus (Public Transport) Costs Module

The public transport sector is characterised by a disconnection between unitary production cost and customer tariff. Firstly, due to relevant subsidies of the sector (already included in the module) and secondly, due to the fact that the tariff in most of the cases is unique (time tariff, season tickets, etc.), with no link to distance travelled. Therefore, a great deal of approximation is needed to derive final costs per pass-km for the mode split starting from detailed production costs.

The structure of the model is presented in Figure 29:

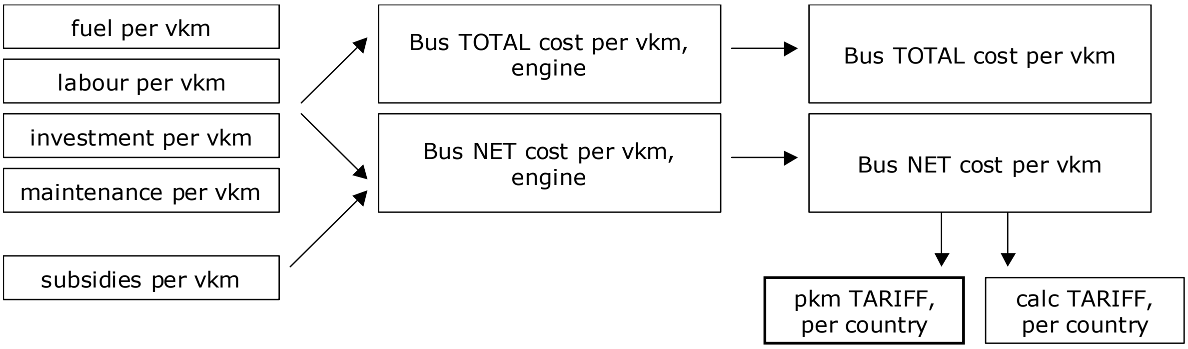


Figure 29: Urban bus cost split

As tariffs cannot be calculated precisely due to the weak link between costs and tariff, values to be used in the logit model, is calculated as follows:

$$T_C = \frac{ANC_c}{LF_c} * TCC_c \qquad \textbf{(eq. 1)}$$

where: Tc = tariff for country c
ANCc = Average Net Cost per vkm for country c
LFc = Load factor for country c
TCCc = Calibration cost coefficient for country c

The coefficient TCC_c has been calibrated during the overall calibration process of the TRA module.

The module calculates an alternative definition of the tariff using the average number of passenger trip on local bus. This computation is done essentially to check that the size of costs is reasonable.

For the cost estimation data about total costs and subsidies, expressed in €/vkm, is available for some Italian cities (elaboration of Cambini et Galleano, 2005 and Dell'Aringa, 2004) and for a selection of Western European countries (Earchimede, 2005).

Although elaborating the two Italian sources one can found a complete set of data, we chose to use the source Earchimede (2005) due to the fact that it was the only one including comparative information about some European countries. Nothing is available for Eastern Europe.

Cross-checking the two sources it has been found that data concerning franchising competitions (Cambini et Galleano, 2005 and Dell'Aringa, 2004) are considerably higher than the used source (Earchimede, 2005): for Italy a cost of 3.5€/vkm instead of a calculated average of 5€/km. Nevertheless the source is trustworthy and is the only one we have been able to find with international data split according to homogeneous categories of costs and the comparable across countries. The same source suggests values for subsidies, too.

The data collected are in Table 14. The cost of fuel used is endogenously calculated. The numbers reported in table have been used for verification.

Table 14: Available data on bus costs.

Country	Labour Cost	Purchase	Maintenance	Fuel	Subsidies
	[€/vkm]	[€/vkm]	[€/vkm]	[€/vkm]	[€/vkm]
ITA	2.30	0.30	0.58	0.316	2.20
GBR	0.80	0.17	0.50	0.333	0.60
GER	2.10	0.35	1.28	0.269	1.50
FRA	1.60	0.36	0.69	0.249	1.90
SWE	1.10	0.20	0.31	0.286	0.90
NLD	1.70	0.30*	0.10	0.297	1.50
BLX	2.00	0.29	0.41	0.299	2.00

* Estimated value
Sources: Earchimede (2005)

The data collected has been expanded to the whole Europe, according to the equivalence reported in Table 15.

Table 15: Equivalence table for bus costs.

Country code	Equivalent to	Country code	Equivalent to
AUT	GER	BLG	ITA
BLX	BLX	CHE	FRA
DNK	SWE	CYP	ITA
ESP	ITA	CZE	ITA
FIN	SWE	EST	ITA
FRA	FRA	HUN	ITA
GBR	GBR	LAT	ITA
GER	GER	LTU	ITA
GRC	ITA	MLT	ITA
IRL	GBR	NOR	GER
ITA	ITA	POL	ITA
NLD	NLD	ROM	ITA
PRT	ITA	SLO	ITA
SWE	SWE	SVK	ITA

Long Distance Bus Costs Module

Long distance buses are defined here as private coach services operating on inter-regional, national and international routes as well as tourist buses. Their cost structure is similar to that used for the public transport services, with the difference that year tolls are considered. Currently, long distance buses are probably not subsidised, but subsidies are included in the structure anyway for policy purposes (e.g. shifting subsidies from rail to coaches).

The structure of the module is the following:

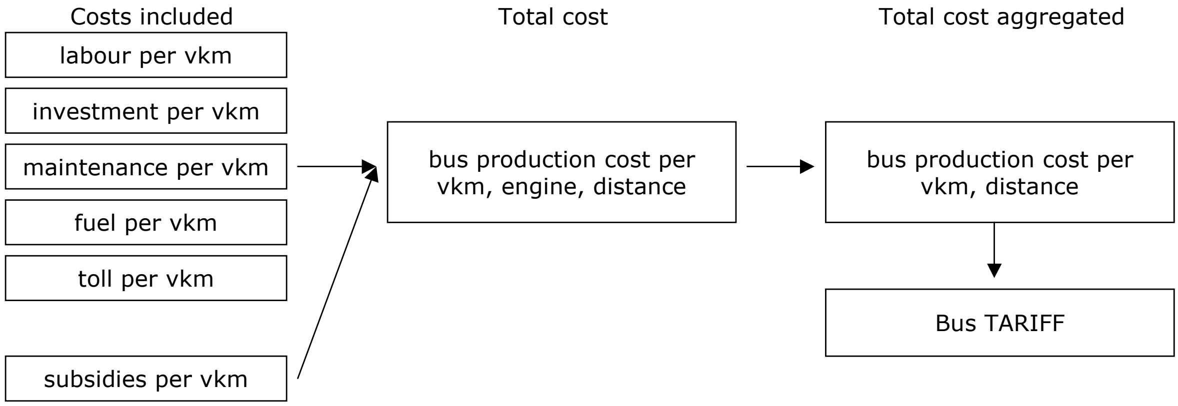


Figure 30: Non-local bus cost split

Unfortunately we have not been able to find any data about coach companies costs in Europe. For estimation some data coming from a periodic publication (Autobus, 2005) describing unitary exercise costs has been used. Since the contents just refers to Italy and does not include all elements required to define each cost components, some hypotheses have been done, in particular:

- The labour costs for long distance buses have been calculated applying to the urban bus value the ratio obtained from Autobus (2005). For Italy this ratio is 65%, while for other countries has been supposed lower.
- The investment and maintenance unitary costs are approximately half for intercity buses compared to urban buses. The same ratio has been applied to all countries.
- The fuel cost ratio is about 80%, applied to all countries.
- Subsidies are supposed to be zero.

Costs have been first estimated using the assumptions above for the countries for which urban bus costs were available (see section 3); Table 16 reports such a data. Therefore data have been extended to the other countries using the same equivalence table used for urban buses (see Table 15). The cost of fuel used is endogenously calculated. The numbers reported in table can be used for verification.

Table 16: Data estimated for long distance bus costs.

Country	Labour Cost	Purchase	Maintenance	Fuel	Subsidies
	[€/km]	[€/km]	[€/km]	[€/km]	[€/km]
ITA	1.50	0.15	0.29	0.253	0
GBR	0.80	0.09	0.25	0.267	0
GER	1.68	0.18	0.64	0.215	0
FRA	1.28	0.18	0.35	0.199	0
SWE	0.88	0.10	0.16	0.229	0
NLD	1.36	0.15	0.05	0.237	0
BLX	1.60	0.15	0.21	0.240	0

Sources: own estimations on Autobus (2005) and Earchimede (2005) data.

Train Costs Module

The structure of the costs is the same for both passenger and freight trains, also because railway companies usually are not able to distinguish labour costs of energy costs, etc, by type of service. Anyway, two different views have been dedicated to the transport by train for passenger and freight. Like for local bus, subsidies are very important in the cost structure, and like for bus it is however difficult to link total productions costs, subsidies and tariffs.

The following figure represents the structure of the module for passenger services.

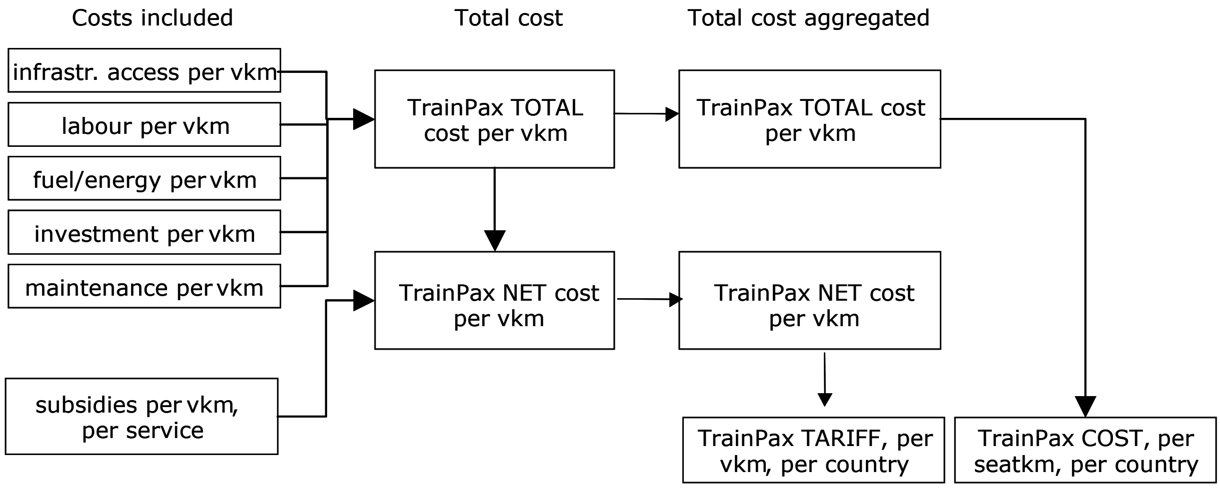


Figure 31: Train passenger cost split

For cost estimation for Italy is available an official document (Cicini et al, 2005) detailing costs splitting for single voices and for different services (local, intercity, high speed, freight).

A complete survey of average costs of rail companies in Europe can be derived from UIC data (even if the last available data refers to 1999). Using the total expenditures and revenues for exercise and the total amount of train*km produced, average cost values for an average train type. Split of costs for different services (local, long, high speed, freight) has been estimated using the proportions of different costs for Italian railways.

The cost for energy provided is the one of large industrial clients in Italy. In any case the amount of energy costs per train*km is extremely limited in comparison to other components (about 4%).

The cost for access to infrastructure could be determined using the official documents for Italy only. For other countries UIC data for infrastructure access costs are quite incomplete (also because data concerns year 1999 and in many countries such a cost has not been existing until very recent time), so this item has been disregarded.

Table 17 reports Italian data while Table 18 provides average data for all countries estimated using UIC data and equivalences reported in Table 19.

Table 17: Data for Italian train costs derived from Cicini et al, (2005)

Service type	Labour	Investment	Maintenance	Energy	Infrastructure access	Other
	[€/km]	[€/km]	[€/km]	[€/kWh]	[€/km]	[€/km]
Intercity	3.74	4.48	2.05	0.084	2.11	1.28
Local	3.80	3.44	1.60	0.084	2.727	1.28
Freight	5.00	2.40	1.90	0.084	2.727	0.57

Sources: Cicini et al (2005).

Table 18: Data for train costs, taken from UIC (1999)

Country	Labour	Investment	Maintenance	Infrastruc-ture access	Subsidies	Other
	[€/km]	[€/km]	[€/km]	[€/km]	[€/km]	[€/km]
AUT	13.54	2.42	5.26	1.82	4.282	1.34
BLX	17.65	4.29	8.14	-	4.639	1.31
DNK	6.59	-	5.72	0.33	-	0.93
ESP	6.14	2.85	4.92	-	1.690	2.37
FIN	7.81	1.89	4.21	1.20	0.787	0.39
FRA	13.47	1.82	8.73	2.92	5.571	5.36
GER	9.85	2.09	10.42	0.00	1.708	0.77
GRC	14.63	2.58	3.42	-	0.049	7.20
IRL	10.74	2.00	10.40	-	3.452	0.96
ITA	13.91	5.64	6.47	-	9.963	0.41
NLD	7.73	2.02	13.47	-	6.001	1.11
PRT	6.82	1.91	6.03	-	0.691	2.25
SWE	4.52	0.93	6.16	0.26	-	0.83
CHE	14.60	5.54	6.60	-	8.951	0.87
CZE	3.97	1.09	2.85	-	1.547	0.33
HUN	3.18	0.65	2.73	-	4.067	0.33
NOR	-	1.24	7.81	-	3.362	0.53
POL	4.64	1.65	2.35	-	1.296	0.99
ROM	2.58	0.19	7.22	-	2.183	0.30
SLO	5.65	1.48	5.00	-	2.395	1.03
SVK	4.10	1.10	3.50	-	2.851	2.13

Sources: own elaboration on Cicini et al (2005) and UIC (1999) data

Table 19: Equivalence table for train costs

Country code	Equivalent to	Country code	Equivalent to
AUT	AUT	BLG	ROM
BLX	BLX	CHE	CHE
DNK	DNK	CYP	n.r.
ESP	ESP	CZE	CZE
FIN	FIN	EST	POL
FRA	FRA	HUN	HUN
GBR	IRL	LAT	POL
GER	GER	LTU	POL
GRC	GRC	MLT	n.r.
IRL	IRL	NOR	NOR
ITA	ITA	POL	POL
NLD	NLD	ROM	ROM
PRT	PRT	SLO	SLO
SWE	SWE	SVK	SVK

Air Passenger Cost

The structure for the calculation of air passenger costs has been slightly changed. Currently, the model already distinguishes fuel and non-fuel costs. Adding further details needed to introduce the distinction between conventional airlines and budget (low cost) companies, which has been done in a simplified way.

The non-fuel cost is calculated as weighted average between the conventional airlines cost (the old cost in the model) and the budget companies cost (estimated on the basis of several OD pair and companies around 0.07 euro/km). The share of the low cost companies has been calibrated in order to reflect the growth that they had during the last years.

Effects of Passenger Cost Update on Policy Simulation

With the proposed structure for passenger cost there are some policies that can be simulated in more detail than in the current version of the model. For instance:

- differential taxation for innovative vehicles (both purchase and fuel taxes);
- change of labour costs due to social legislation, market structure, etc.
- car pooling.
- Subsidies system: the amount of subsidies transferred to public transport can vary to assess the effects both to modal split module and macroeconomic effects module;
- Fleet renewal (in terms of expenditures and therefore impacts on the economic side);
- Public transport companies downsizing due to liberalisation.
- Modifications in the subsidies structure between modes (from train to bus);
- Effect of older vehicles substitution.

- Effects due to liberalisation (fleet renewal, price lowering, cost lowering).

Transport Freight Sub-Module (TRA Fre)

Modelling Road Feeder Traffic for Rail and Ship

In many instances, a door-to-door consignment by rail and sea shipping requires that trucks are used for feeding the main mode (a train or a vessel). Given the aggregate description of modes in ASTRA, this circumstance cannot be simulated in detail. However, in order to avoid the underestimation of road tkm and overestimation of the other modes, a correction has been implemented to the amount of tkm of rail and ship. The size of the correction has been calculated on the basis of tkm data of a sample of OD pairs from SCENES. The calculated share of traffic to be assigned to truck is different for ship and rail - about 14% for rail and 9% for ship. The correction has been applied to total tkm of rail and ship modes and added to road mode after the modal split.

Including selected OD pair from NMS to EU15 countries and vice-versa in the MED freight distance band

In the previous version of the ASTRA, the EU15 and the more recent EU partners were connected only in the long distance band (>700 km). In order to improve the description of the demand between these two groups of countries, a number of O/D pairs have been included also in the medium MED distance band (150-700 km). The relevant O/D pairs have been selected from the analysis of the ETIS BASE and SCENES data.

Implementation of Revised Transport Costs

The revision of transport cost has mainly involved the following freight modes: truck, train and partially ship. For all modules (except ship) the structure of the calculation is similar and is designed to produce as main output the average cost per vehicle*km of every mode. This result is used in the mode split algorithm and other intermediate outputs like taxation unitary revenues.

The new structure implemented is exactly the same for all EU25 countries. This means that also where in the original version of the model a different structure was used for EU15 and NMS, now the cost is computed in the same way and with the same level of detail. Even if checks have been performed that this change did not give rise to problems in other parts of the model, this aspect should be taken into account.

All modules are designed to produce one main output, the average cost per vehicle*km of every mode to be used in the mode split algorithm, and other intermediate outputs like taxation unitary revenues.

In general, the new cost structure and the new data implemented came up with final costs that in many cases are quite different from the original ones. Therefore, a recalibration of the mode split modules has been required.

Truck Costs Module

The module is structured as follows (Figure 32).

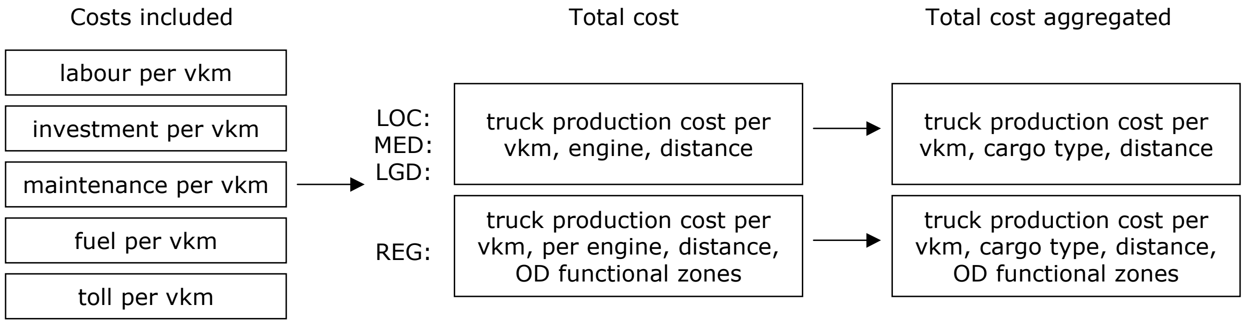


Figure 32: Road freight cost split

The costs are divided into five main categories, according to common specifications found in literature. Taxes, that influence investment and fuel, are kept separated to be used in other parts of the model. Therefore, for instance, fuel cost per vkm is actually the result of three components: pure fuel price, excises and VAT on fuel (the same structure already existing in ASTRA).

In the model, the tolls for REG transport are, differently from other distance classes, specified for different functional zones. That’s why the final output is different between regional and other three distance classes. Also, tolls are not actually computed within the cost per vkm, but are included later at the O/D pair level.

The module reflects the cost structure of a document produced for Italian Ministry and the syndicate of truck operators[5], which contains comparative numerical materials about costs of truck transport. A cross-check has shown that total costs reported in this document are extremely similar to costs estimated for the TREMOVE II project (see note TRT-4 of TREMOVE II project). Also fuel data seems consistent to the current values in ASTRA[6]. Therefore the source looks reliable and reports a detailed desegregation of total cost. The data refers to nine countries only (Italy, Austria, France, Germany, Poland, Slovenia, Spain, Hungary, Ukraine), but with some assumptions (and with previous editions of the same document containing different countries) it has been possible to extend the analysis to almost all EU countries.

The data elaborated for the nine countries are reported in Table 20 below. Costs per vehicle-km have been obtained assuming an average yearly mileage of 100,000 km.

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5 Centro Studi sui Sistemi di Trasporto, (2005), *Indagine conoscitiva sui costi e sulla fiscalità sopportati dalle imprese italiane di autotrasporto*…, Ministero dei Trasporti e della Navigazione, Roma (Italy).

6 In particular, the category for which ASTRA and the document produce the same result is the MED distance for HDV. Differences between emission classes are negligible.

Table 20: Original data on truck costs

Country	Labor Cost	Purchase	Purchase Taxes	Yearly taxes	Insurance	Maintenance
	[€/year]	[€]	[€]	[€/year]	[€/year]	[€/km]
ITA	45 923	153 439	1 399	718	8 067	0.194
AUT	47 083	123 550	160	4 029	3 888	0.157
FRA	53 044	131 929	278	730	6 455	0.154
GER	45 126	120 862	95	2 586	6 933	0.162
POL	21 580	127 992	120	890	2 833	0.104
SLO	32 453	136 167	-	3 600	5 059	0.124
ESP	33 005	130 221	66	788	4 230	0.129
HUN	22 858	135 226	160	1 097	2 406	0.111
UKR	18 765	111 245	105	775	2 373	0.089

Source: CSST, 2005

The following Table 21 summarises the equivalences used between countries. These equivalences have been assumed from similarity of economic and welfare conditions, similarities in markets, geographical proximity, etc.

Table 21: Equivalence table for truck costs

Original Country	Equivalent to		Original Country	Equivalent to
AUT	AUT		BLG	HUN
BLX	GER		CHE	ITA
DNK	GER		CYP	ESP
ESP	ESP		CZE	HUN
FIN	GER		EST	POL
FRA	FRA		HUN	HUN
GBR	FRA		LAT	POL
GER	GER		LTU	POL
GRC	ESP		MLT	ESP
IRL	FRA		NOR	GER
ITA	ITA		POL	POL
NLD	GER		ROM	HUN
PRT	ESP		SLO	SLO
SWE	GER		SVK	HUN

Train Costs Module

As explained above, the structure of the train costs is the same for passenger and freight. The following figure represents the structure of the module for freight rail services.

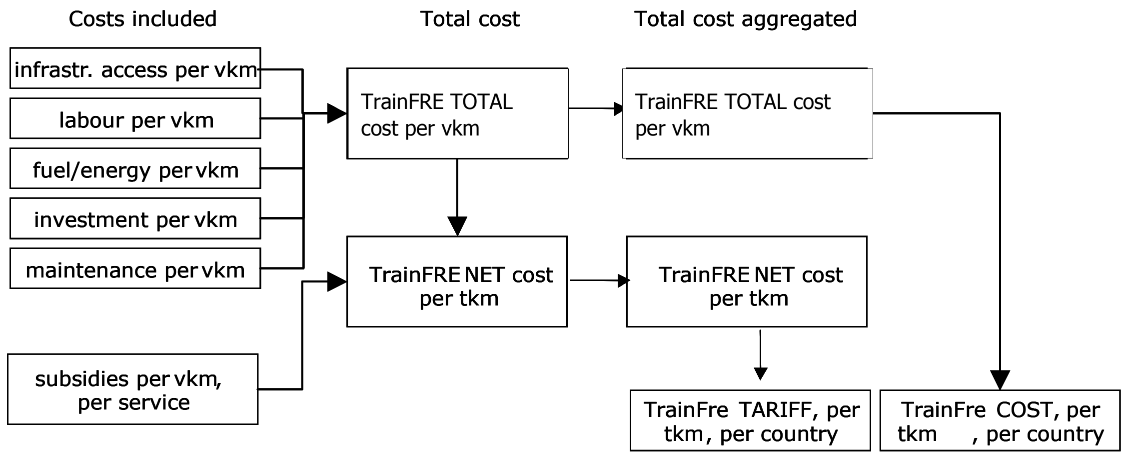


Figure 33: Train freight cost split

The data available are the same described for passenger train cost.

Ship Cost Trend

In the previous version of the ASTRA model, the development of ship costs over time was quite different from that of other competing modes (road freight and rail freight). For the latter, unitary costs tend to increase over time, sometimes quite sharply, while ship costs were constant or even decreasing. This difference gave rise to a growing competitiveness of ship, which does not seem justified. Therefore, the evolution of the ship costs over time has been corrected based mainly on the growth rate of the diesel fuel price index.

Effects of Freight Cost Update on Policy Simulation

With the proposed structure there are some policies that can be simulated in more detail than in the current version of the model. For instance:

- differential taxation for innovative vehicles (both purchase and fuel taxes);
- duty vehicles fleet renewal
- change of labour costs due to social legislation, market structure, etc.
- subsidies system: the amount of subsidies transferred to public transport can vary to assess the effects both to modal split module and macroeconomic effects module;
- effect of older vehicles substitution.
- effects of due to liberalisation (fleet renewal, price lowering, cost lowering).

ASTRA Freight Data Stocks Update

As for passenger, the initial stock of data that fill the transport module has been completely re-estimated. For the preparation of the data for the stocks for freight the ETIS BASE has been selected as main sources of information.

The ETIS base data for freight is mainly represented by a matrix, which contains:

- Tons per commodity, mode and OD (at NUTS II level),
- Distance per OD (calculated as the crow flies between production and consumption).

The matrix is structured by mode chain, but as the information concerning the interchange point is often missing, only the origin and destination information has been used for the estimation.

Firstly, the data needed to be aggregated according to the groups' definition requested by the ASTRA model for:

- The commodity flow,
- The main mode.

The conversion between ETIS commodity groups and ASTRA flows required several assumptions in order to assign the original ETIS group to the correct ASTRA flows: e.g. the "Buildings mineralsand material" and "Machinery & other manufacturing" sectors could be related to more than one flow in ASTRA. From SCENES data for the same sectors the share to distribute the original group into the different floes has been calculated, as reported in the table below.

Table 22: Conversion between ETIS commodity groups and ASTRA flows

ETIS Code	ETIS Commodity group	ASTRA code	ASTRA flow	coeff
0	Agricultural products	GCG	General Cargo	100%
1	Foodstuffs	UNT	Unitised	100%
2	Solid mineral fuels	BLK	Bulk	100%
3	Crude oil	BLK	Bulk	100%
4	Ores, metal waste	BLK	Bulk	100%
5	Metal products	GCG	General Cargo	100%
6	Building minerals & material	BLK	Bulk	77%
		UNT	Unitised	23%
7	Fertilisers	GCG	General Cargo	100%
8	Chemicals	BLK	Bulk	100%
9	Machinery & other manufacturing	UNT	Unitised	83%
		GCG	General Cargo	17%
10	Petroleum products	BLK	Bulk	100%

In order to respect the ASTRA modes definition, the chain mode existing in ETIS has been grouped according to the principle of the main mode. The following table presents each combination considered.

Table 23: Conversion between ETIS chain mode and ASTRA mode

Mode chain	Main mode
IWW	IWW
road-IWW	
Rail	Rail
Rail-IWW	
Road-rail	
Road	Road
road-sea	sea
road-sea-IWW	
road-sea-rail	
Sea	
Sea-IWW	
Rail-sea	
Rail-sea-IWW	

Once that the ETIS data has been converted into a format consistent with ASTRA definition, it has been observed that in the database there where some missing values for several national distances. In order to have a complete database these values has been replaced with SCENES data.

The resulting matrix has been used to calculate the freight traffic by OD pair, flow and mode (in terms of tons/year and tons*km/year) and to compare the aggregated results with Eurostat total tkm per country in 2000 (Transport in figures 2005).

As some discrepancies has been detected, some adjustment has been produced in order to reflect Eurostat aggregated data:

- the ETIS distances data has been in some cases corrected (usually increased),
- the tons data for some New Member State has been corrected.

The new corrected matrix has been used to recalculate the freight traffic by OD pair, flow and mode, with the results that the aggregated comparison with Eurostat total tkm per country in 2000 was acceptable. Looking at the results by mode in the same year the comparison was not so satisfactory: the data has been once more corrected transferring the tons from one mode to another (when both are originally used in a defined OD) in order to reflect the modal split depicted in Eurostat data for 2000.

Table 24: Comparison between data stock and Eurostat total tkm per country in 1990 and 2000

Country	**Observed tkm (Eurostat, elab TRT)**		**Data stocks tkm (ETIS BASE, elab.TRT)**		**Difference (%)**	
	1990	**2000**	**1990**	**2000**	**1990**	**2000**
Austria	29 821	46 544	29 650	38 755	-1%	-17%
Belgi-um&Luxembourg	98 368	111 390	100 777	121 525	2%	9%
Denmark	30 901	30 441	31 727	36 253	3%	19%
Spain	182 078	256 198	174 726	199 221	-4%	-22%
Finland	119 257	125 141	108 185	113 842	-9%	-9%
France	338 467	420 986	333 523	376 648	-1%	-11%
Great Britain	335 900	434 610	309 470	366 694	-8%	-16%
Germany	441 072	586 565	409 644	463 520	-7%	-21%
Greece	67 995	87 830	62 081	70 208	-9%	-20%
Ireland	13 389	32 186	13 564	26 391	1%	-18%
Italy	349 179	412 066	305 164	319 216	-13%	-23%
The Netherlands	150 889	183 370	134 232	160 594	-11%	-12%
Portugal	36 959	34 394	35 700	39 203	-3%	14%
Sweden	69 419	80 810	67 730	90 190	-2%	12%
Bulgaria	34 172	35 322	34 147	28 090	0%	-20%
Switzerland	25 886	32 455	26 648	29 209	3%	-10%
Cyprus	13 326	6 430	11 922	5 861	-11%	-9%
Czech Republic	46 676	55 569	40 674	47 510	-13%	-15%
Estonia	14 252	14 319	13 727	11 859	-4%	-17%
Hungary	34 040	28 791	31 524	31 163	-7%	8%
Latvia	34 888	21 102	31 894	17 458	-9%	-17%
Lithuania	42 425	48 820	41 308	34 620	-3%	-29%
Malta	432	597	461	622	7%	4%
Norway	141 037	163 237	125 468	142 961	-11%	-12%
Poland	181 930	194 663	164 479	178 470	-10%	-8%
Romania	123 622	67 087	114 058	61 403	-8%	-8%
Slovenia	11 374	10 796	10 422	11 197	-8%	4%
Slovakia	26 919	26 916	23 109	21 201	-14%	-21%
Total	**2 994 670**	**3 548 636**	**2 786 013**	**3 043 883**	**-7%**	**-14%**

4.1.3.5 Regional Economics Module

The revision of Regional Economic module concerned the update of the trip rates for NMS countries, which were previously calculated in a simplified way due to lack of information.

Trip rates differentiated into age groups, employment situation and car-availability represent the average mobility behaviour of specific groups of population. In the passenger trip generation stage in the ASTRA Regional Economic model (REM) they are applied to calculate the passenger trips per country and population groups. Most Western European countries and members of EU15 frequently performed mobility or travel surveys among the population helping to identify mobility patterns of specific population clusters, like for example the German and the Dutch mobility survey or the UK travel survey. Analysing and comparing these mobility surveys lead to the insight that mobility patterns and average numbers of trips per person in these countries resemble one another. Country-specific GDP per capita numbers from EUROSTAT show that the values for the year 2000 are also similar and in a range between 25,000 and 26,500 Euro per inhabitant.

In contrast to the various information on trip rates provided by these and many other Western European mobility surveys, no surveys were available for the New Member States of the EU25 and the Candidate Countries Bulgaria and Romania. This lack of information and data required the development of an appropriate methodology to estimate the passenger trip rates in the New Member States. Unfortunately, no available transport database releases total numbers of passenger trips for these countries. Only the passenger transport performance measured in passenger-km can be found in databases like the "Energy & Transport in Figures" pocketbook published by the European Commission each year. This country-specific transport performance indicator could serve as basic for the estimation of trip rates. In practise a transfer from pkm into passenger trips would require an estimation of average length of trips differing from country to country depending on country-specific settlement patterns, the location of workplaces and other indicators. Therefore an alternative methodology has been chosen to estimate the passenger trip rates in the New Member States.

According to the differentiation of trip rates in EU15 countries the country-specific trips per person and day are distinguished between the trip purposes business, private and tourism. The UK travel survey provides the reference values per person and day for all three purposes. In the year 2000 a person in the UK made on average about 2.5 business trips per day, 1.85 private trips per day and 25 holiday trips (trips of more than 2 days) per year. Furthermore the GDP per capita for the initial year 1990 has been taken from EUROSTAT. The following equation describes the chosen methodology for estimating the average number of trips per person per day with trip purpose in the Eastern European countries.

$$AT_{i,TP} = \min AT_{TP} + (AT_{GBR,TP} - \min AT_{TP}) * \frac{GDPpC_i}{GDPpC_{GBR}} \qquad \textbf{(eq. 2)}$$

where: $AT_{i,TP}$ = Average number of trips per person per day with trip purpose TP in country i
$\min AT_{TP}$ = Minimum average number of trips per person per day for trip purpose TP
$AT_{GBR,TP}$ = Average number of trips per person per day with trip purpose TP in the UK
GDP_pC_i = Gross Domestic Product per Capita in country i
GDP_pC_{GBR} = Gross Domestic Product per Capita in the UK

The computation requires the assumption of a minimum number of trips per person and trip purpose per day. This assumption has been performed by determining a minimum number of average trips per person and year of about 800 trips compared to 1021 in the UK. The assumption of business trips being more essential than private or holiday trips and people with lower incomes have to save money by reducing the number of holiday and private trips resulted in the following minimum number of trips per person: 2.3 business trips, 1.5 private trips and 4 holiday trips.

In comparison with the trip rates for EU15 the resulting trip rates for the Eastern European New Member States of EU25 are only disaggregated into three trip purposes and do not consider employment or car-availability. The EU15 passenger trip generation model was originally based on trip rates per age segment, employment status, car-availability and trip purpose taken from SCENES. As these trip rates did not distinguish between different mobility patterns from country to country a special calibration was implemented in ASTRA. The country-specific differences were taken into account by calibrating the trip rates to fit the total numbers of trips per purpose and functional zone in a country. For the estimation of Eastern European trip rates the same approach was applied.

Hence, in the approach the total number of trips per country in a year was computed out of the number of average trips per person and trip purposes by applying employment and population numbers for the initial year 1990 taken from EUROSTAT. The total number of business trips was calculated by assuming an average of 260 working days per year and multiplying them with the employment numbers and trip rates. For the computation of yearly private and holiday trips the whole population was considered. Splitting the trips per country and trip purpose into the functional zones by taking into account the share of population living in the zone enabled the recalculation of country-specific trip rates originally taken from SCENES.

One major assumption behind the trip generation based on trip rates in ASTRA is that trip rates are fixed over time for homogenous segments of populations. Notwithstanding, the trip rates for the New Member States have been increased over the calibration period. This is justified because of the rougher segmentation of individuals available for such countries when compared to the EU15. Employed people and who own a car make more trips and both such groups are expected to increase in the future in the New Member States. Therefore it is expected that trip rates in such countries will tend to become more similar to those in the EU15.

4.1.3.6 Infrastructure Module

The revision of the infrastructure capacity structure included two different activities, as follows:

- Testing different parameters for current flow/capacity functions to emphasize the role of congestion;
- Testing and calibrating a different structure for implementing congestion effects.

Testing Different Parameters for Current Flow / Capacity Functions to Emphasize the Role of Congestion.

The parameters of the flow/capacity functions of the different modes have been tested in order to emphasise the role of the congestion. After several tests, road function has been made steeper in the first part of the function, when the flow/capacity ratio is lower than 1. The intervention has been stronger at local level and weaker for long distance network. The changes allowed the model to simulate a slight reduction of the road modal shares (car and bus) as the occupancy of capacity grows, with correspondent increase of slow trips at local level and rail and air for long distances.

A revision has been done also on rail, air and ship flow/capacity functions in order to prevent non-road modes to increase rapidly their share even when the estimated capacity is reached. New parameters have been set for air and ship while the parameters for rail rested unchanged.

During the tests, some questionable data concerning capacity has been detected. For rail and road alternative values have been estimated and included in the model.

Testing and Calibrating a Different Structure for Implementing Congestion Effects

The original objective of this task was twofold. On the one side, it was planned to test whether steeper speed-flow functions would give rise to model oscillations when congestion appear and, in such a case, to implement a different structure to "smooth" travel time. Secondly, a new structure has been implemented, splitting infrastructure into a congested and non-congested part for which the shares are provided from VACLAV. The non-congested part is related to the base time per km, while the congested part is related to the time per km resulting from the application of the speed-flow curve or – in case an iterative interaction with VACLAV is implemented – directly by output of the VACLAV network model.

4.1.3.7 Vehicle Fleet Module

The previous version of the ASTRA vehicle fleet module (VFT) consisted of four separate models representing the passenger car, bus, light duty vehicle (LDV) and heavy duty vehicle (HDV) fleets in EU27+2 (EU27 plus Norway and Switzerland). The major indicator simulated by each of the four models is the number of vehicles in each country for the simulation period. There is a common structure implemented, which is characterised by a feedback between new vehicle purchases per year, the number of vehicles per age class, the scrapping of vehicles per year and a generated demand regulating the change of vehicle fleets and the replacement of scrapped cars and therefore the new registered vehicles per year.

In contrast to the ASTRA bus and HDV model, the passenger car and LDV model differentiate between diesel and gasoline driven motors. Furthermore the previous version of the car fleet model distinguished between three different cubic size groups for gasoline driven cars and two groups for diesel driven cars. All previous models differentiate emission categories (ece1503 until Euro5) determined by their date of purchase in common. The abovementioned demand driving the change of fleet by new registrations is implemented in a different way in the four models. Bus, LDV and HDV new registrations are induced by vehicle-kilometre driven in the respective freight transport model. For instance LDV registrations are modelled to be dependent on vehicle-kilometres driven in local, regional and medium distance bands, while HDV registrations depend on longer distance vehicle-kilometres driven.

The major objectives of TRIAS, to analyse the impacts of supporting hydrogen and biofuel technologies, required a significant revision of the previous passenger car fleet model. In order to simulate the potentials of hydrogen and biofuels as prospective vehicle technologies IWW expanded the passenger car model with six new car technologies. Figure 34 highlights the six new alternative car technologies besides the five already existing conventional car categories. Hybrid cars (HYB) comprise a combination of combustion and electric motors. The revised model does not distinguish between hybrid cars equipped with diesel respective gasoline motors. An exogenous share is estimated to assign the emissions and fuel consumption to diesel respective gasoline technology. As many contemporary conventional diesel cars allow driving with biodiesel the new car category bioethanol cars (BIO) does only contain cars driving with bioethanol E85. Finally, the new category hydrogen cars (H2) is implemented and incorporates fuel cell cars as well as cars with direct combustion engines. Regarding the current low frequency of filling stations offering alternative fuels the automotive industry developed many alternative fuel cars that can be driven by conventional fuels as well. The revised car fleet model allocates these hybrid car categories to the alternative fuel categories and not to the conventional car categories.

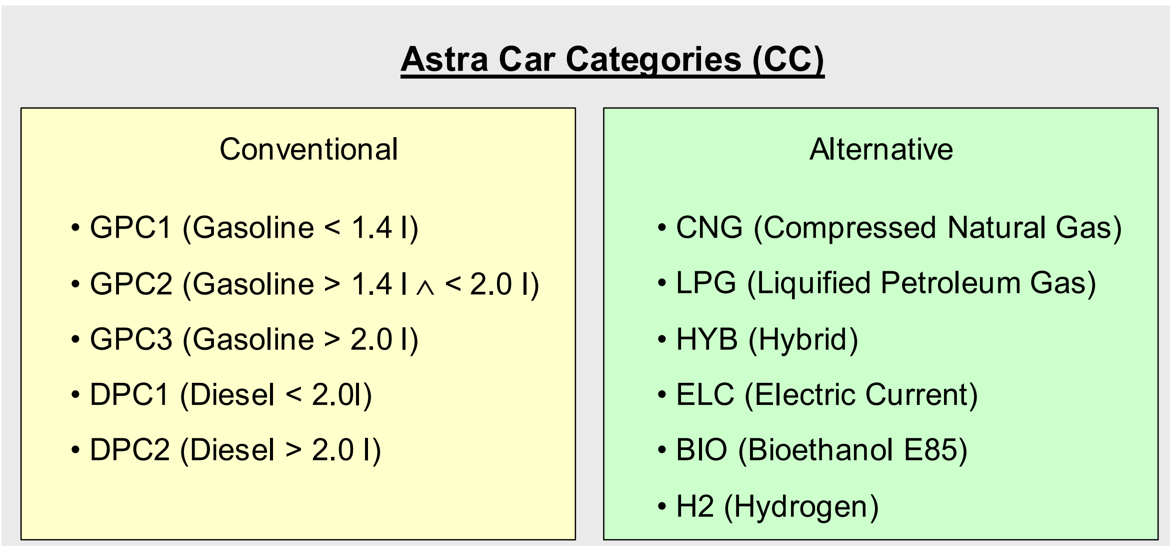
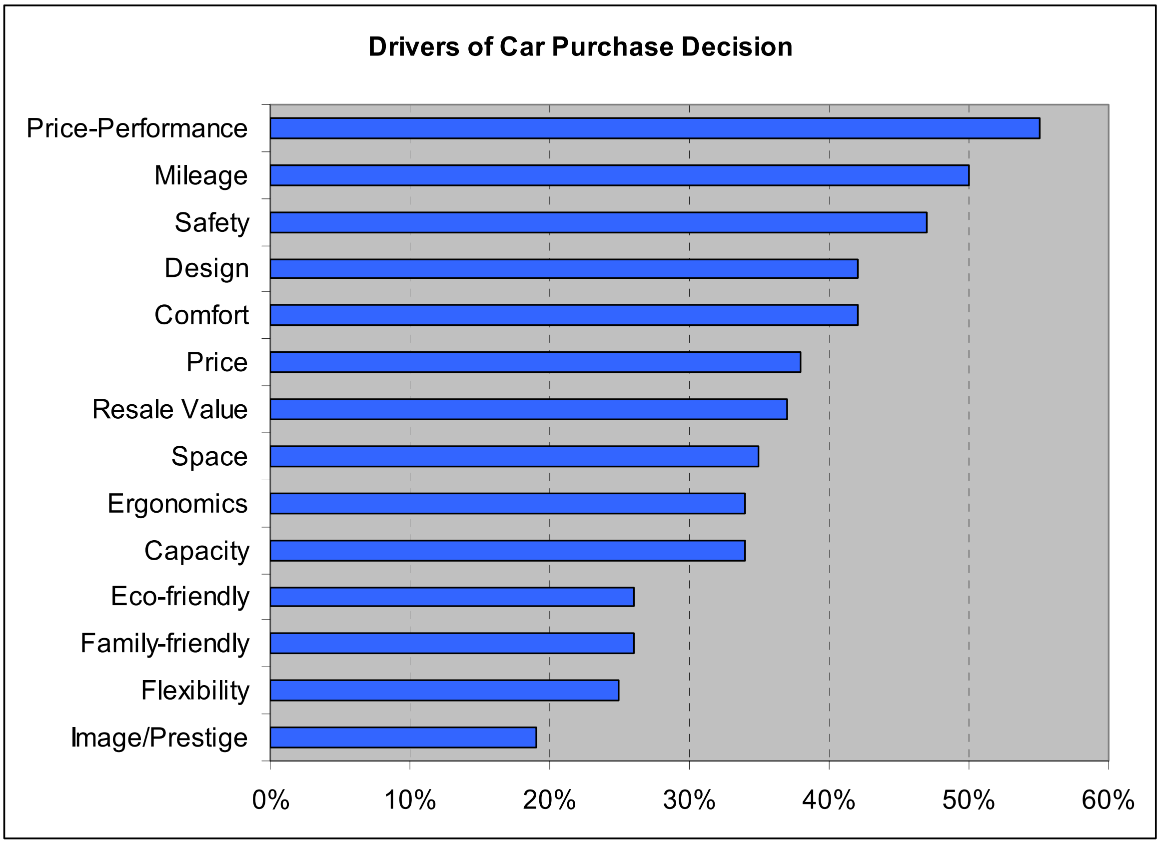


Figure 34: New ASTRA passenger car categories

The purchase decision for one of the five conventional car categories in the previous ASTRA car fleet model was driven by aggregated factors like differences between gasoline and diesel fuel prices, different taxation and a factor representing fashion. In order to integrate the new alternative car technologies IWW identified the major drivers of people that decided to buy a new car. Several US studies and the most recent ARAL (2005) study elaborated via costumer surveys potential factors influencing the decision of a car purchaser for a certain car respective car technology. In the following the European study from Aral is focused, as the new purchase decision model simulates the EU27+2 markets. Figure 35 gives a detailed overview on the survey. According to this study the costumers set a high value on economic efficiency for new cars. Price in combination with the provided performance of a car is the most significant factor with 55% followed by the mileage of the car. Compared with older surveys the factor safety lost significance but ,nevertheless, safety still plays an important role for 47% of all interviewed customers. Besides economic and technical factors influencing the car purchase decision the study included also soft factors like design, image and prestige. In contrast to the economic factors they are supposed to be not as important. The low importance of factors like the environmental-friendly-ness of a new car indicates that alternative fuel cars can only diffuse successfully into the European markets when they can be purchased and operated for an adequate price.

Based on the cognitions of this survey and the feasibility to quantify drivers in a System Dynamics model the revised car fleet model concentrates on the economic efficiency as major impact for the purchase decision.



Source: Aral Study (2005)

Figure 35: Drivers of Car Purchase Decision

Due to the characteristics of the purchase as a discrete choice for one out of eleven car categories respective technologies a logit-model was supposed to be the most sophisticated approach for simulating this decision. The implemented logit-function requires specific user benefits of all eleven car technologies that can be chosen. Similar to the application of logit-functions in the modal-split transport modelling stage this model does not compute benefits but costs that can be put into the logit-function as negative benefits according to the following equation.

$$P_{CC,EC} = \frac{\exp(-\lambda_{EC} * pC_{CC,EC} + LC_{CC,EC})}{\sum_{CC} \exp(-\lambda_{EC} * pC_{CC,EC} + LC_{CC,EC})} \quad \textbf{(eq. 3)}$$

where:
$P_{CC,EC}$ = share of purchased cars per car category CC and country EC
$pC_{CC,EC}$ = perceived total costs per vehicle-km per car category and country EC
λ_{EC} = multiplier lambda per country EC
$LC_{CC,EC}$ = logit const per car category CC and country EC representing the disutility
CC =eleven car categories/technologies
EC =EU27 plus Norway and Switzerland

The revised car fleet model calculates the required average costs per vehicle-km for each car category in a bottom-up approach. On the one hand the model computes variable costs per vehicle-km based on average fuel consumption factors for each technology and country-specific fuel prices provided by POLES. Fuel consumption factors for conventional cars are derived from Umweltbundesamt (2004)[7]. Available sales figures for specific car types for each alternative car category and general information from OEMs are used to generate average fuel consumption factors for the six new car categories.

Besides variable costs the model considers also fixed costs for each car category. Detailed car-ownership taxation, registration fees and purchase costs per country and car category and country-specific average maintenance costs determine the fixed costs per car category and country. All elements of fixed costs are transformed into costs per vehicle-km by dividing through average yearly mileages per car category and country. Average values for yearly mileages are based on car passenger-km and car-ownership taken from EU Energy and Transport in Figures 2005 and average occupancy rates taken from the TRANSTOOLS model. As the conversion of purchase costs into costs per vehicle-km requires information on average lifetime per car category the average lifetime per car category and country is derived from the car stock cohort model via feedback loop. Similar to the approach for computing of average fuel consumption factors for alternative fuel cars, average purchase costs for alternative fuel cars are performed considering sales figures from the last years.

Assuming completely rational purchase decision behaviour based on all variable and fixed costs would disregard other important drivers like the distribution grid of filling stations selling the requested type of fuel. For conventional fuel types like gasoline and diesel the distribution grid is characterised by a good quality in all EU27+2 countries. At present, owners or prospective costumers of alternative fuel cars have to cope with the burden that the procurement of alternative fuels requires significantly longer additional trips or is even not feasible due to lacking filling stations. JANSSEN (2004) concluded in his paper on CNG market penetration that successful diffusion of new car technologies depend on a uniform development of technology and filling station infrastructure. Against the background of these significant impacts due to fuel supply differences the model has to consider the quality of filing station grids as well. Hence, the four mentioned cost categories have to be completed by so-called fuel procurement costs.

[7] Umweltbundesamt (2004): Handbook Emission Factors for Road Transport, Version 2.1

In order to generate these costs per vehicle-km for each car category and country the model requires input in terms of filling station numbers for each fuel category diesel, gasoline, LPG, CNG, electric current, E85 and hydrogen. Conventional filling stations are derived from national statistics offices and automobile associations, alternative fuel filling station numbers were taken from European Natural Gas Vehicle Association[8] and other databases[9]. Due to lacking information about the spatial distribution of filling stations the revised model assumes a homogenous distribution. This leads to an average surface area for each fuel category that have to be served per filling station. The model considers the optimisation efforts of mineral oil groups in locating new filling stations efficiently by assuming a central location in a unit circle representing the average surface area. In order to calculate an average distance that has to be driven for refuelling a car three situations for the car-owner are conceivable:

- refuelling requires no extra trip because the filling station is located on the way to another destination
- refuelling requires an extra trip for the car-owner starting in an area near the filling station (25% of maximum distance)
- refuelling requires an extra trip for the car-owner starting in an area far away from the filling station (75% of maximum distance)

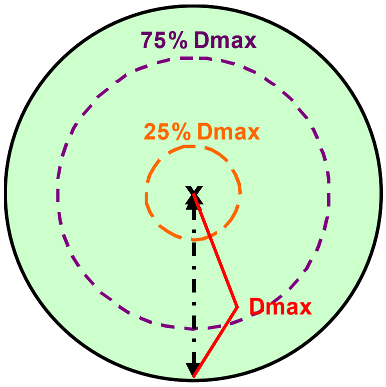


Figure 36: Estimation of average distance to filling station

Weighting the option without extra-trip by 25%, the situation near by 50% and the far away option by 25% the model simulates an average trip distance for each refuelling action. Average cruising ranges per car category allow the calculation of total yearly kilometre that have to be driven for refuelling a car with a certain technology. Finally the model simulates the fuel procurement costs by multiplying the yearly km with fixed and variable costs per vehicle-km and adding the opportunity costs generated via value of time and required time for the procurement trips extracted from the ASTRA transport module (TRA).

The following equation describes the simulation of perceived total car costs per vehicle-km that are composed of variable/fuel, purchase, taxation, maintenance and fuel procurement costs. Furthermore the model considers the importance of purchase cost level for the calculation of perceived costs by setting a car category and country- specific weighting factor.

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[8] European Natural Gas Vehicle Association (ENGVA): http://engva.org

[9] http://www.gas-tankstellen.de, http://www.erdgasfahrzeug-forum.de, http://www.h2stations.org

$$C_{CC,EC} = \alpha_{CC,EC} * pC_{CC,EC} + taxC_{CC,EC} + mC_{EC} + vC_{CC,EC} + procC_{CC,EC} \quad \textbf{(eq. 4)}$$

where:

	$C_{CC,EC}$	=perceived car cost per vehicle-km per car category CC and country EC
	$pC_{CC,EC}$	=purchase cost per vehicle-km per car category CC and country EC
	$taxC_{CC,EC}$	=taxation/registration cost per vehicle-km per car category CC and country EC
	mC_{EC}	= maintenance cost per vehicle-km per country EC
	$vC_{CC,EC}$	= variable/fuel cost per vehicle-km per car category CC and country EC
	$procC_{CC,EC}$	= fuel procurement cost per vehicle-km per car category CC and country EC
	$\alpha_{CC,EC}$	=weighting factor representing the significance of purchase costs
	CC	=eleven car categories/technologies
	EC	=EU27 plus Norway and Switzerland

Finally the logit function simulates the probability of cars purchased for each of the eleven technologies based on the simulated perceived car costs. Figure 37 gives an overview on the implemented approach for simulating the share of each technology on total cars registered. In the process of calibration an optimal set of parameters could be identified for the weighting factor α, logit parameter λ and the logit const LC. IWW calibrated all parameters with the Vensim™ internal optimisation tool. Time series data for car registration per country disaggregated into car categories was taken from EUROSTAT online database[10]. Several lacking datasets, especially for alternative fuel car registrations, required further data sources like data from ACEA[11] and further data sources.

10 EUROSTAT online database: http://epp.eurostat.cec.eu.int

11 European Automobile Manufacturers Association (ACEA): http://www.acea.be

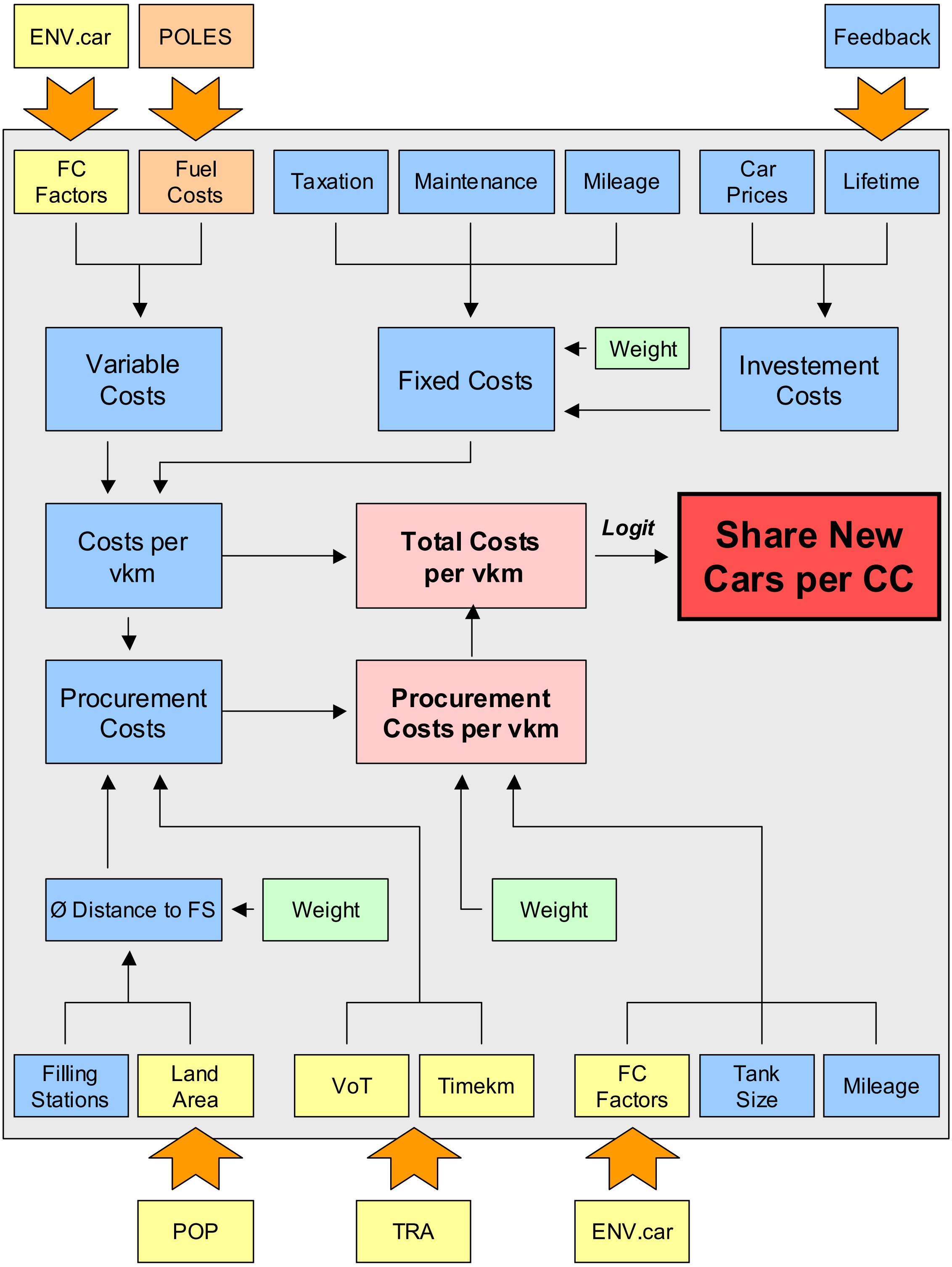

Figure 37: ASTRA car purchase model

After simulating the share of new cars per car category with the new car purchase model this share is multiplied with the total number of new car registered per country. Figure 38 demonstrates the implemented feedback loop in the car fleet model. Starting with an initial share of cars per car category, emission standard, country and age for each simulation period the new purchased cars are added while all scrapped cars in the different age cohorts are subtracted by the model. The number of scrapped cars is one of the drivers of total new registered cars per year as the model assumes that a certain share of all scrapped cars are replaced by new ones. Furthermore new registrations per year are assumed to be dependent on the development of variable costs for operating a car, population, population density, average car prices, the level of motorisation and the average income per adult. Population density as a representative for urbanisation, car price, fuel prices and the level of motorisation dampen new registrations while income per adult and population increase new registrations.

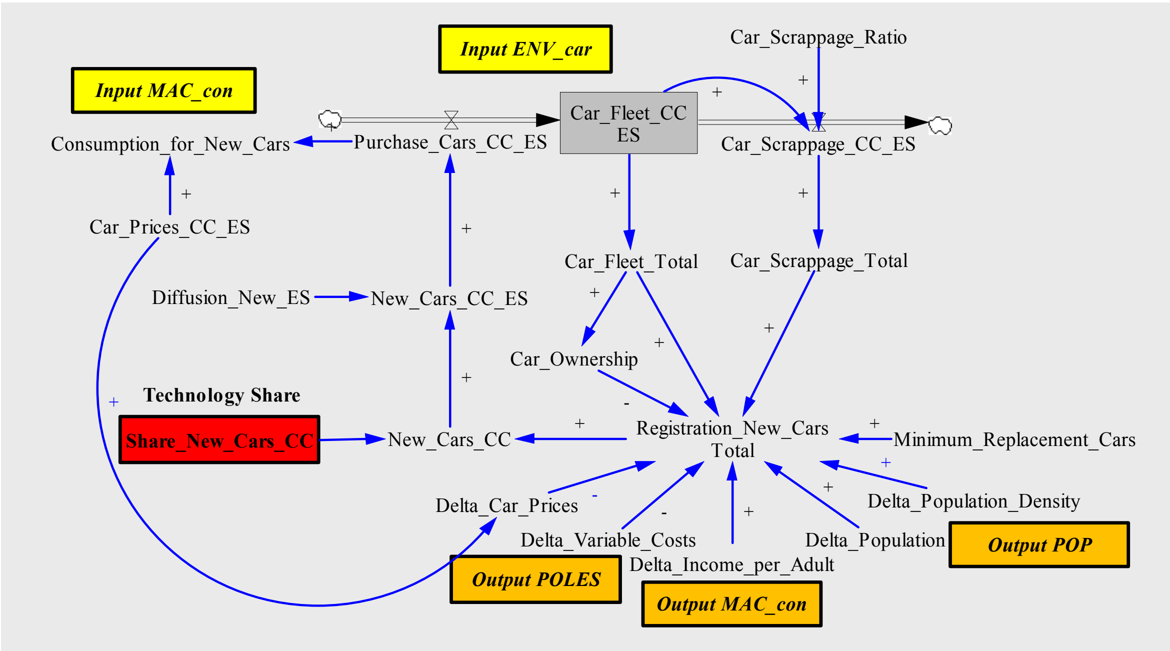

Figure 38: ASTRA car fleet model

Figure 39 illustrates a representative result and highlights the dynamic modelling of emission standards in the car fleet model. The figure demonstrates the development of diesel car stock per emission category in Germany from 1990 to 2050. The total number of diesel cars with cubic capacities less than 2.0 litre is increasing significantly until the year 2035. All other curves represent the life-cycle dynamics of emission standards until the projected Euro7 category. New purchased cars after the year 2020 fulfil per definition the Euro7 standard. Caused by the small intervals between the introduction of new emission standards in Europe the life-cycle curves are characterized by strong growth in the first years and a continuous decrease when the new standards enter the market.

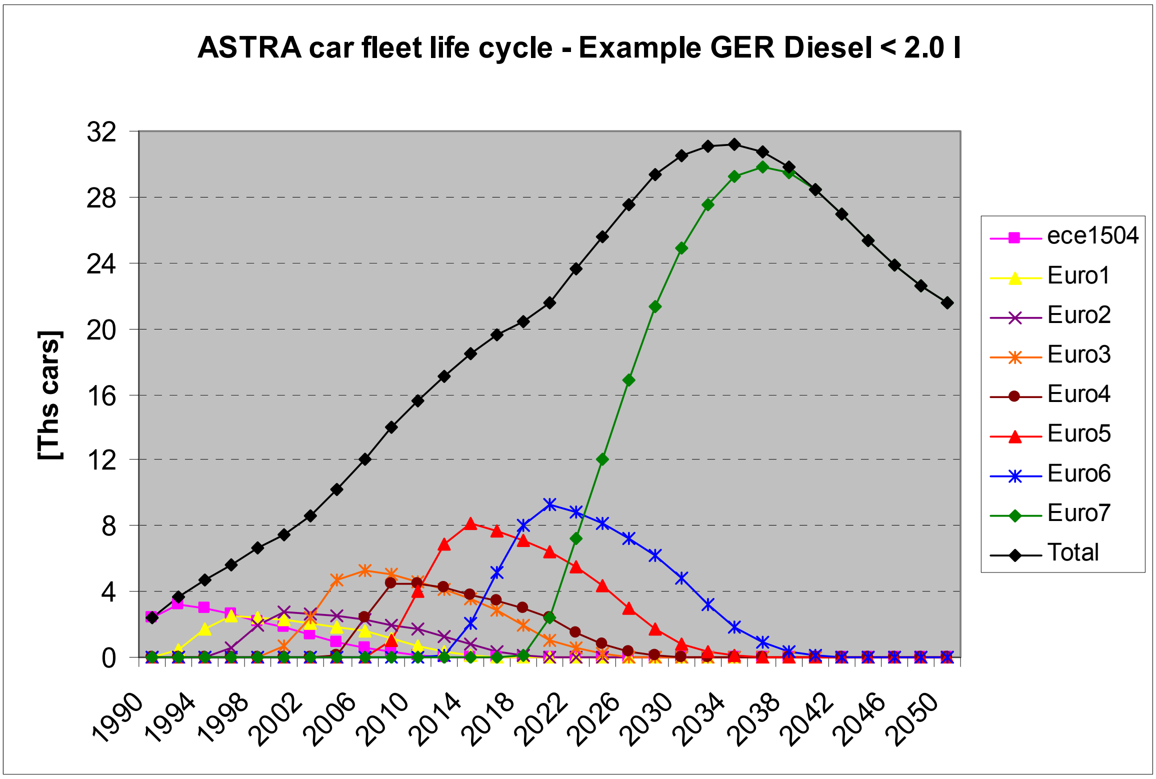

Figure 39: Example for car life cycle modelling in ASTRA VFT module

Finally, the model disaggregates the new cars into car categories respective technologies via the share generated in the car purchase model. Based on pre-defined diffusion years for all modelled emission categories the number of new cars per car category and country are assigned to the respective emission standards. In the ASTRA model the following diffusion years respective periods are implemented: Table 25 shows all emission standards and their assumed diffusion time respective period. In contrast to the previous version of the ASTRA vehicle fleet model the new version includes Euro 6 and Euro 7 emission standards. According to the European Parliament (T6-0561/2006) 2014 was proposed as year of introduction for Euro 6. Based on the average interval between the introduction of two emission categories, IWW decided to diffuse Euro 7 standard cars in the year 2020. The new emission standards Euro 6 and Euro 7 were integrated as well in the bus, light duty and heavy duty vehicle models with the same chronological schedule as in the car fleet model.

Table 25: Diffusion of emission standards in ASTRA

Emission Standard	Diffusion Year/Period
ece1503	before 1990
ece1504	before 1990
Euro 1	1991 until 1992
Euro 2	1994 until 1996
Euro 3	1998 until 2000
Euro 4	2004 until 2005
Euro 5	2007 until 2008
Euro 6	2012 until 2014
Euro 7	2018 until 2020

Source: ASTRA (2007)

Similar to the car purchase model the car fleet model is calibrated based on EUROSTAT car fleet and aggregated new registration data. The calibration tool in Vensim™ optimises weighting factors for all mentioned drivers of new car registration plus the vehicle-age-specific scrapping factors. According to observed historical correlations and results of the optimisation the demographic development, changes in income per adult and variable cost changes prove to be the most important drivers of motorisation.

4.1.3.8 Environmental Module Improvements

The main objective of the ASTRA environmental module (ENV) is the computation of transport related emissions, fuel consumption and accidents. The significant improvements implemented in the other modules of ASTRA for the TRIAS project, especially the expansion of the vehicle fleet module with new alternative car technologies required an update of the previous ENV module. Furthermore the module had to be revised in order to take into account the new emission standards Euro 6 and Euro 7.

The ASTRA ENV module generates CO_2, CO, NO_x, VOC and soot particles emissions for all transport modes. In order to represent the whole life-cycle of transport related emissions, hot emissions, cold start emissions, vehicle production emissions and fuel production emissions are considered. Hot and cold start emissions are simulated on the basis of emission factors per car category, emission standard and, only for hot emissions, different traffic situations taken from HBEFA[12]. The model is able to generate hot emissions for each pollutant via mode-specific transport performance in vehicle-kilometres-travelled provided by the TRA module. The number of trips per mode acts as input for the computation of cold start emissions.

As POLES requires according to the TRIAS interface approach fuel demand in terms of fuel consumption per type of fuel all alternative fuel categories were implemented in the ENV car module. Additionally the averaged passenger car fuel consumption necessary for calculating the variable cost development in the modal split was updated and extended by the new fuel categories.

4.1.4 Implementation of Baseline and Reference Scenario

This section explains major assumptions that have been made in ASTRA to implement the baseline scenario. To make data consistent between the different models or when data comes from different statistics an agreed set of deflators to convert into constant EURO prices for the year 1995 are applied (see Table 26).

Table 26: Applied deflators to harmonize data between models

	1990	1991	1992	1993	1994	1995	1996	1997	1998
GDP-Deflator Euro 1995	1.1993	1.1438	1.0962	1.0578	1.0289	1	0.9791	0.9640	0.9477

12 Handbook of Emission Factors, HBEFA version 2.1 (2004)

	1999	2000	2001	2002	2003	2004	2005	2006	2007
GDP-Deflator Euro 1995	0.9372	0.9252	0.9026	0.8795	0.8598	0.8418	0.8261	0.8101	0.7928

Source: EUROSTAT online database

4.1.4.1 MAC Assumptions

For the exogenous parameters of the macroeconomics module the same assumptions as in previous studies are applied (e.g. Schade 2005) and are extended from 2025 until 2050 with their value of 2025. For a number of exogenous trends this constitutes an optimistic picture. E.g. the annual growth rates of labour productivity are taken as constant after the year 2025. An alternative and also reasonable assumption would have been to assume decreasing growth rates because both potentials for productivity increases diminish over time and the assumption of constant absolute productivity increase is applied in other projects, which implies to use continuously decreasing annual growth rates.

4.1.4.2 FOT Assumptions

A major assumption affecting the trade model of ASTRA concerns the GDP development in regions of countries outside Europe i.e. outside the EU29 countries considered in ASTRA. Assumptions for these trends were taken from the ADAM baseline (EU 6FP project). However, since in past projects a clear cyclical behaviour of these trends was observed the ADAM trends were overlayed with a cyclical behaviour to shape the final exogenous GDP growth trends to be applied in ASTRA. These trends are shown in Figure 40.

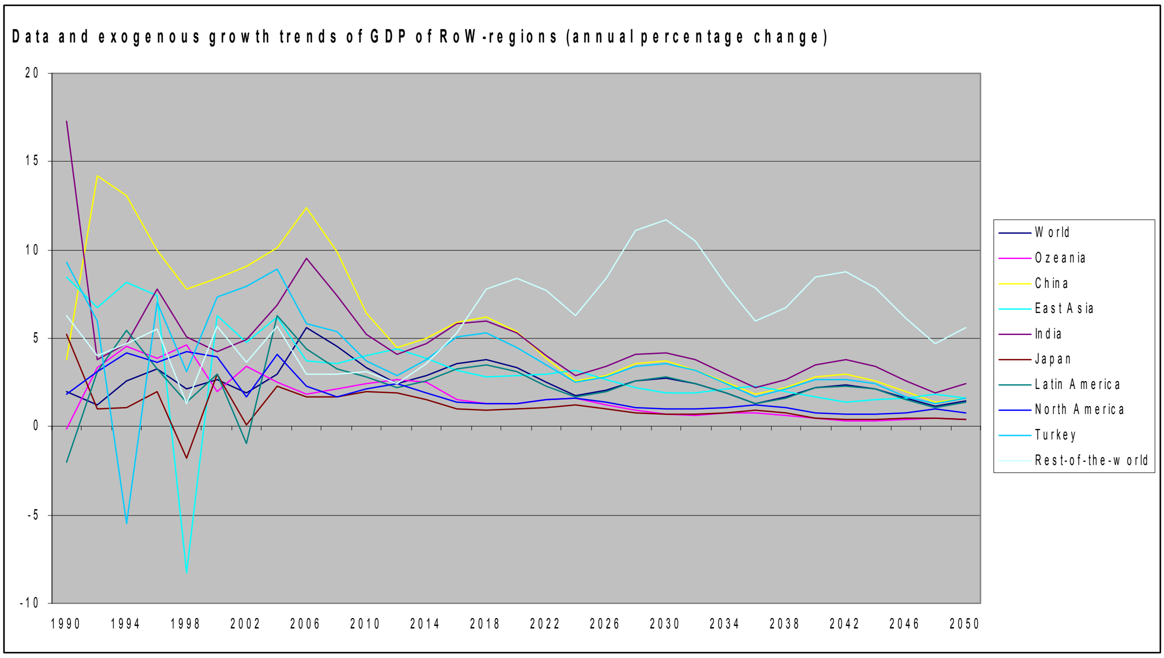

Figure 40: Exogenous GDP growth trends of rest-of-the-world regions in ASTRA

4.1.4.3 TRA Assumptions

As far as the transport module is concerned, the implementation of the reference and baseline scenarios consists in the definition of the how travel costs develop over the future time horizon. The TRIAS baseline and reference scenarios do not differ to each other for assumptions concerning the transport side. Therefore for the TRA module, the two scenarios are identical.

Part of the cost items used in the TRA module develop endogenously as effect of either other components of the ASTRA model (e.g. the vehicle fleet) or of the interaction with the POLES model (e.g. the pure fuel prices). In such a cases, the use of exogenous trends has been avoided and the endogenous trends are taken. For the other cost items, the assumptions made in the ASSESS project (Mid Term assessment of the European Commission white paper, see De Ceuster *et. al.*, 2005) have been considered, namely the assumption of the partial B scenario (see Martens *et. al.*, 2005).

In brief, in ASSESS for the passenger modes, the effect of future policies implementation is supposed to keep user costs constant, with exclusion of train where a slight reduction is expected. For the freight modes, the policy measures considered in the ASSESS scenario are expected to give rise to, sometimes significant, changes of transport costs. However, one the one side the ASSESS measures are still largely unapplied and on the other side they concern taxation and pricing measures which could be at least partially overlapping with the carbon tax envisaged in the TRIAS scenarios. Therefore, as the TRIAS scenarios are not concerned with the level of application of transport policy and its effects, it has been decided to avoid the implementation of cost changes which, on the one side, could alter the relative competitiveness of transport modes even if this does not seem the current baseline trend and, on the other side could make confusion when the TRIAS scenarios are implemented.

One exogenous assumptions included in the TRA freight model is that the road haulage sector become more efficient as the amount of transported goods increases. When there are more trades between countries, more goods to be locally distributed, etc. it is easier to optimise the vehicle loads, avoiding empty trips, etc. Furthermore, the growth of fuel price prompts carriers to improve efficiency. This is translated in the model by means of increasing load factors. The impact of higher load factors is to lower costs per ton-km of road freight.

The following table summarizes the trend of total transport cost per km by mode (passenger and freight) under the assumption considered for the Baseline scenario from 2000 to 2050. The changes in the table are final output of the models in terms of weighted average, so include the evolution of the matrix, of the load factors, etc. This is the reason why even modes for which no specific exogenous changes have been implemented change their costs and, at the same time, the effect on modes where inputs have been implemented is not the mere reproduction of the input.

It can be noticed that car cost per pass-km is supposed to rise as effect of fuel price. Instead road freight cost per ton-km is supposed to diminish because the increment of fuel price (which is just a share of total road freight cost) is more than off-set by the higher load factors.

Table 27: Trend of total transport cost by mode (passenger and freight)

Averaged cost		2000	2010	2020	2030	2040	2050
Passenger averaged cost per pkm							
EU15	Car	100	140	122	112	123	142
	Bus	100	102	101	100	99	100
	Train	100	100	100	101	101	101
	Air	100	107	104	102	106	114
EU12	Car	100	102	93	93	103	114
	Bus	100	100	101	101	102	102
	Train	100	99	97	95	94	92
	Air	100	111	106	104	107	113
Freight averaged cost per tkm							
EU15	Road	100	101	98	95	95	95
	Rail	100	106	109	110	111	113
	Ship	100	104	104	105	106	107
NMS	Road	100	89	83	80	81	82
	Rail	100	104	103	102	101	100
	Ship	100	100	103	107	113	117

The following graphs summarise the base trend of the passenger and freight traffic in the baseline scenario. For a more detailed analysis see section 3. The trend of personal mobility shows an increment at different speed when EU15 and more recent EU Member States are considered. The latter are forecasted to grow faster in the near future as impact of higher incomes and motorisation rates. However, the expected decreasing population in the Eastern Europe countries partially offsets these determinants resulting in a diminished growth rates and finally also in a reduced mobility in absolute terms. The difference between the two groups of countries is more significant looking at the mobility of goods, which in the Eastern Europe countries is expected to increase more significantly due to the higher economic development rates.

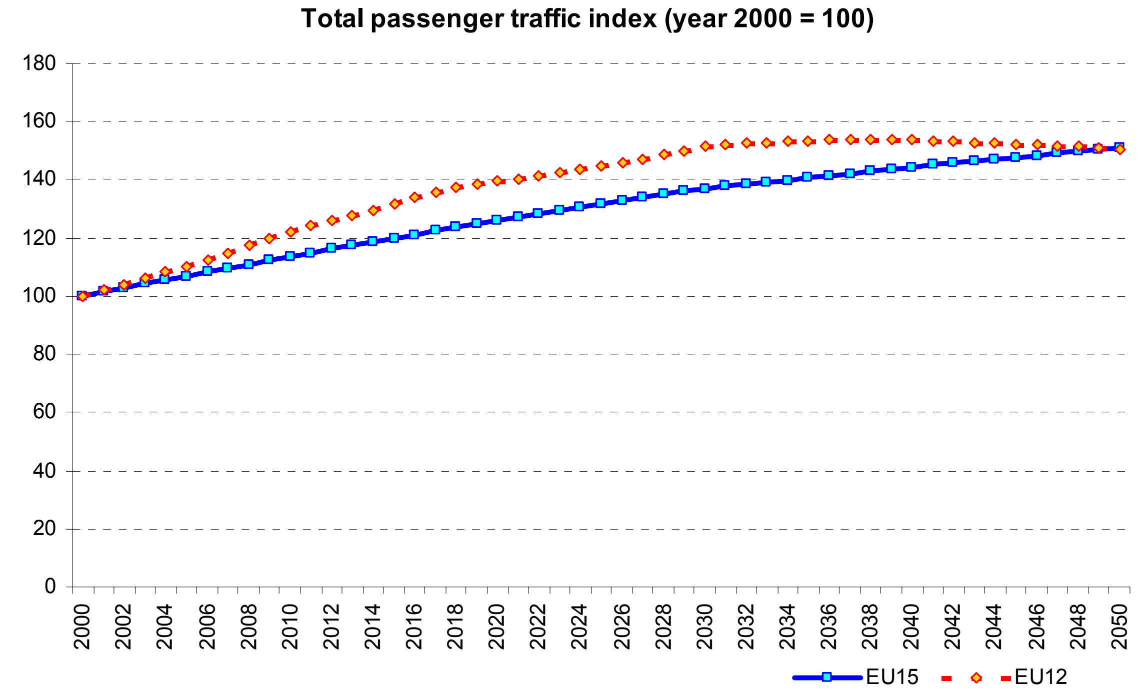

Figure 41: Baseline trend of total pkm

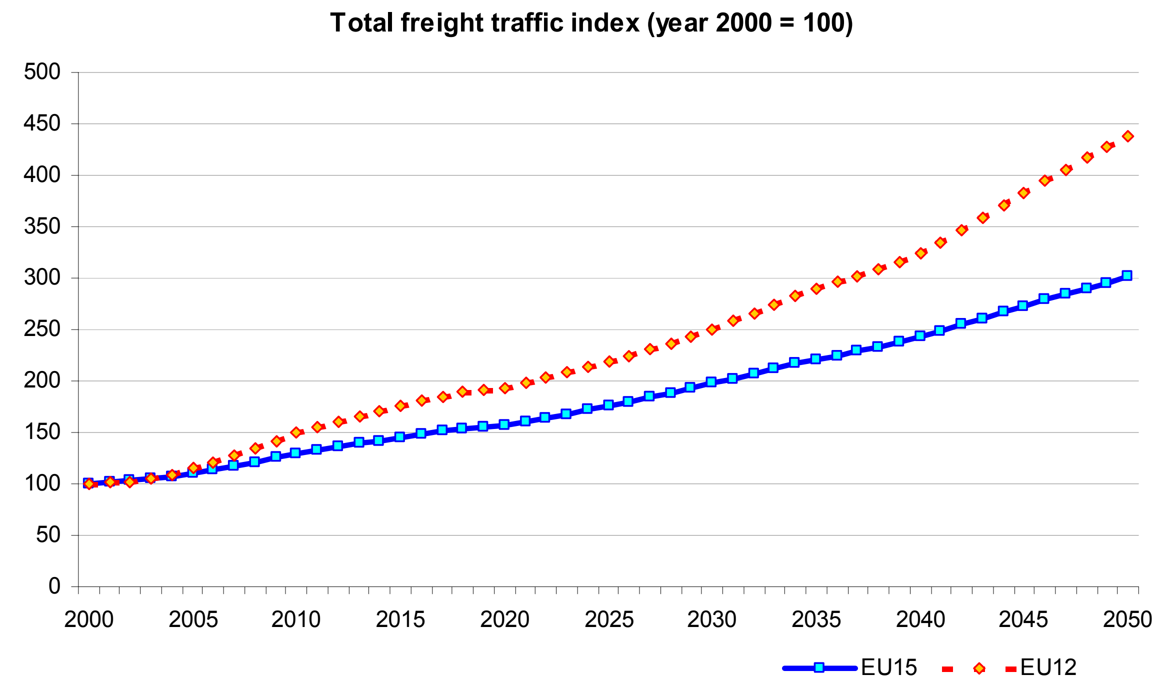

Figure 42: Baseline trend of total tkm

4.1.4.4 REM Assumptions

The REM module uses endogenous input from other model components (population, motorization rate, GDP, intra-EU trade, etc.) Therefore, there is no need of specific assumptions to implement the scenarios.

4.1.4.5 INF Assumptions

No specific assumptions are required in the Infrastructure module to implement the baseline. As far as travel times are derived from the VACLAV model, such a model includes in the future network the new infrastructures assumed in the baseline scenario.

4.1.4.6 VFT Assumptions

Two categories of assumptions are implemented for the TRIAS reference and baseline scenario in the vehicle fleet passenger car module: assumptions on prospective cost development and general assumptions on penetration probability of alternative technologies.

Regarding the costs car-ownership respective car registration taxation is the one driver of the car purchase model that is influenced by the assumptions. Taxation in the TRIAS reference and baseline is assumed to stay on the last available country-specific level. Taxation rates and fees are taken for each country for historical period from 1990 to 2006. The second cost category that is impacted by the TRIAS assumptions is the development of car prices for each of the modelled eleven car categories. Basic prices are taken from the year 1995 for the conventional gasoline and diesel cars and from the year 2005 for alternative technologies. Table 28 displays the assumed car price development for each technology. Bioethanol and hydrogen car price assumptions were taken from the hydrogen and biofuels database developed for TRIAS D1.

Table 28: Assumed car price development per technology

Car Technology	Car price development		
	2020	2030	2050
Conventional	25%	38%	44%
CNG	13%	17%	20%
Hybrid	13%	17%	20%
Electric	13%	17%	20%
Bioethanol	3%	0%	-3%
Hydrogen	0%	-13%	-26%

The third cost type that is estimated in its development is the so-called fuel procurement costs. Fuel procurement costs are mainly influenced by the number of filling station offering a certain fuel type. Table 29 presents the share of conventional filling stations offering hydrogen and bioethanol. This share is estimated by Fraunhofer ISI and University Karlsruhe (TH), IWW.

Table 29: Assumed filling station infrastructure development for H2 and Bioethanol

TRIAS scenario	Country-Group	2020	2030	2040	2050
All (besides BAU+REF)	H2 First Movers	0.3%	2.2%	6.7%	20%
	H2 Slow Movers	0.1%	1.1%	3.3%	10%
First Mover	H2 First Movers	7%	18%	25%	25%
	H2 Slow Movers	3%	9%	14%	14%
Carbon Tax + Subsidies	H2 First Movers	0.3%	2.8%	8.3%	25%
	H2 Slow Movers	0.1%	1.7%	5%	15%
All (besides REF)	Sweden	40%	50%	50%	50%
	BIO First Movers	28%	35%	35%	35%
	BIO Slow Movers	18%	25%	25%	25%
Carbon Tax + Subsidies	Sweden	50%	60%	60%	60%
	BIO First Movers	35%	40%	40%	40%
	BIO Slow Movers	25%	30%	30%	30%

Finally the TRIAS partners decided to exclude certain technologies in the reference and baseline scenario. Projects on behalf of the European Commission like HyWays[13] shaped the experience that successful market penetration depends strongly on mechanisms that can provide incentives to car buyers purchasing a hydrogen driven car. Hence, hydrogen cars are excluded by definition in the TRIAS baseline scenario, which should reflect a prospective business-as-usual behaviour of systems in EU27. The diffusion of cars driven by bioethanol in the EU27 market has already started in the last years. Based on this fact the model allows an endogenous diffusion of bioethanol cars in the baseline scenario whereas the reference scenario does not include bioethanol and hydrogen cars.

4.1.4.7 ENV Assumptions

According to the European Parliament the proposed emission limits for new cars documented in T6-0561/2006[14] were adopted for the CO, NO_x, VOC and soot particles hot emission factors for conventional cars and light duty vehicles for Euro 5 and Euro 6 in the baseline and reference scenario. According to the European Parliament CO and VOC hot emission factors remain on the same level for the emission standards Euro 4 to Euro 6. According to this technological stagnation CO and VOC hot emission factors for the future Euro 7 standard are as well assumed to stay on the same level. In contrast to these pollutants the proposed NO_x hot emission factors for Euro 5 standard decrease by -28% for diesel and –25% for gasoline cars and for Euro 6 standard even by –55% for diesel while gasoline cars emission factors remain on the Euro 5 level. Nevertheless, due to missing studies on expected prospective NO_x hot emission factors, the Euro 7 NO_x hot emission factors in TRIAS are assumed to remain on the Euro 6 level in the baseline and reference scenario.

The only pollutant that is not included in the proposal of emission limits is CO_2. According to the recent EU directive focussing the reduction of average CO_2 emission factors for the vehicle fleets of each automotive company a reduction of -15% CO_2 from Euro 5 to Euro 6 and –5% from Euro 6 to Euro 7 is implemented for conventional cars in the ENV module for the baseline and reference scenario.

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13 http://www.hyways.de/

14 http://www.dieselnet.com/standards/eu/ld.php

CNG cars hot emission factors implemented in the reference and baseline scenario are based on OEM information from Opel and other OEMs offering CNG technology cars. According to the automotive companies CO_2 hot emissions can be reduced on average by –25% up to –30% compared with average conventional gasoline cars. The improvement ranges for CO hot emissions differ between –50% up to –90% reduction for CNG, while 85% up to 90% of NO_x hot emissions can be saved by CNG cars compared with average gasoline cars. VOC and soot particle hot emissions can be reduced to a minimum such that these hot emissions are assumed to be zero for CNG cars. Regarding the stated reduction ranges compared with average gasoline cars, IWW estimated the CNG CO_2, NO_x and CO hot emission factors by taking the average reduction rate and comparison with the emission factors of the gasoline car category that has the highest share in EU27+2 car fleets: GPC2, gasoline cars between 1.4 and 2.0 litre cubic capacity.

Similar to CNG emission factors LPG hot emission factors could be derived from OEM information for the baseline and reference scenario. Compared with an average gasoline car LPG cars emit on average about –15% less CO_2, -80% NO_x, -80% CO and –60% VOC. Comparable to CNG cars soot particle emissions could be minimised for LPG cars such that zero emissions are assumed. Hybrid car hot emission factors could be calculated based on OEM information for Toyota Prius, Honda Civic and Lexus. Bioethanol car hot emission factors were taken from Volvo company information on flexifuel cars. Finally, the model assumes hot emission factors for all pollutants for fuel cell respective direct hydrogen combustion cars and electric cars to be zero. Emissions emerging in the fuel production process are considered in the category fuel production emissions FPE. Country-specific average power plant emissions are considered for electric current emissions.

Table 30: Assumptions on emission reductions after Euro 7 for baseline scenario

Pollutant	Emissions	Mode	Fuel Type	2030	2040	2050	Reduction based on Year	Reduction based on Source
CO	warm	Bus	Diesel	-1%	-3%	-5%	2025	Euro 7
CO	warm	Car	All	-1%	-3%	-5%	2025	Euro 7
CO	warm	HDV	Diesel	-2%	-5%	-8%	2025	Euro 7
CO	warm	LDV	All	-1%	-3%	-5%	2025	Euro 7
CO	fuel production	All	Conventional	-10%	-18%	-24%	1997	MEET D20
CO2	warm	Bus	Diesel	-3%	-10%	-15%	2025	Euro 7
CO2	warm	Car	Gasoline	-5%	-15%	-25%	2025	Euro 7
CO2	warm	Car	Diesel	-5%	-10%	-15%	2025	Euro 7
CO2	warm	Car	Alternative	-5%	-10%	-15%	2025	Euro 7
CO2	warm	HDV	Diesel	-5%	-10%	-15%	2025	Euro 7
CO2	warm	LDV	Gasoline	-10%	-20%	-30%	2025	Euro 7
CO2	warm	LDV	Diesel	-8%	-15%	-20%	2025	Euro 7
CO2	fuel production	All	All	-15%	-20%	-25%	1997	MEET D20
NOx	warm	Bus	Diesel	-10%	-20%	-30%	2025	Euro 7
NOx	warm	Car	All	-10%	-25%	-40%	2025	Euro 7
NOx	warm	HDV	Diesel	-10%	-20%	-30%	2025	Euro 7
NOx	warm	LDV	All	-5%	-10%	-15%	2025	Euro 7
NOx	fuel production	All	All	-15%	-20%	-25%	1997	MEET D20
PM	warm	Bus	Diesel	-10%	-20%	-30%	2025	Euro 7
PM	warm	Car	Diesel	-5%	-15%	-25%	2025	Euro 7
PM	warm	HDV	Diesel	-10%	-20%	-30%	2025	Euro 7
PM	warm	LDV	Diesel	-5%	-10%	-15%	2025	Euro 7
VOC	warm	Bus	Diesel	-1%	-3%	-5%	2025	Euro 7
VOC	warm	Car	All	-1%	-3%	-5%	2025	Euro 7
VOC	warm	HDV	Diesel	-2%	-5%	-8%	2025	Euro 7
VOC	warm	LDV	All	0%	0%	0%	2025	Euro 7
VOC	fuel production	All	Conventional	-10%	-18%	-24%	1997	MEET D20

Source: ASTRA (2007)

Cold start emission factors for conventional cars were taken from handbook of emission factors (HBEFA, version 2.1). Emission factors projected for the year 2015 were implemented as Euro 6 values, 2020 projections as Euro 7 projections.

Table 30 highlights the assumptions on emission reductions for all vehicles registered after Euro 7. Furthermore fuel production emission reductions compared with the values generated in the MEET project are pictures in the following table for the baseline scenario.

4.1.5 Modularisation of ASTRA

In order to further extend the functionality of the ASTRA model by a modelling team that is spread across Europe a split into several independent modules was necessary. The necessity of this task has been discussed in preceding projects. The growing model size became more and more difficult to administrate in an environment with decentralised model development taking place at three different locations in Europe. This was mainly because the model used to be one huge file, and if two people made changes at the same time, these changes had to be consolidated into one model in an extra, manual and time-consuming step.

The solution to this problem seemed to have been found in the tool Conductor, provided by US colleagues of the Los Alamos National Laboratory presenting the Conductor at the System Dynamics Conference 2006 in the Netherlands. At this occasion a workshop was hold and the software was distributed to promote the usage of the Conductor. Use of the Conductor would offer the possibility to separate ASTRA into various independent modules which could be developed further independently by the different modelling teams, and automatically merge these modules into one big file for running a simulation.

After a number of feasibility tests with the Conductor have been made successfully, the first step to use the Conductor was to split ASTRA into separate Vensim model files. In order to use the Conductor for merging the files, a set of rules and standards had to be applied during the splitting of ASTRA. These rules were followed, but when the merging process was tested with the full model, problems arose and the resulting model contained errors. In discussions with the developing team of the Conductor we confirmed that the errors did arise due to specific features of ASTRA that would not be compatible with the version of the Conductor tool, which we had at our disposition. Since, the Conductor is underlying quite strict IPR rules in what concerns the distribution of the software code or of updates of the Conductor, it seemed impossible to find a joint solution within the time frame of the TRIAS project.

That fact led the TRIAS project team to the conclusion that the only sensible long-term solution for continued ASTRA model development would be the development of our own merging tool in order to be able to design the tool exactly to the ASTRA requirements and to quickly react to the discovering of any errors. Therefore the TRIAS team decided to start developing our own tool, the *ASTRA-merger* written in Java. It was developed at Fraunhofer-ISI and is distributed among all project partners along with a user manual.

After having split ASTRA into a set of modules, these have been put into a so-called version-controlled repository, which can be accessed by every project partner via the internet. This serves as the central storage place for the ASTRA model, so that all partners always work with the same version of ASTRA. And due to the modularity it is possible that various people work at the same time on different modules and thereby not disturb each other or overwrite the partners' work. Since having achieved the split into modules in early 2007 any further development and improvement of ASTRA has taken place in the version controlled stand-alone modules of ASTRA.

4.1.5.1 Model Structure – Modules and Associated Partner

For splitting ASTRA a two level nomenclature was developed. The first level is constituted by 9 modules, the second level by 35 models. ASTRA was then split into 35 models each being a separate Vensim model file and each belonging to one of the 9 modules. All the variables were given a prefix according to the module in which they are defined. This prefix is also called namespace. Table 31 lists all modules and models along with the partner responsible for its transformation for the ASTRA merger.

Table 31: List of modules and their associated models in ASTRA

Sphere	Module	Model	Partner
Demography	Population (POP)	Pop.mdl	IWW
Economy	Macroeconomics (MAC)	MAC_con.mdl	ISI
		MAC_emp.mdl	ISI
		MAC_gdp.mdl	ISI
		MAC_gov.mdl	ISI
		MAC_inv.mdl	ISI
		MAC_iot.mdl	ISI
		WEM_mac.mdl	ISI
	Foreign trade (FOT)	FOT_agg.mdl	ISI
		FOT_row.mdl	ISI
		FOT_weu.mdl	ISI
		WEM_fot.mdl	ISI
Transport	Regional economics (REM)	REM.mdl	TRT
	Transport module (TRA)	TRA_fre.mdl	TRT
		TRA_pas.mdl	TRT
	Infrastructure module (TRA)	INF.mdl	TRT
	Vehicle fleet module (VFT)	VFT_bus.mdl	IWW
		VFT_car.mdl	IWW
		VFT_dev.mdl	IWW
		VFT_hdv.mdl	IWW
		VFT_ldv.mdl	IWW
Environment	Environment module (ENV)	ENV_acc.mdl	IWW
		ENV_air.mdl	IWW
		ENV_bus.mdl	IWW
		ENV_car.mdl	IWW
		ENV_dev.mdl	IWW
		ENV_hdv.mdl	IWW
		ENV_ind.mdl	IWW
		ENV_ldv.mdl	IWW
		ENV_rai.mdl	IWW
		ENV_shp.mdl	IWW
		WEM_dco.mdl	IWW
		WEM_env.mdl	IWW
		WEM_ext.mdl	IWW
		WEM_int.mdl	IWW
Other	Scenario settings	SCE.mdl.mdl	ISI
	Scenario iteration control	Overview.mdl	ISI

4.1.5.2 ASTRA Merger

The *ASTRA merger* makes use of the possibility to store Vensim models as text files. It decomposes each module to its elements and recompiles these elements into one valid model.

ASTRA merger was developed as an alternative to Conductor, since we needed the Conductor functionality, but the version provided to us was faulty, and no update could be obtained. Since we started the splitting of ASTRA under the assumption that we will use Conductor for the merging process, we used the Conductor criteria for the splitting into modules. Most of them remained as criteria also valid for use with the ASTRA merger, some dispensable ones were dropped, others remained in order to make the structure of the modules easier to analyse.

Technology

For the implementation of the ASTRA merger we choose Java 5. This decision was based on various reasons:

- Java offers a very powerful programming library for finding patterns in text, so called *Regular Expressions*. These are used for the decomposition of the individual modules into their elements.
- Java is a high level programming language. This means that the application developer does not need to take care of the implementation of low-level tasks like reading from and writing to files.
- Java is optimised for the development of stable code. Performance was no criteria for this task. This judgement was justified by the result. The complete ASTRA model is compiled by the current version of the merger in less than half a minute.
- The responsible developer is experienced in the development of Java applications. He made an assessment of other programming languages but judged Java as the best available option and suggested this to the TRIAS project team.

Rules for modules

Modules have to follow these rules in order for the ASTRA merger to compile a valid Vensim model out of the stand-alone modules, which are also running Vensim models:

- Hold a group of variables called *in*, the so-called interface variables. All variables in this group are data-variables stored in a *vdf* data file. These are all the variables linking the module to other modules receiving data from variables defined in other modules. This enables the module to be run as a stand-alone model. Variables in this group have to be defined using the same subscript ranges as used in the definition of that variable. E.g., if a subscripted variable is defined with two equations, using EU15 and EU12 subranges, then the '.in' group definition must use exactly this combination and not a single definition using a combined subscript range such as EU27.
- Underscores (or underbars as called by Vensim in dialog Tools/Options/Settings – Show underbars) have to be activated so variable names do not contain white spaces.

- No space between variable name and subscript range, i.e. VFT_Car_Fleet_per_EU_country[EUCoun]. This feature is provided by Vensim with the Reform-and-Clean option.
- No colon: in variable names.
- No dot . in variable names.
- No <-> sequence in variable names.
- Formatting of *in* variables: grey and italic and defined as shadow variable to avoid unreadable views after the merging process.

A number of special groups on the Vensim equation level is defined:

- Control,
- Global,
- Subscripts,
- Data,
- Venapp, and
- Policy.

These groups are merged and double defined variables are taken only once. This means that we can have e.g. in the data group exactly the variables needed by the according module. If another module also uses the same variable, then in the merged module the entry appears only once.

It is possible to use the same name for groups in different modules. Vensim makes one group of these by using the "reform and clean" feature with the merged model. But if the same variable is defined more than once, the ASTRA merger does not recognize this and does not remove the surplus definition, which results in an invalid model.

Lookup variables that are used in more than one module should be put in the *Global* group. This guarantees to have the according variable only once in the merged model.

The group *This* is not needed anymore. It was required by the Conductor, but there was no need for it, nor did it appear useful.

The group *out* is used in every module to identify the variables that are used by other modules. This is needed for a better overview of the structure of the model, which helps whenever the model is to be changed.

Using the merger

The relevant files for the merger together with the program itself are stored in the repository where all ASTRA model files are stored. Using the merger simply means starting the *…Run.bat* file.

Table 32: ASTRA merger files

File	Contains
z_VensimTools-ASTRAmerger-InputModulesList.txt	The filenames of all modules, which should be merged into one model. This could also include a subset of ASTRA model files.
z_VensimTools-ASTRAmerger-Properties.txt	Configuration properties
z_VensimTools-ASTRAmerger-Run.bat	Batch file to start the ASTRA merger
z_VensimTools.jar	Java archive containing the program

4.1.5.3 Using the ASTRA merger to run only parts of ASTRA

The intention of the modularisation of ASTRA was to improve the possibility of distributed development and to speed up the calibration of the model. For these tasks, it is necessary to run the individual modules or a number of selected models as stand-alone model. By changing the Merger-Input-Modules-List any combination of models can be selected for merging a partial stand-alone model of ASTRA.

In this case, the partial model will use variables, which are defined in other model that are not part of the merged model. When run as standalone model, the merged model needs these variables as exogenous data. Therefore, for each module, an interface-variables (IV) savelist is maintained containing a list of all variables needed as exogenous input (named XX_IV.lst, with XX being the name of the according module). This savelist is used to create a subset of the result data of a run of the complete ASTRA model. Eventually, this subset serves as exogenous data for the standalone model such that the partial stand-alone model is able to reproduce the results of the full ASTRA model for its variables.

The interface-variables savelist itself contains exactly those variables, which are listed in the 'in' group of each model. And since new variables could be added or removed as the model is developed further, a WinEdt script was written which automatically compiles a list of these 'in' variables to be used as interface-variables savelist. Hence, to create a partial stand-alone model of ASTRA these steps have to be taken:

1. Update the merger modules list to select the models to be merged.
2. Run the ASTRA merger and perform reform-and-clean with the merged model.
3. Open a copy of the merged model in WinEdit and run the script to compile the interface variables savelist.
4. Use the savelist to export the interface data from an existing run of the full ASTRA model.
5. Import the interface data into the merged model and add all exogenous files including the interface datafile to the exogenous data sources in Vensim.
6. Run the merged partial model and verify if the run with the partial model fits to the run with the full model.

4.1.6 Version-Controlled Repository for ASTRA

A version controlled repository for storing the ASTRA model (i.e. the 35 model file plus all supporting files) was introduced. This is a technology used for team working in software development. We decided to use Subversion (subversion.tigris.org), an open-source software being the standard in the software developing community. This technology offers the feature to track changes on a set of files and provides a reference so everybody has the possibility to always work on the latest version of these files. It also avoids that one person accidentally overwrites the changes of a different person, as it is easily possible when files are simply stored in a network folder structure.

This is achieved by simply always storing everyone's work in the repository and by always downloading the latest version from the repository before starting to work. The advantage over a normal centralized file server is that subversion notices and informs the user if he tries to overwrite a file, which was modified in the meantime by a different user. The user can then merge the two different versions into one and make sure that the new version of the file still works. And thanks to the modularisation of ASTRA these kinds of conflicts are minimized.

Size and complexity of the ASTRA model demand a systematic approach for monitoring and managing the continuous process of improving and extending, in particular when we follow the suggested approach to split ASTRA actually into physically separated models and assemble these by the Conductor. Since we work in teams on the same model, not everybody individually by himself, we also need a way of merging the different contributions into one model. This is a common problem in Software development, and there is a standardized way to solve it: Modularisation, Version Controlling, automated compiling of the result. Modularisation will be dealt with by further separating the different parts of the model as described in section 4.1.5.1. This is essential if various people want to modify the model at the same time. Version controlling is described in the next section. And the compilation of our result, i.e. the automated generation of a complete model based on the set of modules is explained in the section on the *ASTRA merger* (chapter 4.1.5.2)

4.1.6.1 Basics on Version Controlling

This chapter is a short, casual introduction to the concepts of systematic *Version Controlling*.

The Repository

Version Controlling centralizes and standardizes the sharing of information. At its core is the *repository*, which is a central store of data. The repository stores information in the form of a *filesystem tree*—a typical hierarchy of files and directories. Any number of *clients* connects to the repository, and then read or writes to these files. By writing data, a client makes the information available to others; by reading data, the client receives information from others. Figure 43 illustrates this.

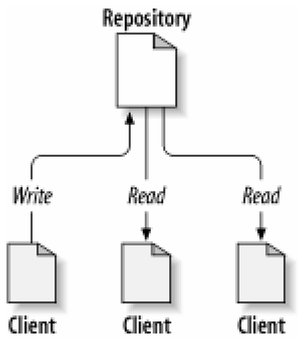


Figure 43: A typical client/server system

So far, this sounds like the definition of a typical file server. And indeed, the repository *is* a kind of file server, but it's not your usual breed. What makes it special is that *it remembers every change* ever written to it: every change to every file, and even changes to the directory tree itself, such as the addition, deletion, and rearrangement of files and directories.

When a client reads data from the repository, it normally sees only the latest version of the file system tree. But the client also has the ability to view *previous* states of the file system. For example, a client can ask historical questions like, "What did this directory contain last Wednesday?" or "Who was the last person to change this file, and what changes did he make?" These are the sorts of questions that are at the heart of any *version control system*: systems that are designed to record and track changes to data over time.

Versioning Approaches

The core mission of a version control system is to enable collaborative editing and sharing of data. But different systems use different strategies to achieve this.

The Problem of File-Sharing

All version control systems have to solve the same fundamental problem: how will the system allow users to share information, but prevent them from accidentally stepping on each other's feet? It's all too easy for users to accidentally overwrite each other's changes in the repository.

Consider the scenario shown in Figure 44. Suppose we have two co-workers, Harry and Sally. They each decide to edit the same repository file at the same time. If Harry saves his changes to the repository first, then it's possible that (a few moments later) Sally could accidentally overwrite them with her own new version of the file. While Harry's version of the file won't be lost forever (because the system remembers every change), any changes Harry made *won't* be present in Sally's newer version of the file, because she never saw Harry's changes to begin with. Harry's work is still effectively lost—or at least missing from the latest version of the file—and probably by accident. This is definitely a situation we want to avoid!

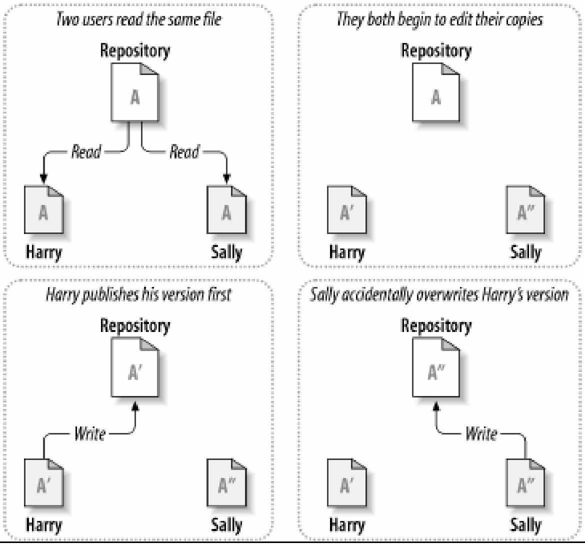


Figure 44: The problem to avoid

The Lock-Modify-Unlock Solution

In the *lock-modify-unlock* model, the repository allows only one person to change a file at a time. This exclusivity policy is managed using locks. Harry must "lock" a file before he can begin making changes to it. If Harry has locked a file, then Sally cannot also lock it, and therefore cannot make any changes to that file. All she can do is read the file, and wait for Harry to finish his changes and release his lock. After Harry unlocks the file, Sally can take her turn by locking and editing the file. Figure 45 demonstrates this simple solution.

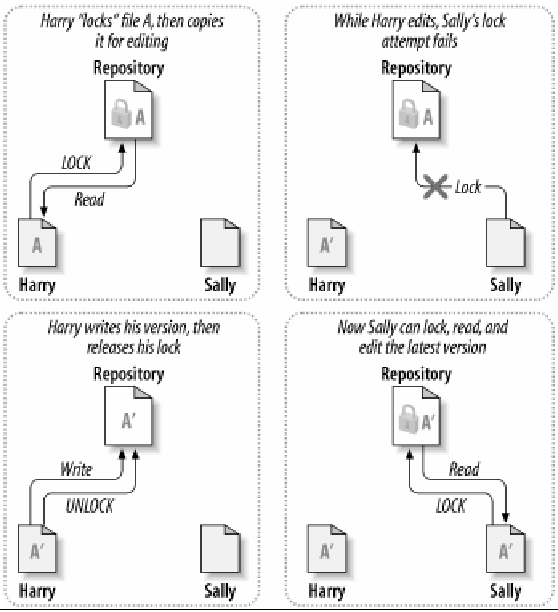


Figure 45: The Lock, Modify, Unlock *Solution*

The problem with the lock-modify-unlock model is that it's a bit restrictive, and often becomes a roadblock for users:

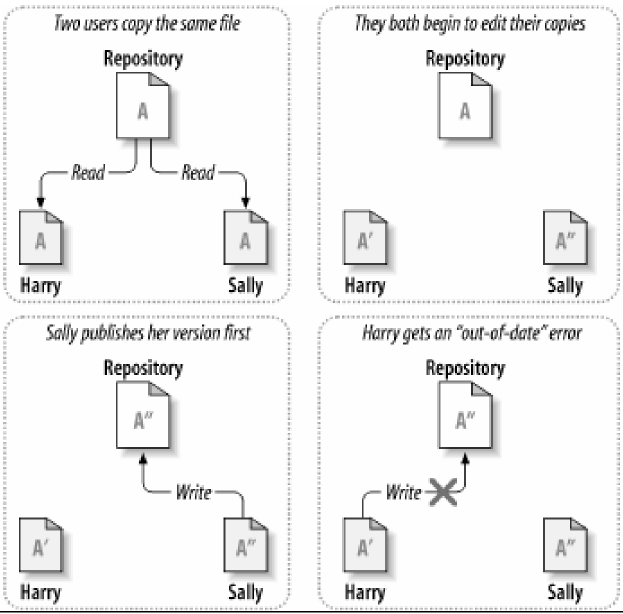
Locking may cause administrative problems. Sometimes Harry will lock a file and then forget about it. Meanwhile, because Sally is still waiting to edit the file, her hands are tied. And then Harry goes on vacation. Now Sally has to get an administrator to release Harry's lock. The situation ends up causing a lot of unnecessary delay and wasted time.

Locking may cause unnecessary serialization. What if Harry is editing the beginning of a text file, and Sally simply wants to edit the end of the same file? These changes don't overlap at all. They could easily edit the file simultaneously, and no great harm would come, assuming the changes were properly merged together. There's no need for them to take turns in this situation.

Locking may create a false sense of security. Pretend that Harry locks and edits file A, while Sally simultaneously locks and edits file B. But suppose that A and B depend on one another, and the changes made to each are semantically incompatible. Suddenly A and B don't work together anymore. The locking system was powerless to prevent the problem—yet it somehow provided a false sense of security. It's easy for Harry and Sally to imagine that by locking files, each is beginning a safe, insulated task, and thus not bother discussing their incompatible changes early on.

The Copy-Modify-Merge Solution

The *copy-modify-merge* model is an alternative to locking. In this model, each user's client contacts the project repository and creates a personal *working copy*—a local reflection of the repository's files and directories. Users then work in parallel, modifying their private copies. Finally, the private copies are merged together into a new, final version. The version control system often assists with the merging, but ultimately a human being is responsible for making it happen correctly.



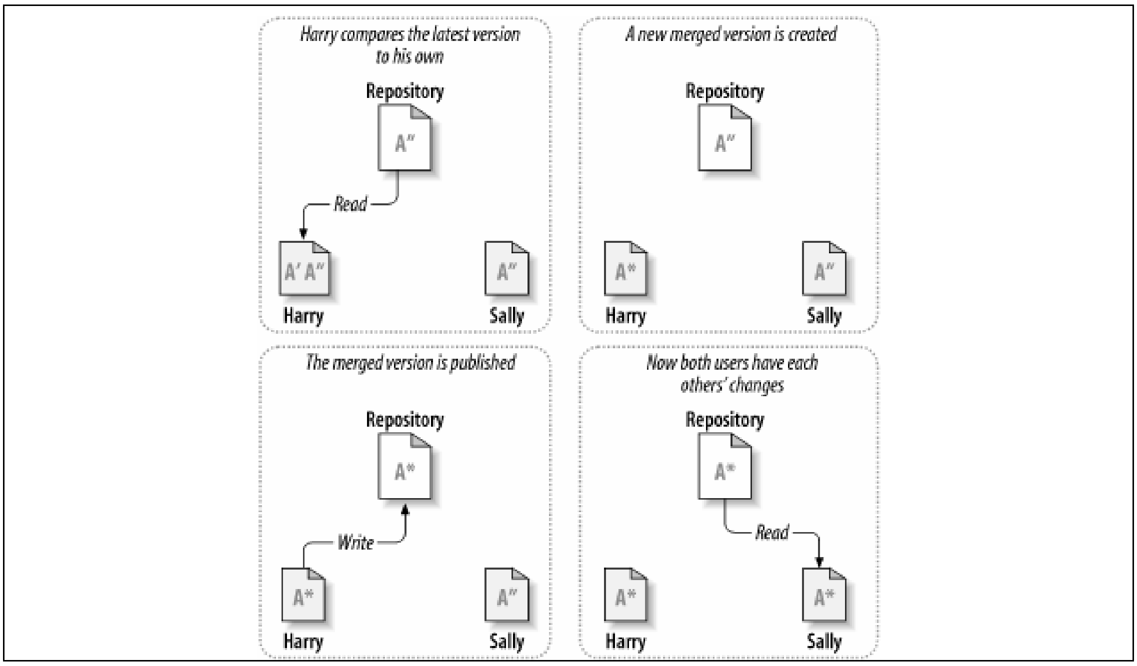


Figure 46: The Copy, Modify, Merge *Solution*

Here is an example. Say that Harry and Sally each create working copies of the same project, copied from the repository. They work concurrently, and make changes to the same file A within their copies. Sally saves her changes to the repository first. When Harry attempts to save his changes later, the repository informs him that his file A is *out-of-date*. In other words, that file A in the repository has somehow changed since he last copied it. So Harry asks his client to *merge* any new changes from the repository into his working copy of file A. Chances are that Sally's changes don't overlap with his own; so once he has both sets of changes integrated, he saves his working copy back to the repository. Figure 46 shows this process.

But what if Sally's changes *do* overlap with Harry's changes? This situation is called a *conflict*, and it's usually not much of a problem. When Harry asks his client to merge the latest repository changes into his working copy, his copy of file A is somehow flagged as being in a state of conflict: he'll be able to see both sets of conflicting changes, and manually choose between them. Note that software can't automatically resolve conflicts; only humans are capable of understanding and making the necessary intelligent choices. Once Harry has manually resolved the overlapping changes—perhaps after a discussion with Sally—he can safely save the merged file back to the repository.

The copy-modify-merge model may sound a bit chaotic, but in practice, it runs extremely smoothly. Users can work in parallel, never waiting for one another. When they work on the same files, it turns out that most of their concurrent changes don't overlap at all; conflicts are infrequent. And the amount of time it takes to resolve conflicts is far less than the time lost by a locking system.

In the end, it all comes down to one critical factor: **user communication**. When users communicate poorly, both syntactic and semantic conflicts increase. No system can force users to communicate perfectly, and no system can detect semantic conflicts. So there's no point in being lulled into a false promise that a locking system will somehow prevent conflicts; in practice, locking seems to inhibit productivity more than anything else (which we sometimes could see for the past ASTRA development, where we mostly followed the lock-modify-unlock approach by appointing someone to be the "model master" for a period during which the others could not really touch the model).

Using Subversion to Control Versions of ASTRA

One state-of-the-art Version controlling system is Subversion (subversion.tigris.org). We decided using this for various reasons:

- Stable and reliable due to a broad user base and a seven year development history as an open-source project, which started in 2000.
- Available at no cost.
- Used in many productive software development projects. Outstanding positive feedback in software developing communities.

This decision was completely justified by the experiences we made during the TRIAS project. We had no data loss and all features of the software worked as expected.

Workflow for the model developer

We exclusively used the *Copy-Modify-Merge* approach to *version controlling* due to the drawbacks of the *Lock-Modify-Unlock* approach as described above. Whenever a model developer needed exclusive access to certain or all files we agreed on timeframes when the other developers must not modify the model. This worked without problems and is completely in line with the philosophy of a version control system. It is intended to support distributed working. It does not free you from the need to communicate.

The following sections are in parts redundant to the preceding chapter. The intention is to give a more concrete description of what version controlling means to us as developers of the ASTRA model. It is written as an instruction to the user.

Getting a Working copy

To get a working copy, you *check out* files of the repository. This means the software simply creates a private copy of the files on the server for you locally on your computer.

This working copy is an ordinary directory tree on your local system, containing a collection of files. You can edit these files however you wish, and in the case of our ASTRA model files they will work at any time just as if there would be no Version Controlling Server. Your working copy is your own private work area: Subversion will never incorporate other people's changes, nor make your own changes available to others, until you explicitly tell it to do so.

Changing your Working Copy

You do your changes. You make sure that your local *working copy* actually remains a valid Vensim model.

Writing changes back

After you've made some changes to the files in your working copy and verified that they work properly, Subversion provides you with commands to “publish” your changes to the other people working with you on your project (by writing to the repository).

If other people published their own changes since you downloaded files form the server the last time, Subversion provides you with commands to merge those changes into your working directory (by reading from the repository) before you write your files into the repository.

This is the critical moment in any teamwork: bringing together the contributions of the different team members. This cannot be done by a computer. If a file that you worked on has been modified in the meantime by somebody else, Subversion reports a *Conflict* and produces a single file merged from the two available versions. But this is only a recommendation. You then have to look at the file and make sure that it is correct. Maybe you delete changes of the other person, or changes you did yourself. If both persons worked on different sections of the file, there is probably nothing to delete. Then you check that the combined version works properly, e.g. by making a "syntax check" in Vensim. If everything is fine, you write the file into the repository, you *check in* and *commit* your contribution to the collective work.

Locking

Even though we clearly prefer *copy-modify-merge*, there are situations in which *locking* is necessary. This is the case especially when changing binary files, such as an Excel file or a graphic file (e.g. jgp). Also when making a lot of changes in the ASTRA model in one step *locking* can make sense. Subversion offers the possibility to work according to the lock-modify-unlock approach by a simple extra command.

Keeping the model intact

Our most important concern is keeping the model semantically and logically correct. No software can ensure that. It is us who are responsible for that. And the only way we can achieve that is by good communication. Various people working on different parts of the model always have to agree on changes before they happen in order to maintain our model intact in every sense: semantically correct, logically correct and calibrated.

4.1.7 Additional Maintenance Tools for the Model Development

During the progression of the project, some possibilities for automation of repetitive modelling tasks by maintenance and support tools were identified. The solutions were implemented in differing ways, depending on the technical possibilities offered by certain software tools.

4.1.7.1 Variable renaming

Splitting the ASTRA model into many modules and sub-modules created the need for a new way to rename variables. Before, Vensim could handle the task because a single variable could be renamed at one location on one view and was automatically renamed in the whole model since this was contained in on single Vensim model file. But as the model was split into more than 30 (sub-) modules, renaming of a variable would mean to check every single module whether it contains the according variable and then rename every single occurrence.

This problem was solved by an additional Java application. The user only needs to provide a list of pairs of current and new variable names in an excel file and a list of the modules, in which the variables should be renamed and the tool takes care of the renaming.

4.1.7.2 Compile Model Variable Lists

We lacked a way of producing a list of all or some of the variables contained in the ASTRA model. Based on the regular expressions implemented in the text editor WinEdt 5.5 various macros were developed to compile list of variables according to various criteria. We now dispose of the possibility to compile variables lists containing:

- All variables.
- All variables together with their subscript definition.
- All variables except those contained in the *in* group.
- All variables contained in the *in* group.
- All variables except those of the type *lookup*.

4.1.7.3 Normalizing Model Files

During the continued work with the merged model files, Vensim continuously adds redundant white space and tabulator characters, making the model source code not very convenient for reading. A WinEdt 5.5 macro was developed to remove these superfluous characters.

4.2 VACLAV

4.2.1 Description of VACLAV

Passenger demand modelling – methodology

For modelling passenger transport demand the VACLAV model will be applied, which is a network-based Europe-wide forecasting model for passenger traffic (modes: rail, road, air, coach). The model structure follows the classic four-step approach of trip generation, trip distribution, modal choice and trip assignment, considering the trip purposes business, private and holiday.

The zonal system underlying the passenger transport demand modelling is NUTS 3, which results in around 1,300 traffic cells. The geographical scope of the model is the whole European continent (including Ireland and UK), as well as Turkey.

The VACLAV passenger transport model has been applied in several major European projects such as

- the STEMM project on behalf of the European Commission DG VII,
- the Forecast 2020 study on behalf of the European Commission,
- the Study on traffic forecasts on the Helsinki corridors,
- the Corridor study for the transport corridor Paris – Strasbourg – Stuttgart – München – Wien,
- the ETIS-BASE project on behalf of the European Commission, DG TREN,
- the TEN-STAC project on behalf of the European Commission, DG TREN,
- the TRANS-TOOLS project on behalf of the European Commission, DG TREN,
- the EUN-STAT project on behalf of the European Commission, DG TREN,
- the Feasibility Study on the Rail Baltica railways on behalf of the European Commission, DG Regio,
- and the TINA Turkey project, on behalf of the European Commission/ EU Delegation in Turkey.

The transport model's basic methodology is illustrated in the following sections per modelling step.

Generation and distribution

For the stage of traffic generation a methodology is applied, which for each population segment assumes specific probabilities for the generation of trips by trip purposes. The information for these assumptions stems from several household surveys.

For the distribution of these trips to destinations a gravitation approach is applied, after having defined for each traffic cell trip purpose-specific determinants for the generation and the attraction of trips, like area, population by sex and age classes, GDP per capita, Gross Value Added by economic sectors, employment, motorisation, climate, landscape and ethnical and cultural descriptors, as well as geographical data. The number of trips between two traffic cells i and j, T_{ij} , is estimated by:

$$T_{ij} = \exp(\beta_0) \cdot G_i^{\beta_1} \cdot A_j^{\beta_2} \cdot C^{\beta_3} \,, \qquad \textbf{(eq. 5)}$$

where

G_i trip generating elements in origin i

A_j trip attracting elements in destination j

C impedance between i and j

β_k model parameter

Modal split

After the computation of the generation and spatial distribution of trips the modal split is calculated. For each origin-destination pair (i, j) the modal split model estimates the probability of selecting a modal alternative m out of a set of available modes. Within VACLAV, the modal choice set comprises four means of transport:

- Passenger car,
- Rail,
- Air and
- Coach.

The mode-choice is performed simultaneously in just one step. In order to allow a more realistic modelling of individuals' modal choice decisions, a logit function enhanced by a Box-Cox transformation is used. The choice probability for mode m on an O/D relation (i, j) is calculated by following formula:

$$P(m \mid ij) = \frac{\exp(U_m)}{\sum_{m' \in \mathbf{C}(i,j)} \exp(U_{m'})} \quad , \qquad \textbf{(eq. 6)}$$

where $U_m = \beta_{m0} + \sum_k \beta_{mk} X_{mk}^{(\lambda_{mk})}$

with $x^{(\lambda)} = \begin{cases} \dfrac{(x^\lambda - 1)}{\lambda} & \lambda \neq 0, x > 0 \\ \ln x & \lambda = 0, x > 0 \end{cases}$

The explanatory variables $X_{mk}^{(\lambda_{mk})}$'s represent the transport service level between zones *i* and *j* in the following dimensions:

- total travel costs (including access /egress costs) $TTC(m \mid ij)$net travel costs (excluding access/egress costs) $NTC(m \mid ij)$

- total travel time (in-vehicle + out-of-vehicle + access/egress) $TTT(m \mid ij)$
- net travel time (excluding access /egress) $NTT(m \mid ij)$
- access / egress distance $AED(m \mid ij)$
- total frequency / number of daily connections $TFR(m \mid ij)$
- total number of transfers $TNT(m \mid ij)$
- car ownership rate of originating zone

The assignment procedure

The final step of the four-stage approach is the assignment of the traffic demand by mode to the corresponding network models. This implies the task of estimating the users' route choice within the transportation networks. For this purpose generalised users costs are calculated (derived from the utility functions in the mode choice model) for every link in the network and shortest path algorithms are applied.

Speeds on road links (and therefore their contribution to user costs) depend on the traffic load situation. This relationship is represented by specific speed-flow and cost-flow functions for each link type. Link types are formally distinguished with respect to technical standards, like the number of lanes and the terrain type (slope, bends). Beyond a characteristic load value ("capacity"), the increase of link flows persistently leads to a speed reduction and hence an increase of user costs, which is called "congestion effect". In order to take into account of the congestion effect, the assignment is applied in an iterative way. The overall traffic demand is split and assigned step by step, such that the link speeds are adjusted according to the new traffic loads after each step.

The assignment tool of the VACLAV model performs the assignment of passenger and freight transport vehicles simultaneously. The road assignment approach enables the consideration and quantification of congestion effects.

The network models used by VACLAV are based on the GISCO and UIC networks, which were subject to careful updating for the purposes of the TEN-STAC project, as well as the ETIS-BASE project. Within the EUN-STAT project the network models have been extended to the neighbouring countries of the EU, in the TINA Turkey project to Turkey.

The following maps illustrate the network models for rail and road for the year 2003.

Figure 47: VACLAV rail network model

Figure 48: VACLAV road network model

4.2.2 Extension to 2030

For the extension of VACLAV to 2030 three inputs needed to be prepared:

- The policies and costs had to be defined,
- rail and road networks had to be adapted to 2030 and
- demand matrices for passengers and freight for 2030 had to be computed.

For the policies and costs, input was taken from ASTRA and harmonized to the current inputs of the years 2000-2020.

The networks have been adapted to provide scenario information for the years 2010 and 2030. For 2030 all TEN projects are included. To create demand matrices for 2010, 2020 and 2030 growth rates for passenger and freight trips were taken from ASTRA and applied to the VACLAV base year matrix. For further information see next chapter Linkage to ASTRA.

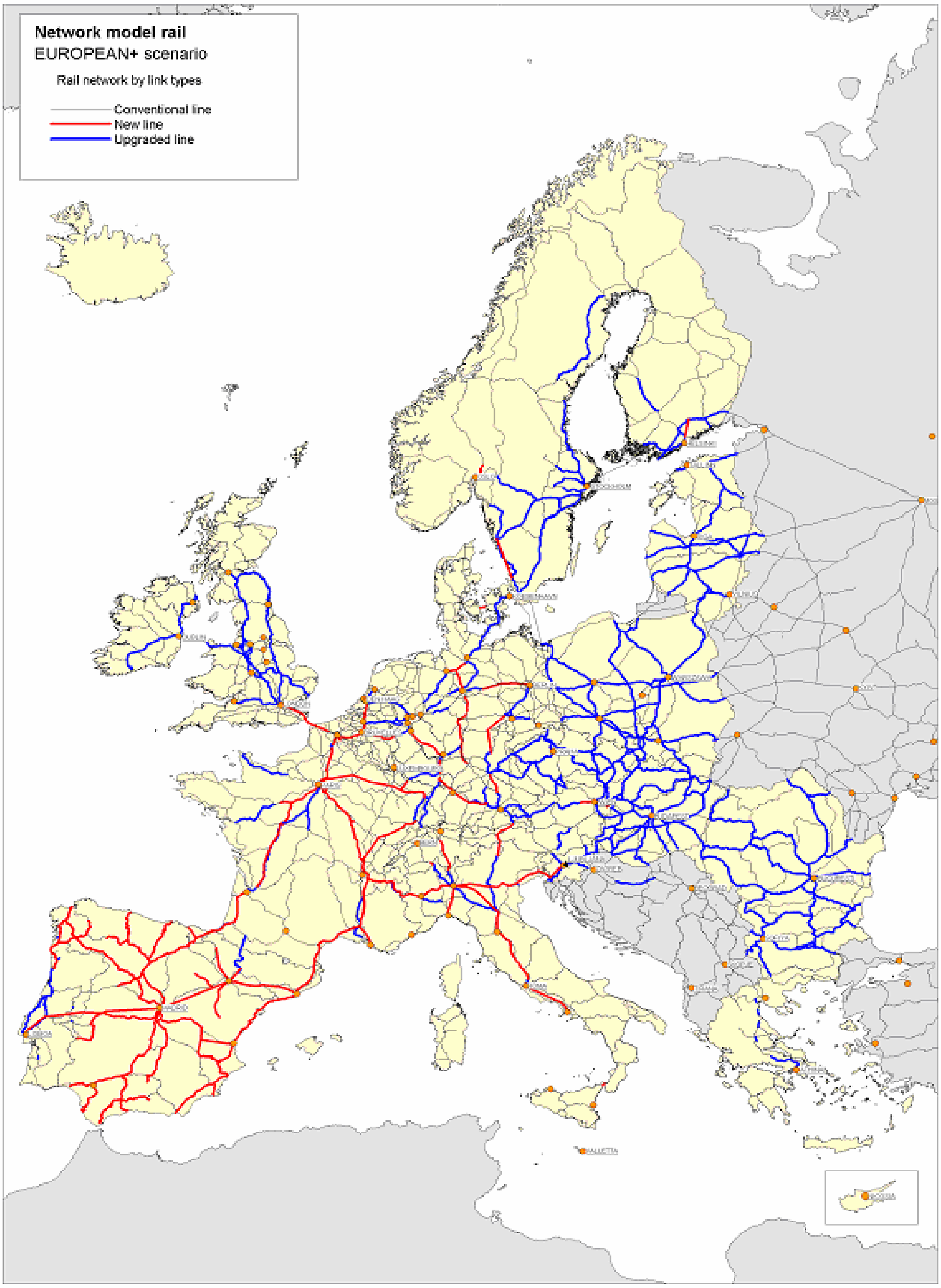


Figure 49: VACLAV rail network for 2030

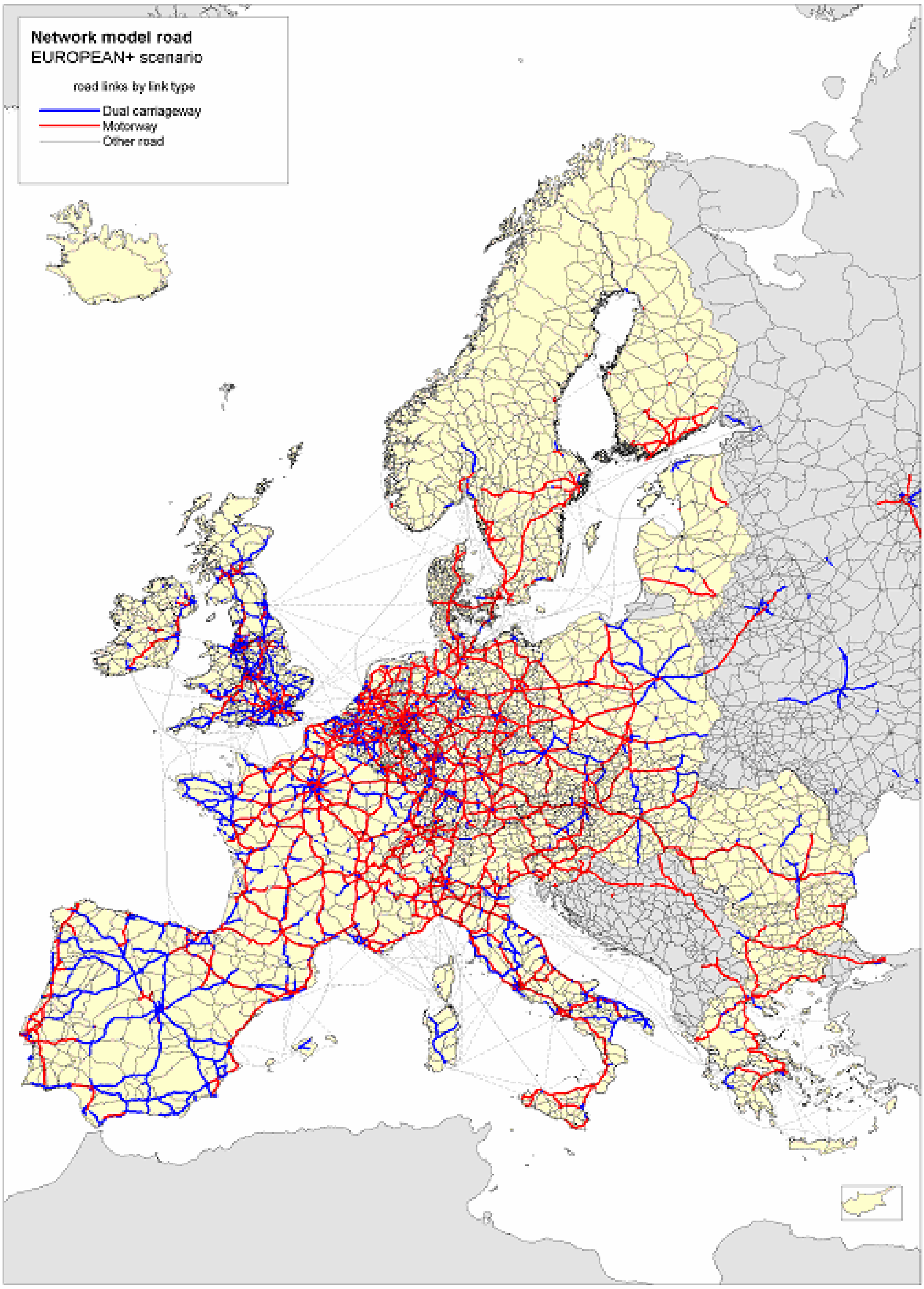


Figure 50: VACLAV road network for 2030

4.2.3 Linkage to ASTRA

The linkage between VACLAV and the ASTRA model has been established with the aim of improving the modelling of the interaction between road demand and supply and of the impact of additional transport infrastructures on travel times. Being a transport network model, VACLAV can provide detailed results about travel time and its sensitiveness to the changes of the demand/supply ratio is obviously higher than ASTRA. At the same time, ASTRA and VACLAV are two separate and independent models, therefore the linkage between the two has been conceived such as the interaction is not necessarily required to run the ASTRA model. In brief, the linkage between ASTRA and VACLAV can work in two different ways:

- "tight linkage": the two models run together, exchanging variables automatically;
- "loose linkage": ASTRA runs using exogenous inputs from VACLAV.

The difference between the two kind of linkage is in the automation of the data exchanging, but also in the bi- directional exchange which takes place in the "tight" linkage compared to the mono-directional exchange (from VACLAV to ASTRA) which occurs in the "loose" linkage.

In the "tight" linkage, the results of the assignment phase in VACLAV is firstly aggregated according to the ASTRA zoning system (i.e. by country and distance band). As VACLAV deals with "inter-urban" trips and local mobility is not really simulated, only results for the regional, medium and long distance bands within ASTRA are produced. The following main variables are built on VACLAV assignment results:

- Average speed (time per km) on long distance road network (by origin/destination pair and distance band);
- Share of demand using tolled motorways (by origin/destination pair and distance band).

The average speed is used in ASTRA to compute the generalised cost of road trips for each O/D pair. While the share of demand using tolled motorways is used in ASTRA to compute the weighted average cost of road trips for each O/D.

VACLAV runs for four time thresholds (years 2000, 2010, 2020 and 2030), for the intermediate years (as ASTRA needs data per each year) is obtained by interpolating such four values.

The ASTRA model reads these variables by means of suitable functions programmed as external libraries and included in the ASTRA structure. The ASTRA base speed by O/D is therefore updated using the trend read from the VACLAV results and the model uses the updated speed trend and the share of demand using tolled motorways in order to compute the modal split over the simulation period.

Then, the trip matrix by mode for the years 2000, 2010, 2020 and 2030 is extracted from ASTRA and split up into the detailed VACLAV zoning system using pre-defined exogenous shares. Such new matrices are used again in VACLAV for a new assignment. The whole procedure iterates until the results of the VACLAV assignment reach an equilibrium.

In the "loose" linkage the procedure is simpler as there just a transfer of information from VACLAV to ASTRA. The same two variables as above (average speed and share of demand using tolled motorways) are extracted from VACLAV plus a third variable: the share of congested long distance road network (by country). This third variable is used in the ASTRA to compute the average speed using the aggregate speed-flow function. VACLAV produces and provides the input variables only once, afterwards ASTRA is run autonomously.

The software PVM (parallel virtual machine) has been incorporated into the ASTRA external function library and VACLAV to enable the direct communication between Windows computer based ASTRA and Linux computer based VACLAV. This allows functions in the external library to start VACLAV on the Linux cluster and to directly exchange data between those two platforms.

The creation of the demand matrices for VACLAV posed more problems than expected. The disaggregation of the matrices for the VACLAV base year 2000 yielded some structural differences, which could not be resolved. The second approach, were demand growth rates from ASTRA were applied directly on the base year matrices in VACLAV, resulted in better results, but still there were regional problems which could not be matched to former assignments. Also these two approaches disabled the modal split in VACLAV since the modal split from ASTRA between functional zones was used. A third setup in which only demand growth rates before the modal split were transferred revealed the same regional problems. IWW is currently working on a methodology to overcome these problems. In order to preserve the structure of the current VACLAV demand matrices new matrices are computed from the ASTRA demand matrices using weight information from VACLAV and a furness iteration algorithm to balance the matrices.

4.3 Regio-SUSTAIN

4.3.1 Description of Regio-SUSTAIN

Regio-SUSTAIN has been developed at the Institute of Economic Policy Research (IWW). It is used as a model to assess the impacts of traffic-related emissions on human beings. Comparisons between different policies and transport scenarios can be estimated with Regio-SUSTAIN. The outcome of the model is two-fold: On the one hand side the local immissions and on the other side the number of inhabitants affected by a special substance, such as NO_x, PM or noise, can be computed.

The core of the model is a comprehensive database, programmed in PostgreSQL (an open-source SQL-database especially for use with spatial data). Inputs to the database are either available from open sources or are computed with external software belonging to IWW. General inputs are spatial data about land cover (in grids of 250m), population numbers and climate/weather conditions from national or international geographical information systems. Beside the general inputs, network related data are necessary, such as network links and traffic numbers.

Figure 51 gives an overview of all functions and interfaces realised in Regio-SUSTAIN. Interfaces are shown as arrows, whereby functions and methods are shown in the form of grey circles.

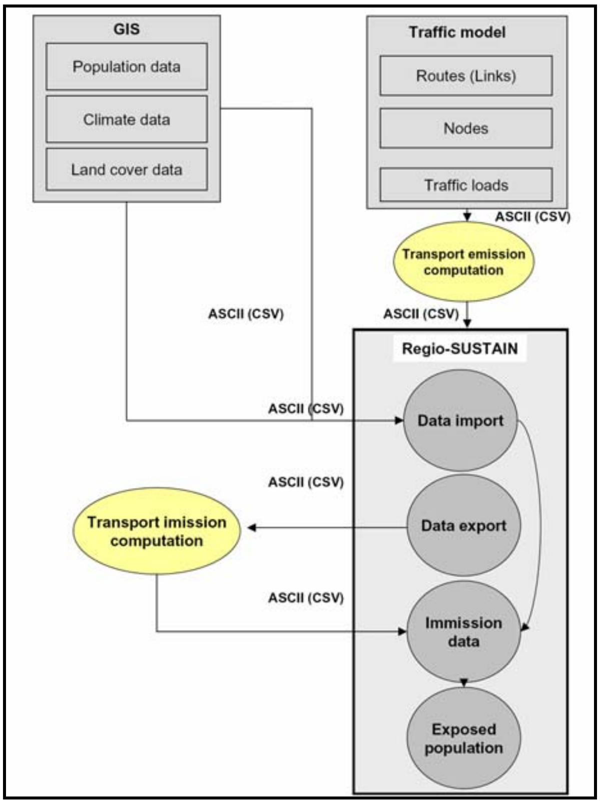


Figure 51: Overview on the original structure of the Regio-SUSTAIN database.

The Geographical Information System

The objective of Regio-SUSTAIN is to compute the immissions as well as the number of persons affected by emissions. Therefore, it is necessary to have detailed information about the population structure in each region. In Regio-SUSTAIN such data is imported by a geographical information system (GIS). With the help of grid-based land cover data sets the share of inhabitants affected can be modelled region by region.

Regio-SUSTAIN reverts to the following inputs coming from geographical information system (GIS):

- grid-based land cover data (e.g. from the Corine land cover database),
- population data (information on NUTS-III region level),
- road transport networks including loads in form of average daily traffic figures for vehicles (subdivided into categories for passenger cars and HGVs - coming from the traffic assignment model VACLAV),
- inclination of the roads and
- climate- and weather data (meteorological service).

The Central Database Function – Population Density

Land cover data comes from the European Corine database, which provides consistent information on land cover and land cover changes across Europe over the past decades. Regio-SUSTAIN uses 250 x 250m grids as reference for calculation.

The Corine land cover database defines two urban classes, namely "Urban dense" and "Urban discontinuous" for Europe. Further 42 land use categories are defined which are not related to human habitation. According to a publication by Gallego (2001), only about 82.5% of the total population in Germany can be assigned to the two urban land cover types. The remaining 17.5% of the population has to be assigned to the other land cover categories (5,392,062 elements). Based on statistical analyses, Gallego presented distribution values for several European countries, for each type of Corine land cover. These distribution values are adopted for the allocation of the population for all land cover types in Regio-SUSTAIN. This might need some clarification:

As an example, the population distribution function of Gallego assigns 28.9% of cells to the CLC class "pasture" in Ireland. This does not mean that 28.9% of the Irish population live in pasture fields, but that 28.9% of the population live in cells, which are defined as "pasture". This may correspond to a large number of small urban villages within the CLC "pasture" class.

Figure 52 shows an example of CLC data sets in a specific area. It describes an example for calculating the population density for CLC categories. The sample area consists of 9 cells (250 x 250m) and covers an area of 0.56 km² (from the CLC database the following information are available: 78% forest, approx. 11% urban dense and approx. 11% Urban discontinuous). It includes a small village with about 100 inhabitants (information based on the Seamless Administrative Boundaries of Europe (SABE) - database). Furthermore, it is known that 30% of the inhabitants live in the category "Urban dense", 70% in "Urban discontinuous" and nobody in "Forest".

Based on these values average population numbers for every CLC category can be estimated. 30 persons are allocated to "Urban dense", 10 to "Urban discontinuous" and nobody to "Forest". Information about the population per region/ polygon (from SABE) is blended with the associated CLC data, which is covered by this polygon.

The approach described by Gallego has been modified by Schmedding (2005). The improvement has been necessary when analysing smaller regions instead of countries like Gallego did. The improved methodology uses the country shares per CLC category of Gallego and multiplies the results with a correction factor. The factor depends on the number of cells belonging to each CLC category and the number of persons allocated to each region by the approach of Gallego. In the case that one CLC category does not exist in an area under consideration, the number of fictitious allocated persons by Gallego have to be reallocated to the existing categories.

The reallocated number of persons has been inserted in the Regio-SUSTAIN database and is used in the TRIAS project.

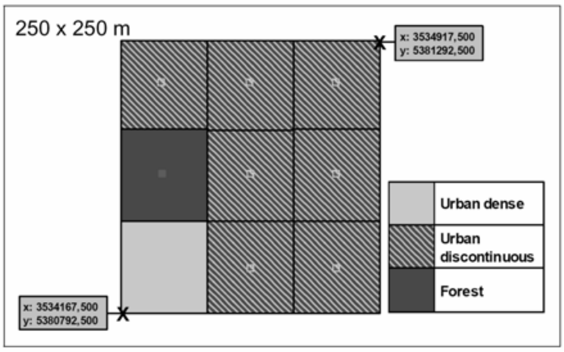


Figure 52: Example of land cover data

Calculation of Emission Levels

At the Institute for Economic Policy Research different Java based models have been developed to calculate transport emissions per kilometre in the area under consideration. Average emissions are calculated for each link of the network and are depending on the road structure in the network, the number of vehicles on the roads, the vehicle fleet on the link and the regional elevation profile. Average emission factors for each vehicle category are taken from the Handbook of Emission Factors published by Infras AG for the German and Swiss Environmental Agency. The output of the Java models is average emission values per km of each network link that are stored in the database and is used for immssion calculations.

Calculation of Immission Levels

Immission levels are modelled with an external software, called SoundPlan, which has been developed by Braunstein & Berndt GmbH in Backnang (Germany). SoundPlan is a comprehensive software package offering noise and air pollution evaluation modules. Using the inputs of Regio-SUSTAIN (emission concentration, road transport network including loads) SoundPlan calculates immission for pre-defined grids (e.g. 250x250m).

Number of affected people

In the last step the information about population density and immission values per grid are merged to calculate the number of affected people. Therefore, concrete exposure levels as well as very precise categories can be defined to get a detailed picture about the environmental impacts of the transport network. The number of exposed people to NO_x, to soot particles and to other emission substances can be compared to international environmental quality standards, which are defined for example by the German Environmental Agency in 1997. The database analyses each grid of the region under consideration and calculates the population number of that specific grid. Aggregating the information about immission values and population numbers lead to the final output of Regio-SUSTAIN the number of affected people by a specific concentration of a given substance, such as NO_x, PM or noise.

4.3.2 Extension to Point Emissions (POLES)

Industrial emissions into air and water from facilities in EU-15 countries for the year 2001 have been registered in the European Pollutant Emission Register (EPER) database of the European Commission. With growth rate calculated from the Prospective Outlook on Long Term Energy System (POLES) energy model and information on emission factor and abatement technology obtained from the RAINS-GAINS database of International Institute for Applied Systems Analysis, some of the emissions (NOx and PM10) have been projected to the 2050 horizon.

4.3.2.1 European Pollutant Emission Register (EPER)

In the article 15 of the Integrated Pollution Prevention and Control (IPPC) Directive, the main purpose of a European Commission emission inventory will be to collect and store comparable emission (to air and water) data of individual polluting industrial sources and activities into an integrated database or register and to provide public accessibility to the registered data. Only emission to air and water are considered as emissions. The data of the current of the existing register, being named as European Pollutant Emission Register (EPER) whose decision was published in the Official Journal of the European Communities under reference 2000/479/EC (17 July 2000), is delivered to the Commission by the national governments of the Member States and this will be updated periodically.

According to the Guidance Document for EPER Implementation[1], the EPER will be used as a public register to provide environmental information on industrial activities covered by the IPPC Directive[2] and has the following objectives related to different groups of users:

to enhance awareness for environmental pollution and to compare emissions by individual facilities or industrial sectors. Making the data accessible on an Internet site will increase the public use of the EPER data by non-governmental organisations and research organisations or interested citizens (*public use*);

to trigger industry in improving environmental performance and innovating industrial processes. The achievements by industry will result into emission reductions that can be monitored and demonstrated in the EPER register (*industry use*);

to evaluate the progress of achievements in meeting environmental targets in national or international agreements; the EPER enables the Commission to identify principal emissions and industrial sources, assess the reported data of Member States with respect to some international agreements and to publish the results periodically (*government use*).

The data submission regulated by OJ 2000/479/EC or known as "EPER Decision"[3] should be conducted by Member States including all individual facilities with one or more activities as mentioned in Appendix I to Council Directive 96/61/EC or known as the IPPC Directive. The

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1 http://www.eper.cec.eu.int/eper/documents/eper_en.pdf

2 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31996L0061:EN:HTML

3 http://eper.cec.eu.int/eper/documents/comission_17072000.pdf

Commission Decision (EPER Decision) gives details of the list of pollutants to be reported (and its threshold value), the report format, emission source categories and their corresponding (NOSE-P) codes to be reported, and the definition used in EPER.

The mandatory reporting of emissions according to the requirements of the EPER Decision is a stepwise process with the following key elements (Guidance Document for EPER Implementation):

Identifying and selecting the facilities with Appendix I activities. Article 1, sub 1 of the EPER Decision requires Member States to report emissions from all individual facilities with one or more activities as mentioned in Appendix I of the IPPC Directive. These activities are identified by the source categories as specified in Appendix A3 of the EPER Decision.

Determining pollutant specific emissions from all individual facilities with Appendix I activities. Article 1, sub 2 of the EPER Decision requires Member States to include in the report the emissions to air and water for all pollutants for which the threshold values are exceeded. Both pollutants and threshold values are specified in Appendix A1 of the EPER Decision.

Reporting the emissions for individual facilities with Appendix I activities. The emission data shall be reported for each facility according to the format of Appendix A2 of the EPER Decision (Article 1, sub 3). Member States are required to provide this report on CD-ROMs.

Reporting aggregated emission data for all pollutants of Appendix A3 of the EPER Decision in an overview report. This overview report includes the national totals of all individually reported emissions for both each of the source categories and the NOSE-P codes as specified in Appendix A3 of the EPER Decision (Article 1, sub 4). Member States shall provide this overview report on paper and on CD-ROMs.

Disseminating all reported data by the Commission. The Commission will make the facility specific data as well as the aggregated data provided by each Member State publicly accessible on the Internet (Article 4).

The current EPER database[4] contains emissions information of industrial facilities of EU-15 countries for the year of 2001. The member countries submitted this report data on June 2003. The second reporting year was on June 2006, which should include report of the year 2004. After review and evaluation in 2006 a decision can be taken on a subsequent annual reporting by Member States in December of the year T on releases in the year T-1. From 2008 onwards, the Member States are encouraged to have a regular reporting system in place and send annual report to the Commission in December of year T, instead of June a year later (T+1). As many international protocols require emission reporting in December, a future reporting in December will be enable Member States to synchronise the EPER reporting with other international reporting requirements (UNFCC, UN/ECE, etc.)

[4] http://www.eper.cec.eu.int/eper/

4.3.2.2 Regional Air Pollution Information and Simulation (RAINS) and the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS)

The Regional Air Pollution Information and Simulation (RAINS) model developed by the International Institute for Applied Systems Analysis (IIASA) combines information on economic and energy development, emission control potentials and costs, atmospheric dispersion characteristics and environmental sensitivities towards air pollution (Schöpp *et al.*, 1999). The model addresses threats to human health posed by fine particulates and ground-level ozone as well as risk of ecosystems damage from acidification, excess nitrogen deposition (*eutrophication*) and exposure to elevated ambient levels of ozone.

These air pollution related problems are considered in a multi-pollutant context (Figure 53), quantifying the contributions of sulphur dioxide (SO2), nitrogen oxides (NOx), ammonia (NH3), non-methane volatile organic compounds (VOC), and primary emissions of fine (PM2.5) and coarse (PM10-PM2.5) particles (Table 33). The RAINS model also includes estimates of emissions of relevant greenhouse gases such as carbon dioxide (CO2) and nitrous oxide (N2O). Current work is progressing to include methane (CH4) as another direct greenhouse gas as well as carbon monoxide (CO) and black carbon (BC) into the model framework.

Table 33: Multi-pollutant/multi-effect approach of the RAINS model

	Primary PM	SO2	NOx	VOC	NH3
Health impacts:					
- PM	✓	✓	✓	✓	✓
- O3			✓	✓	
Vegetation impacts:					
- O3			✓	✓	
- Acidification		✓	✓		✓
- Eutrophication			✓		✓

Source: Amann et al., 2004

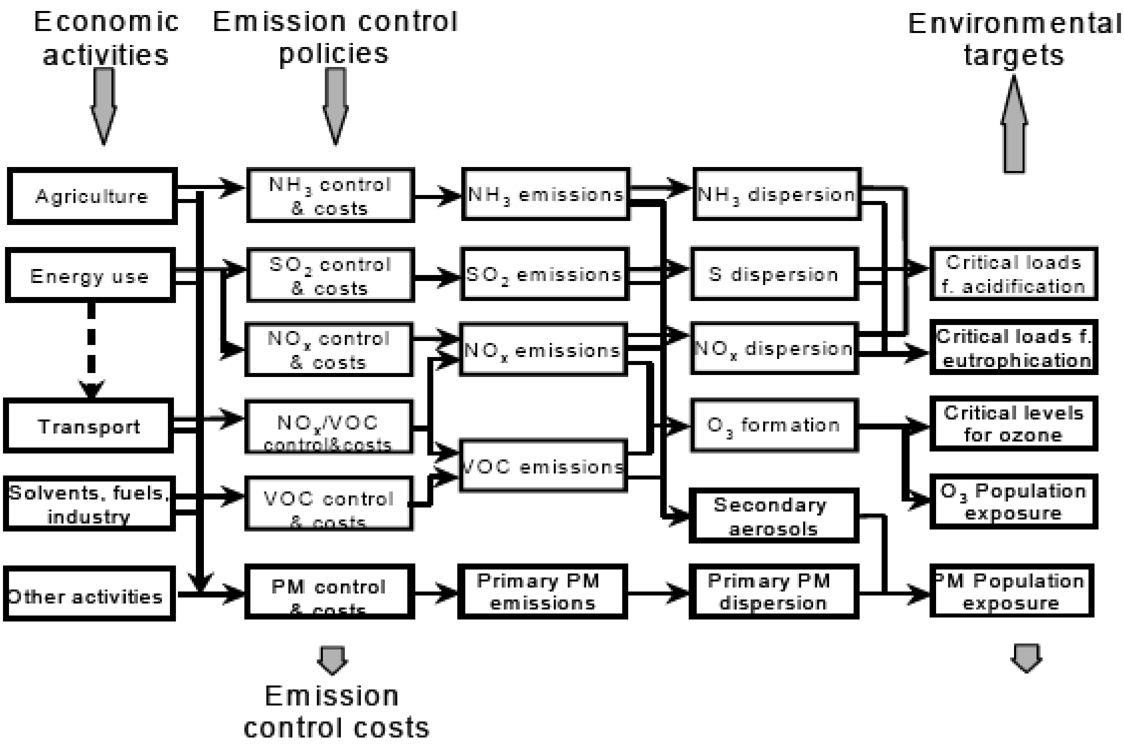

Figure 53: Flow of information in the RAINS model

Source: Amann et al., 2004

The European implementation of the RAINS model incorporates databases on energy consumption for 40 regions in Europe, distinguishing 22 categories of fuel use in six economic sectors. The time horizon extends from the year 1990 up to the year 2030. Emissions of SO2, NOx, NH3, and VOC for 1990 are estimated based on information collected by the CORINAIR 90[5] inventory of the European Environmental Agency and on national information. Options and costs for controlling emissions of the various substances are represented in the model by considering the characteristic technical and economic features of the most important emission reduction options and technologies. A detailed description of the RAINS model, on-line access to certain model parts as well as all input data to the model can be found on the Internet[6].

The RAINS model has two capabilities:

scenario analysis: in which the model is able to estimate the (economic) costs and environmental effects of an exogenously assumed pattern of emission controls;

optimisation mode: in which the model using a non-linear optimisation mode is capable to identify the least-cost allocation of emission controls that meet exogenously determined environmental targets. This enables the development of multi-pollutant, multi-effect pollution

5 http://reports.eea.europa.eu/92-9167-022-7/en/

6 http://www.iiasa.ac.at/rains

control strategies. In particular, the optimisation can be used to search for cost-minimal balances of controls of the six pollutants (SO2, NOx, VOC, NH3, primary PM2.5, primary PM10-2.5(=PM coarse)) over the various economic sectors in all European countries that simultaneously achieve user-specified targets for human health impacts, ecosystem protection, and maximum allowed violations of WHO guideline values for ground-level ozone, etc.

Over the last years, IIASA has extended its RAINS model to explore synergies and trade-offs between the control of local and regional air pollution and the mitigation of global greenhouse gas emissions. This new GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) model assists in the search for pollution control strategies that maximise benefits across all scales.

The European implementation of the GAINS model has been released in December 2006. It covers 43 countries in Europe. This new GAINS model incorporates the latest version of the RAINS-Europe as it has been prepared for the 2007 of the National Emission Cellings Directive[7] resulted from bilateral consultations between IIASA modelling team and national experts of the IIASA country members. GAINS combines it with estimates of emissions, mitigation potentials and costs for the six greenhouse gases included in the Kyoto protocol, fully compatible with the methodology applied for the conventional air pollutants. GAINS-Europe is implemented on the Internet and an online version[8] is available.

4.3.2.3 Methodology

Results and information from the two models, RAINS-GAINS and POLES, and EPER database are combined to produce the projection of CO2, NOx, and PM10.

Information from EPER Database

EPER database provides information on industrial facilities in each of EU-15 countries for the year 2001. In the data structure, as seen in Figure 54, the emission information is detailed in type, value, method, pollutant name, and facility name. The emission types are water and/or air, the value is expressed in ton of pollutant, the method are described measured and/or calculated, and the pollutant name follows the pollutant identification as given by the **appendix A1** of the EPER decision.

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7 http://www.iiasa.ac.at/rains/nec2007.html?sb=18

8 http://www.iiasa.ac.at/rains/gains-online.html

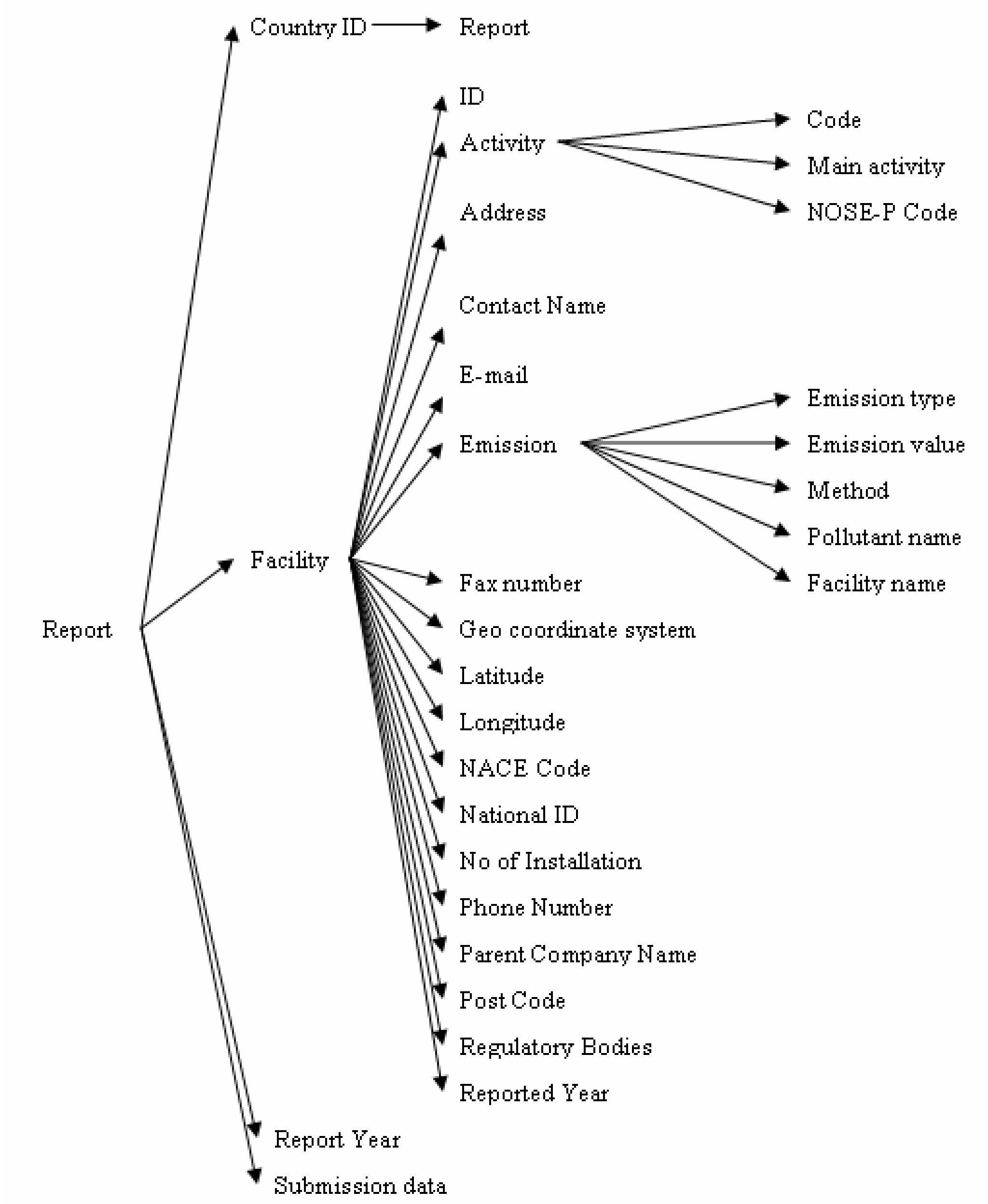

Figure 54: EPER Data Structure

Results and Projection from POLES Reference Scenario

POLES energy model is able to give projection on world long-term energy projections, national-regional energy balance and CO2 emission simulation, analysis of new energy technology potentials, markets and diffusion, and test of energy policies and energy RTD strategies. The actual POLES energy model has the capacity to produce those outputs until 2050 horizon. In order to project NOx and PM10 emissions to the 2030 horizon, a Business as Usual or Reference scenario has been run and result for *fuel consumption* per country (of the EU-15) and per sector have been extracted.

The POLES Reference scenario describes the economic and technological fundamentals that determine the dynamics of the world energy system; it also includes elements of policy or political development that are likely to occur in the period. It reflects the geo-political conjuncture that dominates the short and medium-term availability and price of world oil; it also reflects a minimum degree of political initiative in climate policy in all regions of the world. The Reference case accordingly visualizes a world adjusting to constraints on access to oil and gas and on emissions of CO2.

The Reference case represents the "minimum" climate policies by an exogenous carbon value that modifies the investment and consumption decisions of the economic agents. It assumes that Europe keeps the lead in climate policies, although in this case these policies are developed in a minor key. Assumption used for carbon value in Europe is in line to the estimates provided by the European Emission Trading System[9]. The POLES' Reference scenario has been used as a reference scenario in World Energy and Technology Outlook 2050 (WETO-H2 Project)[10] of the DG-Research Commission European under the 6th Framework Programme.

Information and Results from RAINS Model Database

The central objective of the integrated assessment models it to assist in the cost-effective allocation of emission reduction measures across various pollutants, several countries and different economic sectors. In order to capture these differences across Europe in a systematic way, a methodology has been developed to estimate the emissions and emission control costs of standard technologies under the specific conditions characteristic for the various European countries[11].

The methodology of emissions estimation consists in aggregation schemes for the emission sources, energy scenarios development, options for emissions reduction, cost evaluation, and control strategies and cost curves. The section of *aggregation schemes for the emission sources* is particularly relevant for the work conducted.

For the NOx, the RAINS model groups first the emission generating activities into sectors of economic activities which can be called as the *Primary* RAINS sectors (*centralized power plants and district heating, fuel conversion other than power plants, domestic, commercial, and agricultural use, transportation, industrial, non-energy use-feedstocks and other emission source*). In order to take into account more factors which are highly relevant for emission generation, the primary sectors are divided into *secondary* sectors. For example power plants and district heating as primary sector is divided into new boilers, existing boilers – dry bottom, existing boiler- wet bottom. Those economic sector groups are further subdivided into

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9 Kyoto Protocol Implementation study for DG Environment with the POLES model:

http://europa.eu.int/comm/environment/climat/pdf/kyotoprotocolimplementation.pdf

10 http://ec.europa.eu/research/fp6/ssp/weto_h2_en.htm

11 RAINS internet side provides documentations of methodologies used to calculate emissions in the framework of an integrated assessment model for the analyses carried out for the NEC directive in 1998/99. The actual data for 2004 review are available from the on-line version of the RAINS model. However the documentations of methodologies from 1998/99 are very relevant to understand the principles of emissions calculations.

the type of fuel. Complete information in this aggregation could be seen at Cofala and Syri (1998)[12].

For the PMx, the aggregation objective is to categorise the emission producing processes into a reasonable number of groups with similar technical and economic properties. One important requirement in aggregating emission sources is that it should include only source categories with a contribution of at least 0.5 percent to the total anthropogenic emissions in a particular country.

The emission sources are divided first into nine primary sectors: *stationary combustion, process emissions, mining, storage and handling, road transport, off-road transport, open burning of waste, agriculture,* and *other source*. These nine primary sectors are categorised into three big primary sector groups: *stationary combustion sources, stationary non-combustion sources,* and *mobile sources*, which are in turn split by relevant fuel types. Some groups are further disaggregated to distinguish, for example, between existing and new installation in power plants, or between tire and brake wear for non-exhaust emission from transport. Full list of RAINS PMx sectors could be seen in Klimont, et al. (2002)[13].

Finally for all pollutants, RAINS the emission estimating is conducted in country level. The calculations are performed for 36 European countries and four sea regions within the EMEP modelling domain. In addition, Rusia (because of the large geographical area) and Germany (because of the implementation differences in the base year 1990) are further divided into sub-national regions.

4.3.2.4 *Compatibility*

EPER and POLES Sectors Compatibility

In the EPER database, each industrial facility corresponds to one economic activity category as described by the NACE code[14]. There are 344 economic sectors identified by NACE Code in EPER database and they belong into 4 big sections:

- Section C: mining and quarying (21 activities)
- Section D: manufacturing (318 activities, grouped into 12 subsections)
- Section E: electricity, gas, and water supply (4 activities)
- Section O: other community, social and personal service activities (1 activity: sewage and refuse disposal, sanitation and similar activities)

On the other side, four energy source sectors are identified in POLES: steel industries (STI), chemical industry (CHI), non metallic mineral industry (NMM), service (SER), and other indus-

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[12] http://www.iiasa.ac.at/%7Erains/reports/noxpap.pdf

[13] http://www.iiasa.ac.at/rains/reports/ir-02-076.pdf

[14] The NACE nomenclature (National Classification of Economic Activities) is the European classification of economic activities. It is based on economic sectors and is composed of four digits (there is a fifth one for national use). The first two digit codes indicate the divisions, the third-digit codes indicate the groups, the fourth-digit codes indicate the classes.

tries (OIN). POLES model exclude the four activities in the section E of EPER (electricity, gas, and water supply), so finally, the rest 340 economic sectors identified within industrial facilities registered in EPER database enter one of the 5 energy source sectors in POLES (see **appendix 1**). Most of the activities are categorised in OIN sectors (238 activities), followed by STI (47), NMM (31), CHI (24) and SER (1).

POLES and RAINS-GAINS Fuels and Sectors Compatibility

As explained previously, emissions data and result in RAINS-GAINS are categorised into sectors (and sub-sectors) of activities and fuel types in the country level. In POLES model, the data and results are as well categorised into sector (as mention in Table 35 and in the previous section) and fuel in the country level. However these aggregations are not directly compatible.

For fuel type, POLES energy model is simply differentiated in *gas*, *oil*, and *coal* fuel. In RAINS-GAINS, the fuel type division is more detailed. The coal, for example, is divided into eight type of coal and several types of fuel in RAINS-GAINS are not represented in POLES energy model. The coal fuel from POLES has to be divided into 8 (eight) coal types available in RAINS-GAINS. This "fuel split" of POLES' coal is made possible by the existing information on coal percentage in RAINS-GAINS. The relationship between POLES and RAINS-GAINS fuel type is presented in Table 34 below.

Table 34: POLES – RAINS-GAINS fuel type relationship

RAINS-GAINS fuels	POLES fuels
Brown coal/lignite, grade 1 (BC1)	COAL
Brown coal/lignite, grade 2 (BC2)	
Hard coal, grade 1 (HC1)	
Hard coal, grade 2 (HC2)	
Hard coal, grade 3 (HC3)	
Derived coal (DC)	
Other solid-low S (OS1)	
Other solid-high S (OS2)	
Heavy fuel oil (HF)	n/a
Medium distillates (MD)	OIL
Light fractions (LF)	n/a
Natural Gas (incl. other gas)	GAS
Renewable (solar, wind, small hydro)	n/a
Hydro	n/a
Nuclear	n/a
Electricity	n/a
Heat	n/a
No fuel use	n/a

For NOx from stationary sources, the sector desegregation in RAINS is more detailed than that in POLES (Table 35 below).

Table 35: POLES – RAINS/GAINS sector type relationship for NOx stationary

RAINS/GAINS sectors		POLES sectors
Primary	**Secondary**	
Power plants and district heating plants (PP)	New boilers (PP_NEW)	n/a
	Existing boilers, dry bottom (PP_EX_OTH)	
	Existing boilers, wet bottom (PP_EX_WB)	
Fuel production and conversion (other than power plants) (CON)	Combustion (CON_COMB)	n/a
	Losses (CON_LOSS)	
Domestic (DOM)	Residential, commercial, institutional, agriculture	SER
Industry (IN)	Combustion in boilers, gas turbines and stationary engines (IN_BO)	STI, OIN, NMM, CHI
	Other combustion (IN_OC)	
	Process emissions (IN_PR)	
Non-energy use of fuels (NONEN)	Use of fuels for non-energy purposes (feedstocks, lubricants, asphalt)	n/a
Other emissions (OTHER)	Other sources: (air traffic LTO cycles, waste treatment and disposal, agriculture)	n/a

The RAINS-GAINS sectors in the Table 35 are further disaggregated by abatement technologies. For example the industrial boilers (IN_BO) and furnaces (IN_OC) are divided into 6 technologies, each correspond to a certain removal rate:

- ISFCM (Combustion modification – solid fuels)
- IOGCM (Combustion modification – oil and gas)
- ISFCSC (Combustion modification + selective catalytic reduction – solid fuels)
- IOGCSC (Combustion modification + selective catalytic reduction – oil and gas)
- ISFCSN (Combustion modification + selective non-catalytic reduction – solid fuels)
- IOGCSN (Combustion modification + selective non-catalytic reduction – oil and gas)

Unfortunately, the information on abatement technology split for each sector is so far unavailable. For practical reason, the arithmetical average of removal rate from the existing technologies is then calculated to obtain the removal rate of abatement technology for the corresponding sector.

For the PM10, similar to NOx, the STI, OIN, NMM, and CHI sectors from POLES enter into *industry* (IN) primary sector of RAINS-GAINS while SER corresponds to *domestic* (DOM) primary sector of RAINS-GAINS. However, RAINS-GAINS information or results are disaggregated into secondary sector or sub-sector which means that POLES information or results have to be disaggregated into the same level of sub-sector. For example: in RAINS-GAINS, the domestic sector (DOM) in stationary sources is divided into 7 (seven) following sub-sectors:

- combustion of liquid fuels (DOM)
- fireplaces (DOM_FPLACE)
- stoves (DOM_STOVE)
- single house boilers (<50 kW) – manual (DOM_SHB_M)
- single house boilers (<50 kW) – automatic (DOM_SHB_A)
- medium boilers (<1 MW) – manual (DOM_MB_M)
- medium boilers (<50 MW) – automatic (DOM_MB_A)

A combination of sector and fuel from POLES, for example SER-coal (BC1) which corresponds to DOM-BC1 in RAINS-GAINS, has to be split then into seven sub-sectors. This is possible since the information on each sub-sector use percentage is available. However, in this work, no sub-sector split is conducted. For the sake of simplicity, the sub-sector with the highest percentage is chosen instead of a sub-sector split. In this example, the DOM_MB_A-BC1 is chosen since the DOM_MB_A sub-sector has the highest use percentage for the DOM_BC1 combination.

Table 36 shows the relationship between POLES' sector-fuel and RAINS-GAINS' sector-fuel for the stationary PM10 emission.

Table 36: POLES – RAINS/GAINS sectors and fuel types relationship for PM10 stationary

POLES Sectors	POLES fuels	RAINS sectors and fuels (Emission from fuel combustion)
STI, OIN, CHI, NMM	OIL	IN_OC_MD
	GAS	IN_OC_natural gas
	COAL	IN_OC3-BC1
		IN_OC3-BC2
		IN_OC3-HC1
		IN_OC3-HC2
		IN_OC3-HC3
		IN_OC-DC
		IN_OC-OS1
		IN_OC-OS2
SER	OIL	DOM_MD
	GAS	DOM
	COAL	DOM_MB_A-BC1
		DOM_MB_A-BC2
		DOM_MB_A-HC1
		DOM_MB_A-HC2
		DOM_MB_A-HC3
		DOM_STOVE-DC
		DOM_STOVE-OS1
		DOM_STOVE-OS2

Furthermore, the same as in the NOx, the sub-sector in PM10 emission above is disaggregated into abatement technology which corresponds to the removal rate or efficiency. In the power plants and industry, some of those technologies are:

- cyclone (CYC),
- wet scrubber (WSCRB),
- electrostatic precipitator 1 field (ESP1), 2 fields (ESP2) and 3 fields and more (ESP3),
- wet electrostatic precipitator (WESP),
- fabric filters (FF),
- regular maintenance, oil fired boiler (GHIND),
- regular maintenance, domestic oil boiler (GHDOM).

4.3.2.5 Projection Method

The abated PM10 emission is obtained simply by summing up, for all fuel types, the multiplication of emission factor, fuel consumption, and the abatement rate. The emission factor, as a constant coefficient, is obtained from RAINS/GAINS while the fuel consumption is produced by POLES.

$$P_{i,j}(y) = \sum_{f} ef_{i,j,f} * fc_{i,j,f}(y) * (1 - (re_{i,f}(y) * pr_{i,f}(y)) \qquad (1)$$ **(eq. 7)**

P: PM10 emissions in country *i*, year *y*, and sector *j*
ef: emission factor of fuel *f*, from sector *j*, in country *i*
fc: fuel consumption of fuel *f*, from sector *j*, in country *i*
re: removal efficiency in country *i* for fuel *f*
pr: penetration rate of abatement technology in country *i* for fuel *f*

RAINS/GAINS provides the removal efficiency rate and the penetration rate of the abatement technologies for the years 1990, 1995, 2000, 2005, 2010, 2015, 2020, 2025, and 2030. The between years values are calculated by assuming a linear growth.

The growth rate of this emission per country and per sector is then applied as multiplier to the EPER database PM10 emission of the year 2001 for each industrial facility to obtain the PM10 emission projection of each facility for the period of 2001 to 2030.

The growth rate of the PM10 emission of each installation is assumed to be equal to the growth rate of the PM10 emission of the corresponding country and sector and the installation production technology related to the PM10 emissions is assumed to remain unchanged during the observed period.

The abated NOx emission is as well obtained by summing up, for all fuel types, the multiplication of emission factor and fuel consumption taken into account the removal efficiency and penetration rate of the abatement technology (**eq. 2** below). The emission factor (constant), the removal and penetration rate (for the same years as PM10) are obtained from RAINS/GAINS while the fuel consumption from POLES.

$$N_{i,j}(y) = \sum_{f} ef_{i,j,f} * fc_{i,j,f}(y) * (1 - (re_{i,f}(y) * pr_{i,f}(y)) \qquad (2)$$ **(eq. 8)**

N: NOx emissions in country *i*, year *y*, and sector *j*
ef: emission factor of fuel *f*, from sector *j*, in country *i*
fc: fuel consumption of fuel *f*, from sector *j*, in country *i*
re: removal efficiency in country *i* for fuel *f*
pr: penetration rate of abatement technology in country *i* for fuel *f*

The growth rate of abated NOx emission of each installation is assumed to be equal to the growth rate of the abated NOx emission of the corresponding country and sector and the installation production technology related to the abated NOx emissions is assumed to remain unchanged during the observed period.

4.3.2.6 Results

Projection results can be seen in the **appendix 3** and **4**.

Table 37: NACE Code included in EPER Database in Relation to Energy Sector in POLES Model

NaceCo-deID	Code	Text	POLES SECTOR
26		**Section C Mining and quarrying**	
27		***SubSection CA Mining and quarrying of energy producing materials***	
32	11.00	Extraction of crude petroleum and natural gas + service activities, excl..	OIN
33	11.10	Extraction of crude petroleum and natural gas	OIN
34	11.11	Extraction of crude petroleum	OIN
35	11.12	Extraction of natural gas	OIN
36	11.13	Extraction of bituminous shale and sand	OIN
37	11.20	Service activities incidental to oil and gas extraction excluding surveying	OIN
38	12.00	Mining of uranium and thorium ores	OIN
39		***SubSection CB Mining and quarrying except energy producing materi-als***	
40	13.00	Mining of metal ores	OIN
41	13.10	Mining of iron ores	OIN
42	13.20	Mining of non-ferrous metal ores, except uranium and thorium ores	OIN
43	14.00	Other mining and quarrying	OIN
44	14.10	Quarrying of stone	OIN
45	14.11	Quarrying of stone for construction	OIN
46	14.12	Quarrying of limestone, gypsum and chalk	OIN
47	14.13	Quarrying of slate	OIN
48	14.20	Quarrying of sand and clay	OIN
49	14.21	Operation of gravel and sand pits	OIN
50	14.22	Mining of clays and kaolin	OIN
51	14.30	Mining of chemical and fertiliser minerals	OIN
52	14.40	Production of salt	OIN
53	14.50	Other mining and quarrying n.e.c	OIN
54		**Section D Manufacturing**	
55		***SubSection DA Manufacture of food products; beverages and tobacco***	
56	15.00	Manufacture of food products and beverages	OIN
57	15.10	Production, processing and preserving of meat and meat products	OIN
58	15.11	Production and preserving of meat	OIN
59	15.12	Production and preserving of poultry meat	OIN
60	15.13	Production of meat and poultry meat products	OIN
61	15.20	Processing and preserving of fish and fish products	OIN
62	15.30	Processing and preserving of fruit and vegetables	OIN
63	15.31	Processing and preserving of potatoes	OIN
64	15.32	Manufacture of fruit and vegetable juice	OIN

NaceCodeID	Code	Text	POLES SECTOR
65	15.33	Processing and preserving of fruit and vegetables n.e.c	OIN
66	15.40	Manufacture of vegetable and animal oils and fats	OIN
67	15.41	Manufacture of crude oils and fats	OIN
68	15.42	Manufacture of refined oils and fats	OIN
69	15.43	Manufacture of margarine and similar edible fats	OIN
70	15.50	Manufacture of dairy products	OIN
71	15.51	Operation of dairies and cheese making	OIN
72	15.52	Manufacture of ice cream	OIN
73	15.60	Manufacture of grain mill products, starches and starch products	OIN
74	15.61	Manufacture of grain mill products	OIN
75	15.62	Manufacture of starches and starch products	OIN
76	15.70	Manufacture of prepared animal feeds	OIN
77	15.71	Manufacture of prepared feeds for farm animals	OIN
78	15.72	Manufacture of prepared pet foods	OIN
79	15.80	Manufacture of other food products	OIN
80	15.81	Manufacture of bread; manufacture of fresh pastry goods and cakes	OIN
81	15.82	Manufacture of rusks and biscuits and of preserved pastry goods and cakes	OIN
82	15.83	Manufacture of sugar	OIN
83	15.84	Manufacture of cocoa; chocolate and sugar confectionery	OIN
84	15.85	Manufacture of macaroni, noodles, couscous and similar farinaceous products	OIN
85	15.86	Processing of tea and coffee	OIN
86	15.87	Manufacture of condiments and seasonings	OIN
87	15.88	Manufacture of homogenised food preparations and dietetic food	OIN
88	15.89	Manufacture of other food products n.e.c	OIN
89	15.90	Manufacture of beverages	OIN
90	15.91	Manufacture of distilled potable alcoholic beverages	OIN
91	15.92	Production of ethyl alcohol from fermented materials	OIN
92	15.93	Manufacture of wines	OIN
93	15.94	Manufacture of cider and other fruit wines	OIN
94	15.95	Manufacture of other non-distilled fermented beverages	OIN
95	15.96	Manufacture of beer	OIN
96	15.97	Manufacture of malt	OIN
97	15.98	Production of mineral waters and soft drinks	OIN
98	16.00	Manufacture of tobacco products	OIN
99		***SubSection DB Manufacture of textiles and textile products***	
100	17.00	Manufacture of textiles	OIN
101	17.10	Preparation and spinning of textile fibres	OIN
102	17.11	Preparation and spinning of cotton-type fibres	OIN
103	17.12	Preparation and spinning of woollen-type fibres	OIN

NaceCo-deID	Code	Text	POLES SECTOR
104	17.13	Preparation and spinning of worsted-type fibres	OIN
105	17.14	Preparation and spinning of flax-type fibres	OIN
106	17.15	Throwing and preparation of silk including from noils and throwing and	OIN
107	17.16	Manufacture of sewing threads	OIN
108	17.17	Preparation and spinning of other textile fibres	OIN
109	17.20	Textile weaving	OIN
110	17.21	Cotton-type weaving	OIN
111	17.22	Woollen-type weaving	OIN
112	17.23	Worsted-type weaving	OIN
113	17.24	Silk-type weaving	OIN
114	17.25	Other textile weaving	OIN
115	17.30	Finishing of textiles	OIN
116	17.40	Manufacture of made-up textile articles, except apparel	OIN
117	17.50	Manufacture of other textiles	OIN
118	17.51	Manufacture of carpets and rugs	OIN
119	17.52	Manufacture of cordage, rope, twine and netting	OIN
120	17.53	Manufacture of nonwovens and articles made from nonwovens, except apparel	OIN
121	17.54	Manufacture of other textiles n.e.c	OIN
122	17.60	Manufacture of knitted and crocheted fabrics	OIN
123	17.70	Manufacture of knitted and crocheted articles	OIN
124	17.71	Manufacture of knitted and crocheted hosiery	OIN
125	17.72	Manufacture of knitted and crocheted pullovers, cardigans and similar art.	OIN
126	17.73	Manufacture of knitted and crocheted outerwear	OIN
127	17.74	Manufacture of knitted and crocheted underwear	OIN
128	17.75	Manufacture of other knitted and crocheted articles and accessories	OIN
129	18.00	Manufacture of wearing apparel; dressing and dyeing of fur	OIN
130	18.10	Manufacture of leather clothes	OIN
131	18.20	Manufacture of other wearing apparel and accessories	OIN
132	18.21	Manufacture of workwear	OIN
133	18.22	Manufacture of other outerwear	OIN
134	18.23	Manufacture of underwear	OIN
135	18.24	Manufacture of other wearing apparel and accessories n.e.c	OIN
136	18.30	Dressing and dyeing of fur; manufacture of articles of fur	OIN
137		***SubSection DC Manufacture of leather and leather products***	
138	19.00	Tanning & dressing of leather; manufacture of luggage, handbags, saddlery..	OIN
139	19.10	Tanning and dressing of leather	OIN
140	19.20	Manufacture of luggage, handbags and the like, saddlery and harness	OIN
141	19.30	Manufacture of footwear	OIN
142		***SubSection DD Manufacture of wood and wood products***	

NaceCo-deID	Code	Text	POLES SECTOR
143	20.00	Manufacture of wood & of products of wood & cork and of straw & plaiting...	OIN
144	20.10	Sawmilling and planing of wood, impregnation of wood	OIN
145	20.20	Manufacture of veneer sheets and of plywood and other panels & boards	OIN
146	20.30	Manufacture of builders' carpentry and joinery	OIN
147	20.40	Manufacture of wooden containers	OIN
148	20.50	Manufacture of other products of wood, of cork, straw & plaiting materials	OIN
149	20.51	Manufacture of other products of wood	OIN
150	20.52	Manufacture of articles of cork, straw and plaiting materials	OIN
151		SubSection DE Manuf. of pulp, paper & paper product; publishing & printing	OIN
152	21.00	Manufacture of pulp, paper and paper products	OIN
153	21.10	Manufacture of pulp, paper and paperboard	OIN
154	21.11	Manufacture of pulp	OIN
155	21.12	Manufacture of paper and paperboard	OIN
156	21.20	Manufacture of articles of paper and paperboard	OIN
157	21.21	Manufacture of corrugated paper(board) and of containers of paper(board)	OIN
158	21.22	Manufacture of household & sanitary goods and of toilet requisites	OIN
159	21.23	Manufacture of paper stationery	OIN
160	21.24	Manufacture of wallpaper	OIN
161	21.25	Manufacture of other articles of paper and paperboard n.e.c	OIN
162	22.00	Publishing, printing and reproduction of recorded media	OIN
163	22.10	Publishing	OIN
164	22.11	Publishing of books	OIN
165	22.12	Publishing of newspapers	OIN
166	22.13	Publishing of journals and periodicals	OIN
167	22.14	Publishing of sound recordings	OIN
168	22.15	Other publishing	OIN
169	22.20	Printing and service activities related to printing	OIN
170	22.21	Printing of newspapers	OIN
171	22.22	Printing n.e.c	OIN
172	22.23	Bookbinding and finishing	OIN
173	22.24	Composition and plate-making	OIN
174	22.25	Other activities related to printing	OIN
175	22.30	Reproduction of recorded media	OIN
176	22.31	Reproduction of sound recording	OIN
177	22.32	Reproduction of video recording	OIN
178	22.33	Reproduction of computer media	OIN
179		***SubSection DF Manufac. of coke, refined petroleum products & nuclear fuel***	
180	23.00	Manufacture of coke, refined petroleum products and nuclear fuel	STI
181	23.10	Manufacture of coke oven products	STI

NaceCo-deID	Code	Text	POLES SECTOR
182	23.20	Manufacture of refined petroleum products	STI
183	23.30	Processing of nuclear fuel	OIN
184		***SubSection DG Manufac. of chemicals, chemical products and man-made fibres***	
185	24.00	Manufacture of chemicals, and chemical products	CHI
186	24.10	Manufacture of basic chemicals	CHI
187	24.11	Manufacture of industrial gases	CHI
188	24.12	Manufacture of dyes and pigments	CHI
189	24.13	Manufacture of other inorganic basic chemicals	CHI
190	24.14	Manufacture of other organic basic chemicals	CHI
191	24.15	Manufacture of fertilisers and nitrogen compounds	CHI
192	24.16	Manufacture of plastics in primary forms	CHI
193	24.17	Manufacture of synthetic rubber in primary forms	CHI
194	24.20	Manufacture of pesticides and other agro-chemical products	CHI
195	24.30	Manufacture of paints, varnishes & similar coatings, printing ink & mastics	CHI
196	24.40	Manufacture of pharmaceuticals, medicinal chemicals and botanical products	CHI
197	24.41	Manufacture of basic pharmaceutical products	CHI
198	24.42	Manufacture of pharmaceutical preparations	CHI
199	24.50	Manuf. of soap, detergents & perfumes; toilet, cleaning & polishing prepar.	CHI
200	24.51	Manufacture of soap and detergents, cleaning and polishing preparations	CHI
201	24.52	Manufacture of perfumes and toilet preparations	CHI
202	24.60	Manufacture of other chemical products	CHI
203	24.61	Manufacture of explosives	CHI
204	24.62	Manufacture of glues and gelatines	CHI
205	24.63	Manufacture of essential oils	CHI
206	24.64	Manufacture of photographic chemical material	CHI
207	24.65	Manufacture of prepared unrecorded media	CHI
208	24.66	Manufacture of other chemical products n.e.c	CHI
209	24.70	Manufacture of man-made fibres	OIN
210		***SubSection DH Manufacture of rubber and plastic products***	
211	25.00	Manufacture of rubber and plastic products	OIN
212	25.10	Manufacture of rubber products	OIN
213	25.11	Manufacture of rubber tyres and tubes	OIN
214	25.12	Retreading and rebuilding of rubber tyres	OIN
215	25.13	Manufacture of other rubber products	OIN
216	25.20	Manufacture of plastic products	OIN
217	25.21	Manufacture of plastic plates, sheets, tubes and profiles	OIN
218	25.22	Manufacture of plastic packing goods	OIN
219	25.23	Manufacture of builders' ware of plastic	OIN
220	25.24	Manufacture of other plastic products	OIN

NaceCodeID	Code	Text	POLES SECTOR
221		***SubSection DI Manufacture of other non-metallic mineral products***	
222	26.00	Manufacture of other non-metallic mineral products	NMM
223	26.10	Manufacture of glass and glass products	NMM
224	26.11	Manufacture of flat glass	NMM
225	26.12	Shaping and processing of flat glass	NMM
226	26.13	Manufacture of hollow glass	NMM
227	26.14	Manufacture of glass fibres	NMM
228	26.15	Manufacture and processing of other glass, incl. technical glassware	NMM
229	26.20	Manuf. of non-refractory ceramic goods other than for construction and of	NMM
230	26.21	Manufacture of ceramic household and ornamental articles	NMM
231	26.22	Manufacture of ceramic sanitary fixtures	NMM
232	26.23	Manufacture of ceramic insulators and insulating fittings	NMM
233	26.24	Manufacture of other technical ceramic products	NMM
234	26.25	Manufacture of other ceramic products	NMM
235	26.26	Manufacture of refractory ceramic products	NMM
236	26.30	Manufacture of ceramic tiles and flags	NMM
237	26.40	Manufacture of bricks, tiles and& construction products, in baked clay	NMM
238	26.50	Manufacture of cement, lime and plaster	NMM
239	26.51	Manufacture of cement	NMM
240	26.52	Manufacture of lime	NMM
241	26.53	Manufacture of plaster	NMM
242	26.60	Manufacture of articles of concrete, plaster and cement	NMM
243	26.61	Manufacture of concrete products for construction purposes	NMM
244	26.62	Manufacture of plaster products for construction purposes	NMM
245	26.63	Manufacture of ready-mixed concrete	NMM
246	26.64	Manufacture of mortars	NMM
247	26.65	Manufacture of fibre cement	NMM
248	26.66	Manufacture of other articles of concrete, plaster and cement	NMM
249	26.70	Cutting, shaping and finishing of stone	NMM
250	26.80	Manufacture of other non-metallic mineral products	NMM
251	26.81	Production of abrasive products	NMM
252	26.82	Manufacture of other non-metallic mineral products n.e.c	NMM
253		***SubSection DJ Manufacture of basic metals and fabricated metal products***	
254	27.00	Manufacture of basic metals	STI
255	27.10	Manufacture of basic iron and steel and of ferro-alloys (ECSC)*	STI
256	27.20	Manufacture of tubes	STI
257	27.21	Manufacture of cast iron tubes	STI
258	27.22	Manufacture of steel tubes	STI
259	27.30	Other first processing of iron & steel & prod. of non-ECSC* ferro	STI

NaceCo-deID	Code	Text	POLES SECTOR
260	27.31	Cold drawing	STI
261	27.32	Cold rolling of narrow strips	STI
262	27.33	Cold forming or folding	STI
263	27.34	Wire drawing	STI
264	27.35	Other first processing of iron & steel; prod. of non-ECSC* ferro	STI
265	27.40	Manufacture of basic precious and non-ferrous metals	STI
266	27.41	Precious metals production	STI
267	27.42	Aluminium production	STI
268	27.43	Lead, zinc and tin production	STI
269	27.44	Copper production	STI
270	27.45	Other non-ferrous metal production	STI
271	27.50	Casting of metals	STI
272	27.51	Casting of iron	STI
273	27.52	Casting of steel	STI
274	27.53	Casting of light metals	STI
275	27.54	Casting of other non-ferrous metals	STI
276	28.00	Manufacture of fabricated metal products, except machinery and equipment	STI
277	28.10	Manufacture of structural metal products	STI
278	28.11	Manufacture of metal structures and parts of structures	STI
279	28.12	Manufacture of builders' carpentry and joinery of metal	STI
280	28.20	Manufacture of tanks, reservoirs & containers of metal & central heating...	STI
281	28.21	Manufacture of tanks, reservoirs and containers of metal	STI
282	28.22	Manufacture of central heating radiators and boilers	STI
283	28.30	Manufacture of steam generators, except central heating hot water boilers	STI
284	28.40	Forging, pressing, stamping and roll forming of metal; powder metallurgy	STI
285	28.50	Treatment and coating of metals; general mechanical engineering	STI
286	28.51	Treatment and coating of metals	STI
287	28.52	General mechanical engineering	STI
288	28.60	Manufacture of cutlery, tools and general hardware	STI
289	28.61	Manufacture of cutlery	STI
290	28.62	Manufacture of tools	STI
291	28.63	Manufacture of locks and hinges	STI
292	28.70	Manufacture of other fabricated metal products	STI
293	28.71	Manufacture of steel drums and similar containers	STI
294	28.72	Manufacture of light metal packaging	STI
295	28.73	Manufacture of wire products	STI
296	28.74	Manufacture of fasteners, screw machine products, chain and springs	STI
297	28.75	Manufacture of other fabricated metal products, n.e.c	STI
298		***SubSection DK Manufacture of machinery and equipment n.e.c***	
299	29.00	Manufacture of machinery and equipment n.e.c	OIN

NaceCo-deID	Code	Text	POLES SECTOR
300	29.10	Manufacture of machinery for the production & use of mechanical power, exc.	OIN
301	29.11	Manufacture of engines and turbines, except aircraft, vehicle & cycle eng.	OIN
302	29.12	Manufacture of pumps and compressors	OIN
303	29.13	Manufacture of taps and valves	OIN
304	29.14	Manufacture of bearings, gears, gearing and driving elements	OIN
305	29.20	Manufacture of other general purpose machinery	OIN
306	29.21	Manufacture of furnaces and furnace burners	OIN
307	29.22	Manufacture of lifting and handling equipment	OIN
308	29.23	Manufacture of non-domestic cooling and ventilation equipment	OIN
309	29.24	Manufacture of other general purpose machinery n.e.c	OIN
310	29.30	Manufacture of agricultural and forestry machinery	OIN
311	29.31	Manufacture of agricultural tractors	OIN
312	29.32	Manufacture of other agricultural and forestry machinery	OIN
313	29.40	Manufacture of machine- tools	OIN
314	29.50	Manufacture of other special purpose machinery	OIN
315	29.51	Manufacture of machinery for metallurgy	OIN
316	29.52	Manufacture of machinery for mining, quarrying and construction	OIN
317	29.53	Manufacture of machinery for food, beverage and tobacco processing	OIN
318	29.54	Manufacture of machinery for textile, apparel and leather production	OIN
319	29.55	Manufacture of machinery for paper and paperboard production	OIN
320	29.56	Manufacture of other special purpose machinery n.e.c	OIN
321	29.60	Manufacture of weapons and ammunition	OIN
322	29.70	Manufacture of domestic appliances n.e.c	OIN
323	29.71	Manufacture of electric domestic appliances	OIN
324	29.72	Manufacture of non-electric domestic appliances	OIN
325		***SubSection DL Manufacture of electrical and optical equipment***	
326	30.00	Manufacture of office machinery and computers	OIN
327	30.10	Manufacture of office machinery	OIN
328	30.20	Manufacture of computers and other information processing equipment	OIN
329	31.00	Manufacture of electrical machinery and apparatus n.e.c	OIN
330	31.10	Manufacture of electric motors, generators and transformers	OIN
331	31.20	Manufacture of electricity distribution and control apparatus	OIN
332	31.30	Manufacture of insulated wire and cable	OIN
333	31.40	Manufacture of accumulators, primary cells and primary batteries	OIN
334	31.50	Manufacture of lighting equipment and electric lamps	OIN
335	31.60	Manufacture of electrical equipment n.e.c	OIN
336	31.61	Manufacture of electrical equipment for engines (F1) & vehicles (F2) n.e.c	OIN
337	31.62	Manufacture of other electrical equipment n.e.c	OIN
338	32.00	Manufacture of radio, television and communication equipment and appara-	OIN

NaceCo-deID	Code	Text	POLES SECTOR
		tus	
339	32.10	Manufacture of electronic valves & tubes & other electronic components	OIN
340	32.20	Manufacture of TV & radio transmitters & apparatus for line telephony &	OIN
341	32.30	Manufacture of TV & radio receivers, sound or video recording or ... app.	OIN
342	33.00	Manufacture of medical, precision and optical instruments, watches & clocks	OIN
343	33.10	Manufacture of medical & surgical equipment & orthopaedic appliances	OIN
344	33.20	Manufacture of instruments & appliances for measuring, checking, testing,..	OIN
345	33.30	Manufacture of industrial process control equipment	OIN
346	33.40	Manufacture of optical instruments and photographic equipment	OIN
347	33.50	Manufacture of watches and clocks	OIN
348		SubSection DM Manufacture of transport equipment	OIN
349	34.00	Manufacture of motor vehicles, trailers and semi-trailers	OIN
350	34.10	Manufacture of motor vehicles	OIN
351	34.20	Manufacture of bodies (coachwork) for motor vehicles & of trailers &	OIN
352	34.30	Manufacture of parts & accessories for motor vehicles & their engines	OIN
353	35.00	Manufacture of other transport equipment	OIN
354	35.10	Building and repairing of ships and boats	OIN
355	35.11	Building and repairing of ships	OIN
356	35.12	Building and repairing of pleasure and sporting boats	OIN
357	35.20	Manufacture of railway and tramway locomotives and rolling stock	OIN
358	35.30	Manufacture of aircraft and spacecraft	OIN
359	35.40	Manufacture of motorcycles and bicycles	OIN
360	35.41	Manufacture of motorcycles	OIN
361	35.42	Manufacture of bicycles	OIN
362	35.43	Manufacture of invalid carriages	OIN
363	35.50	Manufacture of other transport equipment n.e.c	OIN
364		SubSection DN Manufacturing n.e.c	OIN
365	36.00	Manufacture of furniture; manufacturing n.e.c	OIN
366	36.10	Manufacture of furniture	OIN
367	36.11	Manufacture of chairs and seats	OIN
368	36.12	Manufacture of other office and shop furniture	OIN
369	36.13	Manufacture of other kitchen furniture	OIN
370	36.14	Manufacture of other furniture	OIN
371	36.15	Manufacture of mattresses	OIN
372	36.20	Manufacture of jewellery and related articles	OIN
373	36.21	Striking of coins and medals	OIN
374	36.22	Manufacture of jewellery and related articles n.e.c	OIN
375	36.30	Manufacture of musical instruments	OIN
376	36.40	Manufacture of sports goods	OIN
377	36.50	Manufacture of games and toys	OIN

NaceCo-deID	Code	Text	POLES SECTOR
378	36.60	Miscellaneous manufacturing n.e.c	OIN
379	36.61	Manufacture of imitation jewellery	OIN
380	36.62	Manufacture of brooms and brushes	OIN
381	36.63	Other manufacturing n.e.c	OIN
382	37.00	Recycling	OIN
383	37.10	Recycling of metal waste and scrap	OIN
384	37.20	Recycling of non-metal waste and scrap	OIN
657		**Section O Other community, social and personal service activities**	
658	90.00	Sewage and refuse disposal, sanitation and similar activities	SER

Table 38: RAINS Sectors Related to Stationary Sources with Energy Combustion

RAINS sector	RAINS code	NFR category	SNAP sector
Centralized power plants and district			
New power plants	PP_NEW	1A1a	0101, 0102, 020101, 020102, 020201, 020301
New power plants, grate combustion	PP_NEW1		
New power plants, fluidized bed combustion	PP_NEW2		
New power plants, pulverized fuel combustion	PP_NEW3		
Existing plants [(1)], wet bottom boilers	PP_EX_WB		
Existing plants [(1)], other types (of boilers)	PP_EX_OTH		
Other types, grate combustion	PP_EX_OTH1		
Other types, fluidized bed combustion	PP_EX_OTH2		
Other types, pulverized fuel combustion	PP_EX_OTH3		
Fuel conversion			
Energy consumed in fuel conversion process	CON_COMB	1A1c	0104
Fuel conversion, grate combustion	CON_COMB1		
Fuel conversion, fluidized bed combustion	CON_COMB2		
Fuel conversion, pulverized fuel combustion	CON_COMB3		
Residential, commercial, institutional, agricultural use			
Combustion of liquid fuels	DOM	1A4a	020103-06, 020202-03, 020302-05
Fireplaces	DOM_FPLACE	1A4b	
Stoves	DOM_STOVE		
Single house boilers (<50 kW) - manual	DOM_SHB_M		
Single house boilers (<50 kW) - automatic	DOM_SHB_A		
Medium boilers (<1 MW) - manual	DOM_MB_M	1A4a	
Medium boilers (<50 MW) - automatic	DOM_MB_A		
Fuel combustion in industrial boilers			
Combustion in boilers	IN_BO	1A2	010301-03, 010501-03, 0301
Combustion in boilers, grate combustion	IN_BO1		
Comb. in boilers, fluidized bed combustion	IN_BO2		
Comb. in boilers, pulverized fuel combustion	IN_BO3		
Other combustion	IN_OC		010304-06, 010504-06, 0302, 0303
Other combustion, grate combustion	IN_OC1		
Other combustion, fluidized bed combustion	IN_OC2		
Other combustion, pulverized fuel combustion	IN_OC3		

Source: Klimont, et al., (2002), table 2.2.

4.3.3 Extensions for TRIAS

Regio-SUSTAIN has been chosen for small scale analyses of environmental impacts which are caused by transport and energy sources. To fulfil this objective the original Regio-SUSTAIN model had to be enhanced for the TRIAS project mainly because of the following reasons:

- The original model has been developed for transport issues (only line sources have been considered),
- Population numbers have been based on data from the year 2000 and
- Disaggregated population densities for each NUTS III region have been calculated.

The geographical scope of TRIAS is the European Union (EU25). Regio-SUSTAIN will be applied only to two regions, namely the Ruhr area and South of Spain, since larger areas would involve too complex calculations, especially when analysing different scenarios.

4.3.3.1 Population Forecast

The methodology of Regio-SUSTAIN for disaggregating population to CORINE land cover data has been developed by Gallego (2001) and modified by Schmedding (2006). Distribution values are applied for all land cover types to calculate the number of persons per geographical cell. Integrated in the original Regio-SUSTAIN model are population numbers from Eurostat which refer to the base year 2000.

TRIAS is aimed at providing quantitative estimates of the potential of conventional and alternative vehicle and fuel technologies until 2050 including their impacts on the economy, the environment and society. Having in mind demographic tendencies in Germany (Ruhr area[15]) and Spain (South of Spain[16]), projections over the following forty years should also consider demographic developments. Therefore, a demographic module has been implemented into Regio-SUSTAIN. Population growth rates of Eurostat which are available on NUTSII level are applied in the module. The following table summarises the yearly growth rates which are implemented into the Regio-SUSTAIN demographic model.

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15 The Ruhr area is defined as the following NUTS III regions: Mettmann, Düsseldorf, Duisburg, Essen, Mülheim, Oberhausen, Bottrop, Gelsenkirchen, Unna, Bochum, Dortmung, Herne and Ennepe-Ruhr Kreis

16 South of Spain is defined as the following NUTS III regions: Cordoba, Huelva and Sevilla

Table 39: Growth rates per year

NUTS II Region	**Name of NUTS II Region**	**NUTS III Region**	**Name of NUTS III Region**	**Population growth rate[17] [% per year]**			
				2000-2005	2005-2010	2010-2020	2020-2030
DEA1	Düsseldorf	DEA1C	Mettmann	-0.1013	-0.1025	-0.1587	-0.2549
		DEA11	Düsseldorf	-0.1013	-0.1025	-0.1587	-0.2549
		DEA12	Duisburg	-0.1013	-0.1025	-0.1587	-0.2549
		DEA13	Essen	-0.1013	-0.1025	-0.1587	-0.2549
		DEA16	Mülheim	-0.1013	-0.1025	-0.1587	-0.2549
		DEA17	Oberhausen	-0.1013	-0.1025	-0.1587	-0.2549
DEA3	Münster	DEA31	Bottrop	+0.1202	+0.1076	-0.0201	-0.1334
		DEA32	Gelsenkirchen	+0.1202	+0.1076	-0.0201	-0.1334
DEA5	Arnsberg	DEA5C	Unna	-0.1976	-0.1599	-0.2081	-0.3088
		DEA51	Bochum	-0.1976	-0.1599	-0.2081	-0.3088
		DEA52	Dortmund	-0.1976	-0.1599	-0.2081	-0.3088
		DEA55	Herne	-0.1976	-0.1599	-0.2081	-0.3088
		DEA56	Ennepe-Ruhr Kreis	-0.1976	-0.1599	-0.2081	-0.3088
ES61	Andalucia	ES613	Cordoba	+1.1569	+0.7950	+0.4601	+0.1948
		ES615	Huelva	+1.1569	+0.7950	+0.4601	+0.1948
		ES618	Sevilla	+1.1569	+0.7950	+0.4601	+0.1948

[17] Growth factors until 2030 have been available from Eurostat only for NUTS II regions. The factors have been applied to each NUTS III region even though differences are expected to occur between the regions.

4.3.3.2 Enhancement to Stationary Emission Facilities

The original Regio-SUSTAIN model has been focused on line-sources, like road and rail-networks, which is however insufficient for the objective of the TRIAS project. TRIAS analyses beside the transport sector also the energy sector where emissions emerge mostly from spot-sources, like power plants. Figure 55 illustrates the extension of Regio-SUSTAIN for the TRIAS project.

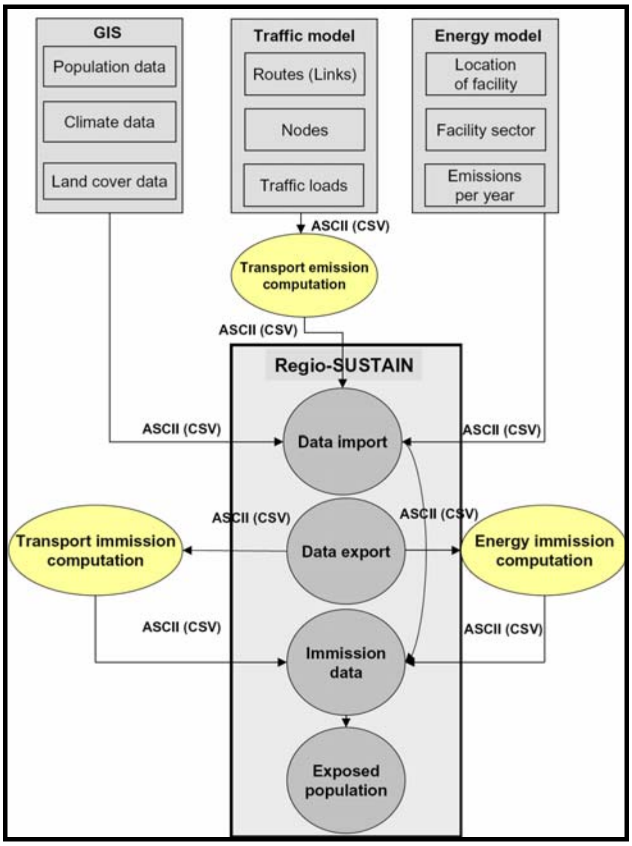

Figure 55: Overview on the structure of the enhanced Regio-SUSTAIN database for the TRIAS project

Input data for stationary facilities come from the energy model POLES. Parameters like the geographical location of each facility, facility sector and emissions per year per facility are integrated in the database. Regio-SUSTAIN is used as a Screening-model to analyse regions, such as the Ruhr area, with a disaggregated approach. This procedure applied for large geographical areas needs some general assumptions, otherwise the complexity of such a screening-model would not allow detailed scenario analyses:

- A constant wind profile has been applied,
- Stationary facilities for each sector are assumed to be identical (size of the chimney, average emission factors) and
- A simplified elevation profile has been assumed for the two areas under investigation.

Regio-SUSTAIN is linked to an immission calculation model for energy facilities which is called CemoS2 (Chemical Exposure Model System). CemoS2 has been developed for the exposure prediction of hazardous chemicals released to the environment by the University of Osnabrueck (Germany).

Based on the above assumptions and the input emissions calculated by POLES a detailed dispersion field for each sector and each substance under investigation is calculated. CemoS2 uses the dispersion-advection equation for the calculation and is therefore able to derive deposits from stationary concentrations as well as from average deposit rates. The result of the immission calculation with CemoS2 is a data file which is imported in Regio-SUSTAIN. The data file includes information about the concentration (kg/m³) of each substance (e.g. NO_x) in the area around the stationary facility. The area around the facility is divided into small cells having disaggregated information for each cell.

Regio-SUSTAIN uses the information from stationary and line sources to calculate overall immission concentrations for each geographical cell in the region under consideration. Therefore, a transformation of the local projection system of CemoS2 into the global projection system of Regio-SUSTAIN has to be carried out. Having the same geographical system and overall concentrations per cell, the number of exposed inhabitants can be calculated with Regio-SUSTAIN.

4.3.4 Linkage to VACLAV

VACLAV has been created as a network flow model which follows the traditional four-step approach of trip generation, trip distribution, choice of mode and trip assignment. VACLAV provides Regio-Sutain with information in a geographically referenced format, including data about daily average traffic on each link of the network. Data exports of VACLAV are in a format (ASCII) which can further be used for calculations. These data are updated for each scenario run and are imported into the Regio-SUSTAIN database.

4.3.5 Linkage to ASTRA

The inputs for Regio-SUSTAIN coming from the dynamic assessment model ASTRA refer to the transport module of ASTRA. The transport module calculates the modal-split for six transport modes with further subcategories for each mode of transport. Regio-SUSTAIN's application for the TRIAS project focuses on road transport because road transport is mainly responsible for the emissions under consideration (NO_x and PM). Therefore, the linkage between the two models is based on an exchange of the modal-split structure from ASTRA to Regio-SUSTAIN. The structure is expected to change over time as well as with changing scenario assumptions. Regio-SUSTAIN imports the modal-split in the database. Regio-SUSTAIN uses the Handbook of Emissions Factors (HBEFA) of the German Environmental Agency to apply average emission factors to the vehicle fleet. Emission factors are heavily dependent on the type of vehicle what makes it necessary to consider the modal-split structure in the model. In combination with the average daily traffic on each network link coming from VACLAV the total emissions are calculated for each part of the network.

5 Baseline Scenario Results

This section provides selected results from the TRIAS modelling framework for the baseline scenario. After an introductory section giving an overview on major developments, the results are not anymore presented along the lines of the different models that generated them, but the description of results is organized along a functional structure consisting of:

- Demographic developments and population structure,
- Economic developments including the national economic system and international trade,
- Transport system with the key elements transport demand and transport technologies
- Energy system with the key elements energy demand, fuel prices and transport fuel demand, and
- Environment including indicators on emissions of CO_2 and air pollutants on national level as well as concentrations of air pollutants on regional level.

5.1 Overview on major developments

The TRIAS scenarios provide trajectories for the analysed indicators until 2050. We are using different ways of presenting the results e.g. absolute indicators or indices. The most suitable way to present a variety of indicators across different fields is to use indices, which we calculate relative to the base year 2000. Figure 56 shows three different groups of indicators. The first group includes indicators that remain stable or only show very moderate growth until 2050. This includes population and employment, which both show a peak in the period 2025 to 2035 and then decline, but overall remain very close to the level of the year 2000. Transport energy demand, transport CO_2 emissions (life cycle perspective) and passenger performance, which are the other three indicators of this group, increase by up to 50% until 2050. The second group reveals a growth of about 200% until 2050. GDP and freight transport performance belong to this group, which indicates that the models do not foresee a decoupling between freight transport and GDP, but at least a relative decoupling between transport energy demand and GDP, which can be assigned to technological improvements including not only improved energy efficiency of individual technologies but also switches between different technologies. The last group in the figure represented by one indicator only reaches a growth of more than 300%. This includes exports, which reveals that the models expect a continuation of current globalisation trends leading to further specialisation of production in different world regions and hence growing transport activity between different locations of goods production.

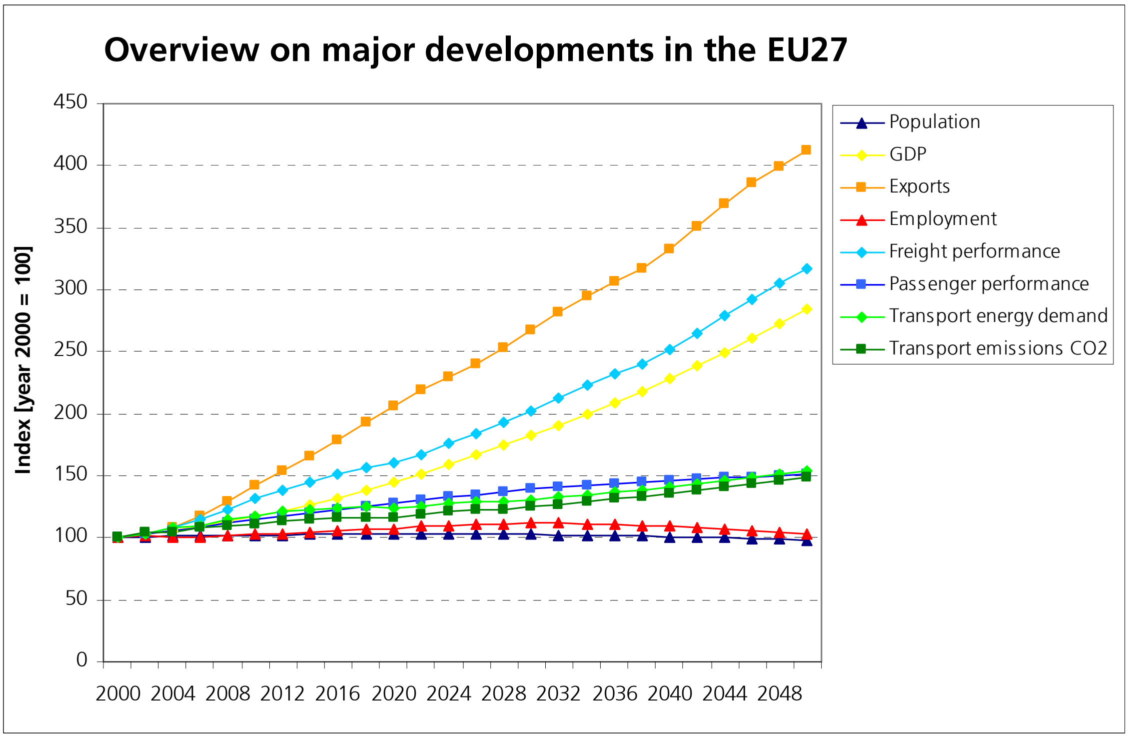

Figure 56: Major developments in the transport-energy-economic system of the EU27

Taking a closer look at indicators of the transport and energy system in Figure 57 we can observe that for both freight and passenger transport the volumes grow slower then the performance, which indicates that travel distances continue to grow, and in particular for passenger transport this is the most relevant driver of continued growth. Despite stabilisation of the population the car fleet continues to grow significantly. One major reason is the catching-up of the new EU member states joining the EU in the years 2004 and 2007 in terms of car-ownership. Further in some countries income continues to grow strongly, which is one of the strongest drivers of car purchase, and finally it seems that ASTRA generating this indicator is more on the optimistic side of forecasts for this indicator.

Consumption and prices of the currently dominating fuels, gasoline and diesel, behave differently. For gasoline, we observe a strongly rising fuel price as well as a sharp reduction of demand reaching about -50% until 2030, which is due to both improved efficiency and fuel switch of cars. For diesel the fuel price increase is much more moderate. Efficiency improvements of trucks and buses, which consume a large share of diesel, remain lower then for cars such that together with the strong growth of freight transport diesel fuel demand doubles until 2050. In addition part of the fuel switch of cars is from gasoline cars to diesel cars, which also drives the growth of diesel fuel demand.

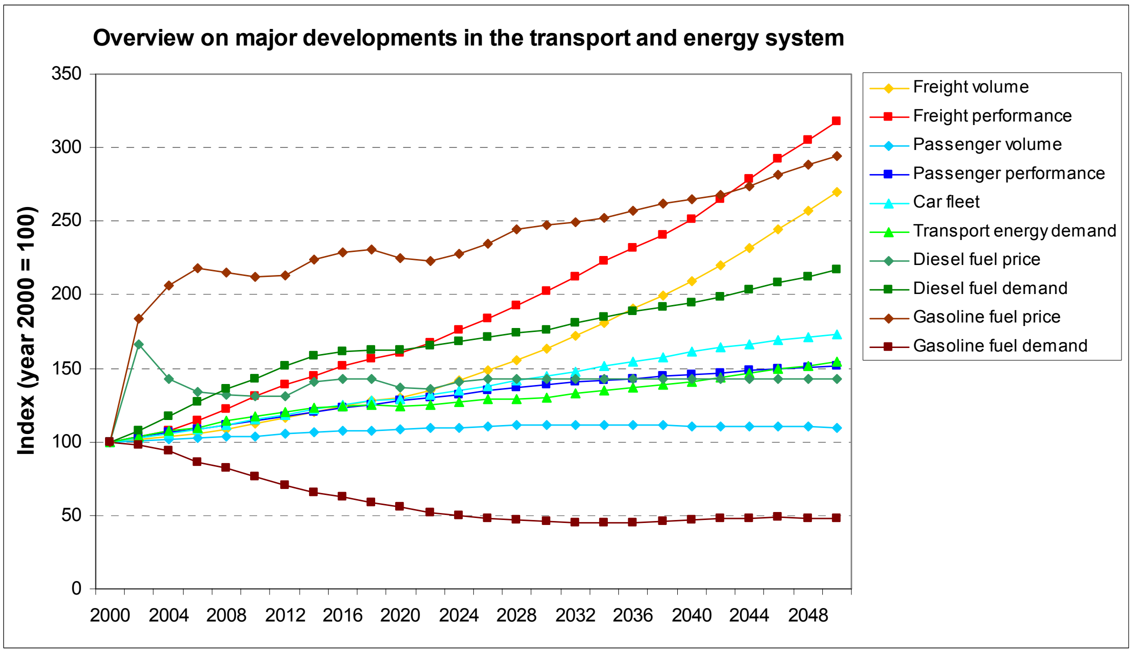

Figure 57: Major developments in the transport and energy system of the EU27

5.2 Demographic Development

One of the main characteristics of the ASTRA population module (POP) is the independency of outputs from other ASTRA modules. The POP module can be easily run as a stand-alone model. It is mainly based on EUROSTAT data for fertility and death rates and the parameterisation impacting the country-specific differences in death rates and the migration balance. Future development of fertility and death rates are calibrated in order to fit EUROSTAT baseline projections until 2050. Because of its independency on other modules and the different scenario inputs the depicted results are valid for all TRIAS scenarios. In contrast to the Far in excess of the EUROSTAT baseline projections the ASTRA POP module is able to simulate the demographic changes per age cohort for each EU27 country.

Average annual population growth rates are presented in Table 40 for each country and total EU27 population. All countries with positive population growth until 2050 are highlighted by light green colour, countries with declining population by light orange colour. The POP module estimates a decline of EU27 total population by annually –0.09% from 2005 to 2050. In other words this annual decline leads to a EU27 population decrease of –3.4% or in total numbers 16.6 Mio less people until 2050.

Table 40: Average yearly population growth rates

Country	2005-2020	2021-2030	2031-2040	2041-2050	2005-2050	Total Change
AUT	0.19%	0.08%	-0.06%	-0.24%	***0.01%***	***0.62%***
BLX	0.24%	0.20%	0.07%	-0.03%	***0.12%***	***6.21%***
DNK	0.16%	0.00%	-0.02%	-0.15%	***0.01%***	***0.67%***
ESP	0.38%	-0.03%	-0.21%	-0.42%	***-0.02%***	***-0.91%***
FIN	0.20%	0.08%	-0.13%	-0.23%	***0.00%***	***0.15%***
FRA	0.32%	0.24%	0.12%	0.02%	***0.17%***	***8.95%***
GBR	0.30%	0.22%	0.10%	-0.07%	***0.14%***	***7.25%***
GER	-0.01%	-0.15%	-0.32%	-0.51%	***-0.20%***	***-9.55%***
GRC	0.23%	-0.10%	-0.24%	-0.38%	***-0.08%***	***-3.78%***
IRL	0.99%	0.64%	0.45%	0.33%	***0.58%***	***33.49%***
ITA	0.03%	-0.22%	-0.33%	-0.46%	***-0.19%***	***-9.14%***
NLD	0.34%	0.18%	0.05%	-0.10%	***0.13%***	***6.60%***
PRT	0.14%	-0.07%	-0.24%	-0.43%	***-0.11%***	***-5.21%***
SWE	0.39%	0.35%	0.23%	0.07%	***0.25%***	***13.10%***
BLG	-0.80%	-0.94%	-1.01%	-0.94%	***-0.82%***	***-33.62%***
CYP	1.02%	0.64%	0.35%	0.17%	***0.54%***	***30.73%***
CZE	-0.12%	-0.29%	-0.42%	-0.45%	***-0.27%***	***-12.62%***
EST	-0.47%	-0.42%	-0.32%	-0.33%	***-0.35%***	***-16.22%***
HUN	-0.25%	-0.27%	-0.31%	-0.29%	***-0.25%***	***-11.74%***
LAT	-0.55%	-0.44%	-0.42%	-0.35%	***-0.41%***	***-18.42%***
LTU	-0.42%	-0.36%	-0.31%	-0.38%	***-0.34%***	***-15.56%***
MLT	0.80%	0.47%	0.39%	0.24%	***0.46%***	***25.81%***
POL	-0.20%	-0.23%	-0.38%	-0.41%	***-0.26%***	***-12.36%***
ROM	-0.48%	-0.52%	-0.62%	-0.65%	***-0.50%***	***-22.29%***
SLO	0.08%	-0.10%	-0.16%	-0.32%	***-0.09%***	***-4.57%***
SVK	-0.12%	-0.21%	-0.36%	-0.48%	***-0.25%***	***-11.62%***
Total EU27	***0.10%***	***-0.04%***	***-0.17%***	***-0.29%***	***-0.07%***	***-3.40%***

Source: ASTRA (2007)

Overall 16 countries are losing to some extent significantly population. In relative terms especially Eastern European members of the EU are affected by population decrease, while most Western European member states are characterised by stagnating or even slightly growing population. German and Italian population decrease most significantly by –9.6% and -7.7%. Besides Slovenia all Eastern European member states with negative growth rates even outperform these relative decreases. Outstanding Bulgarian, Romanian and the Baltic states population decrease significantly by –15.6% (Lithuania) up to –33.6% (Bulgaria). Most of these countries lose population due to recent and prospectively expected high emigration rates compared with immigration. Additionally most countries losing population suffer among the ageing society problem. Old vintages with high birth rates are in many countries already retired and finally more deaths compared with births lead to decreasing population. In contrast Ireland, Cyprus and Malta denote high positive population growth rates up to +33.5% (Ireland) until 2050. Similar to the countries that are losing most population in relative terms these countries benefit most from expected high immigration rates and therefore positive migration balances.

Figure 58 underlines the problem of ageing society in EU27. The age group 65 plus indicated as "Retired Persons" in the following figure increases by nearly +48.6% until 2050 compared with 2005. Especially the decades from 2010 to 2040 are characterised by strong growth of persons older than 65 due to high birth rates in the respective years while the number of retired persons is stagnating in the last decade from 2040 to 2050. Labour force is decreasing by –11.9% until 2050 suffering among the transition of people in the "Retired Persons" class and decreasing children numbers by –16.9%.

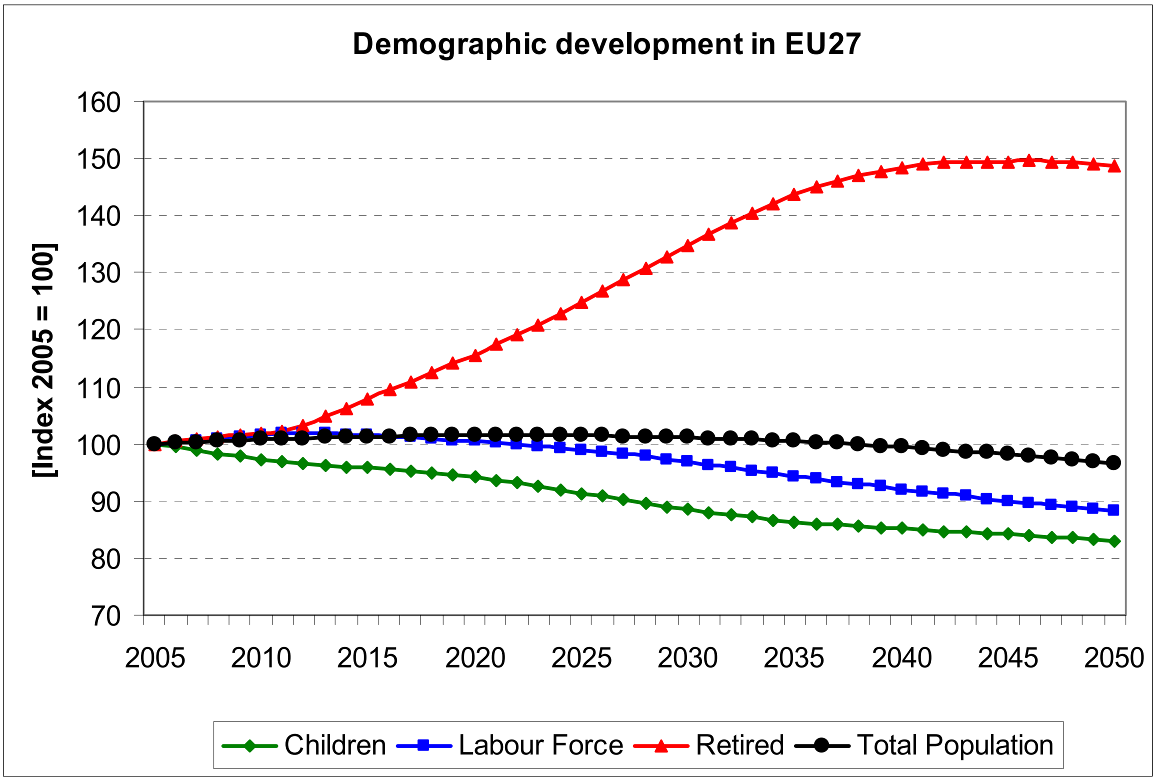

Figure 58: Demographic development in EU27

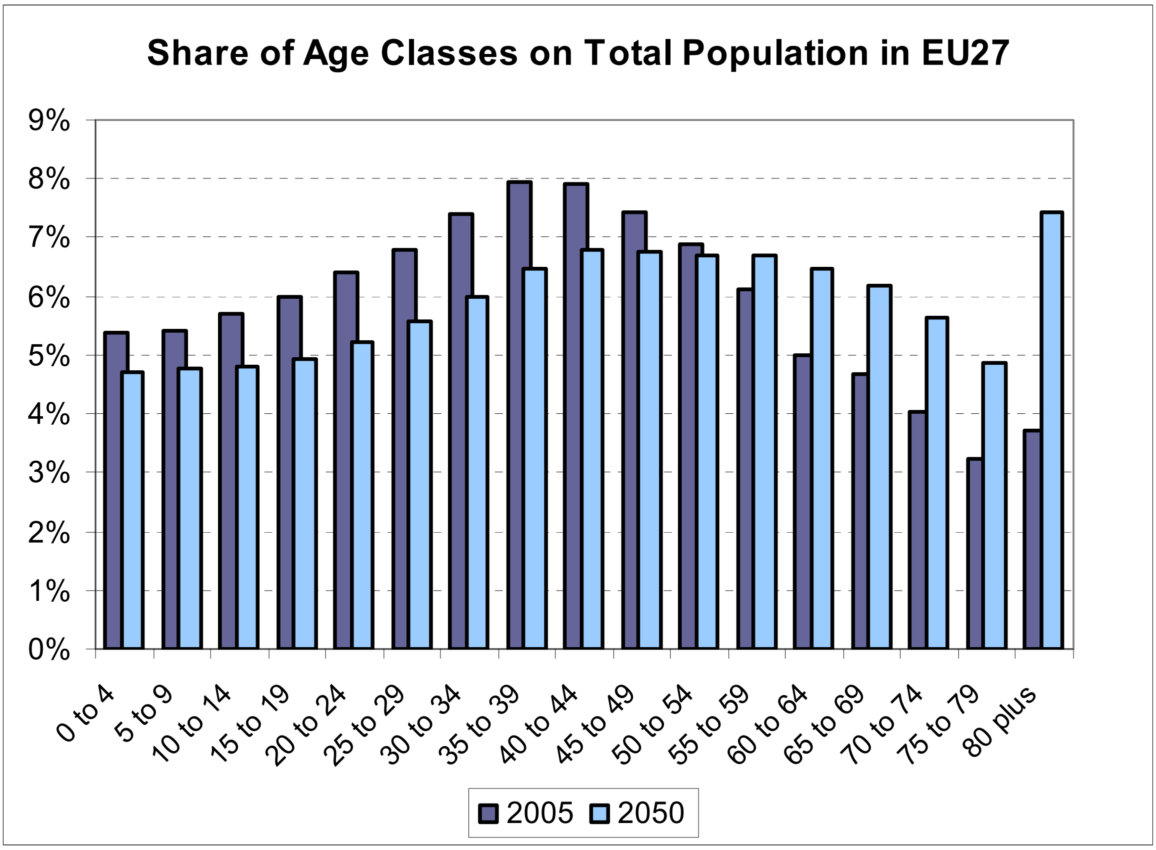

Figure 59: Share of age classes on total population in EU27

Figure 59 presents a more detailed picture of prospective demographic structure in EU27. The significant increase of the oldest age groups, especially the group 80 years plus, indicates the observed increasing life expectancy in EU27.

The following Figure 60 pictures demographic trends of selected EU27 countries. Development of the age cohorts children (0 to 17 years), labour force (18 to 64 years) and retired (65 years plus) are presented for Germany (GER), Poland (POL), Spain (ESP) and Romania (ROM). All countries show the ageing society problem with more or less significantly increasing population in retirement and decreasing numbers of children. Spain is characterised by a strong increase of retired persons after 2020. The total number of retired persons is nearly doubling until 2050. The same but slightly less worrying trend is visible in Poland starting 8 years earlier in 2012. This trend is influenced by high birth numbers in Poland in the period from 1946 to 1960.

The demographic development in Romania shows a similar trend. Nevertheless the development is special compared with the other countries. High emigration rates of people in working age lead to significantly decreasing birth numbers. In contrast to Spain and Poland the growth of the age group older than 65 is not as strong, but the high emigration rates of people in working age and strong decline of children lay a burden on the Romanian economy. Demographic trends estimated for Germany indicate also a relatively strong increase of retired persons until 2035 followed by 15 years impacted by low birth numbers in the years 1970 to 1985. Birth rates are only slightly decreasing compared to Poland and Romania but affect the total population development also negative.

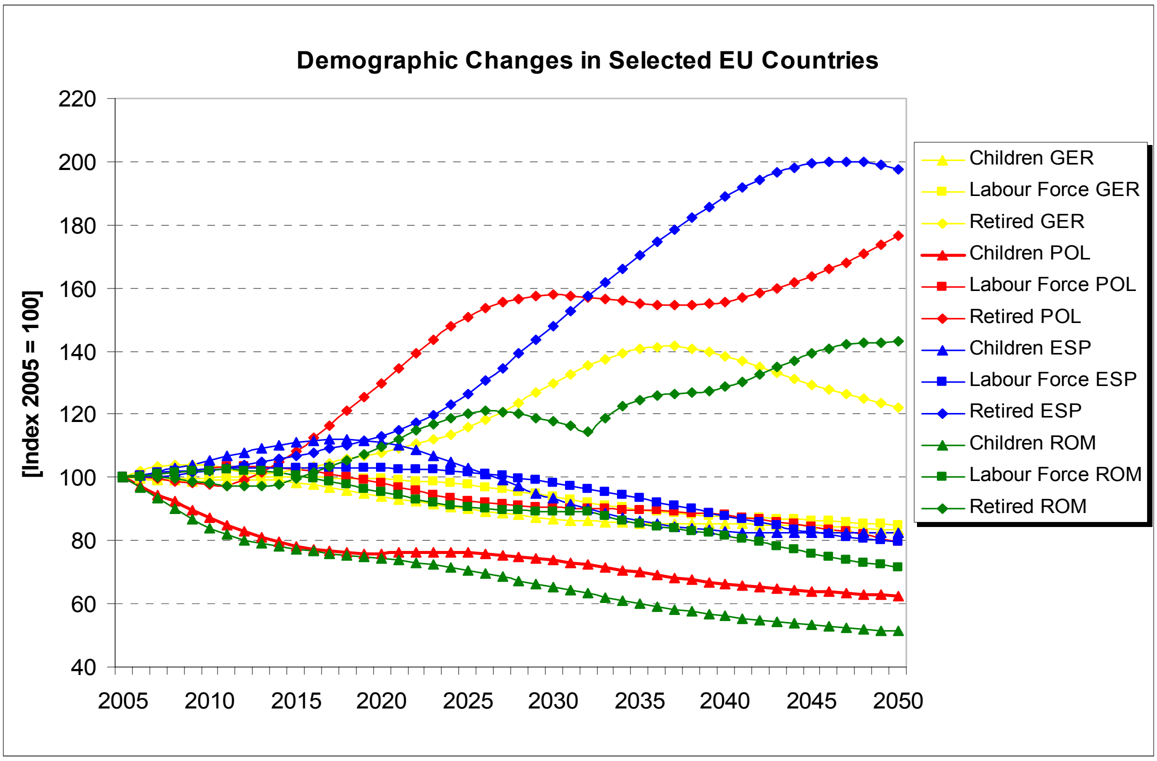

Figure 60: Demographic changes in selected EU countries

Table 41 gives an overview on the demographic trends assessed for all EU27 countries for the years 2030, 2040 and 2050. In general, the problem of ageing society can be observed in all countries. The age groups older than 65 years denote the highest growth while for nearly all countries the numbers of births decline significantly compared with the base year 2005.

Table 41: Demographic changes per age class

Country	2030			2040			2050		
	0 to 17	18-64	65 plus	0 to 17	18-64	65 plus	0 to 17	18-64	65 plus
AUT	92.3	97.8	140.3	92.3	92.8	156.3	89.7	91.7	148.6
BLX	99.3	100.7	132.7	100.8	99.4	139.8	100.6	99.9	136.5
DNK	93.1	98.0	135.9	96.7	94.0	146.9	95.6	94.3	136.8
ESP	93.3	98.3	148.0	83.0	87.8	189.0	82.6	79.5	197.8
FIN	99.0	97.3	142.7	97.9	97.0	135.7	93.0	95.9	132.1
FRA	100.0	101.4	141.4	100.9	100.4	152.3	100.3	101.0	151.6
GBR	96.4	104.1	135.2	97.1	101.7	151.1	95.4	102.1	146.5
GER	86.9	93.8	129.9	85.2	87.6	138.5	83.2	84.9	121.9
GRC	84.4	97.6	136.0	77.2	89.8	157.7	73.4	82.6	166.0
IRL	116.7	118.1	169.9	115.3	119.3	217.3	121.8	117.1	256.1
ITA	89.3	94.1	120.4	82.7	86.5	135.0	79.4	80.9	134.4
NLD	94.9	96.7	168.7	97.6	93.8	181.3	98.8	94.7	168.8
PRT	82.3	101.1	128.6	76.9	92.8	156.4	72.6	85.5	166.1
SWE	103.1	107.6	127.2	104.2	108.4	138.8	104.0	109.6	139.3
BLG	66.1	78.3	104.0	54.6	72.5	93.3	48.7	62.9	96.4
CYP	86.2	125.5	184.1	82.8	124.5	229.9	78.8	123.4	260.5
CZE	76.3	92.7	137.4	68.1	88.1	143.1	63.5	80.1	160.5
EST	71.8	97.0	85.7	61.0	95.4	88.6	56.5	86.7	106.8
HUN	76.9	91.8	125.6	71.2	87.7	132.1	68.1	82.0	144.0
LAT	69.8	90.0	102.8	59.5	90.2	93.5	55.5	84.2	102.7
LTU	63.8	95.2	111.3	56.5	91.4	119.3	51.8	84.5	132.3
MLT	100.2	122.4	124.1	96.9	126.1	141.9	93.8	125.2	165.9
POL	73.8	90.4	157.8	66.3	88.0	155.8	62.5	79.7	176.6
ROM	65.4	89.2	117.8	56.1	81.5	128.6	51.2	71.5	143.1
SLO	71.8	98.1	145.5	63.0	94.4	162.6	58.4	87.8	177.6
SVK	65.0	95.3	158.9	56.6	92.5	161.8	51.9	83.7	182.4

Source: ASTRA (2007)

Many EU27 countries recognised the negative demographic trend and the arising burden on the national economies. Politicians attached higher value to family issues in order to stop the negative trend. Nevertheless the results highlight that demographic development and the attempt of regulating the future demographic structure is a long-term process. Increasing birth rates due to family-friendly policy impact the economy only earliest decades later when children enter the labour market.

5.3 Economic Development

Basically ASTRA calculates the economic development of the European countries endogenously, i.e. GDP the leading indicator to measure economic development is derived from a number of causal relationships of ASTRA. For the purpose of harmonisation with other European studies parameters of these causal relationships can be adapted to provide GDP developments that are consistent with the development in the other studies. This does neither mean that the GDP development of ASTRA is exactly the same as the one in the other studies nor does it mean that it is taken exogenously as it still depends on the causal relationships implemented in ASTRA. In particular this is important for the policy analysis, because only when ASTRA endogenously calculates GDP, it is feasible to capture macroeconomic growth impacts of the policies.

In the case of TRIAS the GDP development of ASTRA was adapted to fit to the baseline scenario of the European ADAM project (http://www.adamproject.eu/). For most of the countries it was achieved to have a deviation of +/-20 % to the ADAM baseline in the year 2050.

Figure 61 presents the development of selected major economic indicators for the EU27 group of countries. GDP grows from the year 2000 by about 185 % until the year 2050, which is equivalent to an annual growth of a bit more than +2 %. Private consumption follows nearly the same growth path, while exports and investments increase significantly stronger than GDP reaching +290 % for investments and +310 % for exports. This is equivalent to an annual growth of about +2.7 % for investments and +2.8 % for exports. The trajectory for total factor productivity (TFP) represents only an approximation since this indicator is calculated on country level based on sectoral inputs it is not possible to present an exact value for the EU27 as this involves some weighting process (while for GDP and the other previous monetary indicators the EU27 value can be added up across the 27 countries to get the EU27 value). The weighted indicator for TFP increases by +170 % until 2050, which still makes it the largest contributor to growth of GDP on the supply side. The only indicator that remains nearly stable over the whole time horizon is employment, For employment we observe an annual growth of close to +0.4 % until 2030 and an annual decline of a bit above -0.4 % for the period 2030 until 2050. Since, population declines slightly stronger this implies a slight increase of the activity rate of the population.

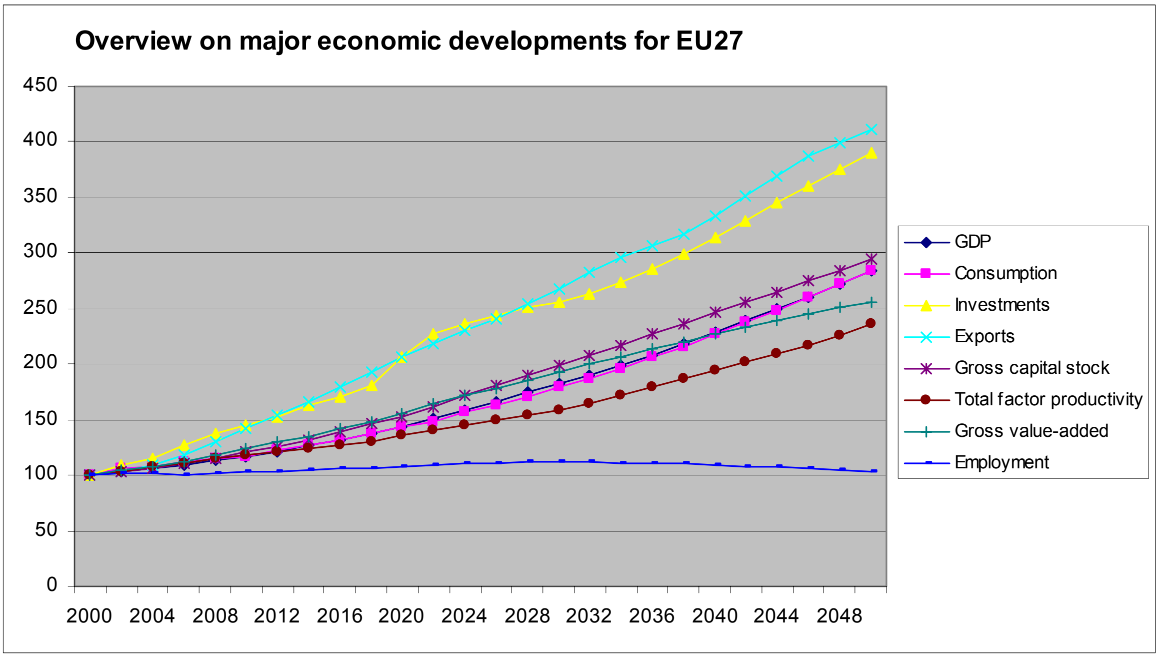

Figure 61: Overview on major economic trajectories for EU27

Countrywise GDP growth of the EU15 countries is presented in Figure 62 and for the EU12+2 countries in Figure 63. Overall the group of EU12 countries grows significantly stronger revealing an annual growth of +2.8 % compared with +2 % of the group of EU15 countries. Partially this documents the catch-up of these countries, but on the other hand it is also a mathematical artefact as the base value to calculate percentage changes is much smaller for EU12 countries then for EU15 countries. In such cases it is even possible that absolute growth could be smaller for those countries, which reveal a higher percentage growth. This is not the case here, as the share of GDP of the EU15 countries on total GDP of EU27 decreases from 95% in 2000 to about 93% in 2050. The ranking of countries in terms of GDP remains mostly stable though some stronger growing countries like Spain and the United Kingdom increase their relative importance, while Germany and France slightly loose importance. In the case of France, the growth potential should be underestimated by ASTRA in TRIAS.

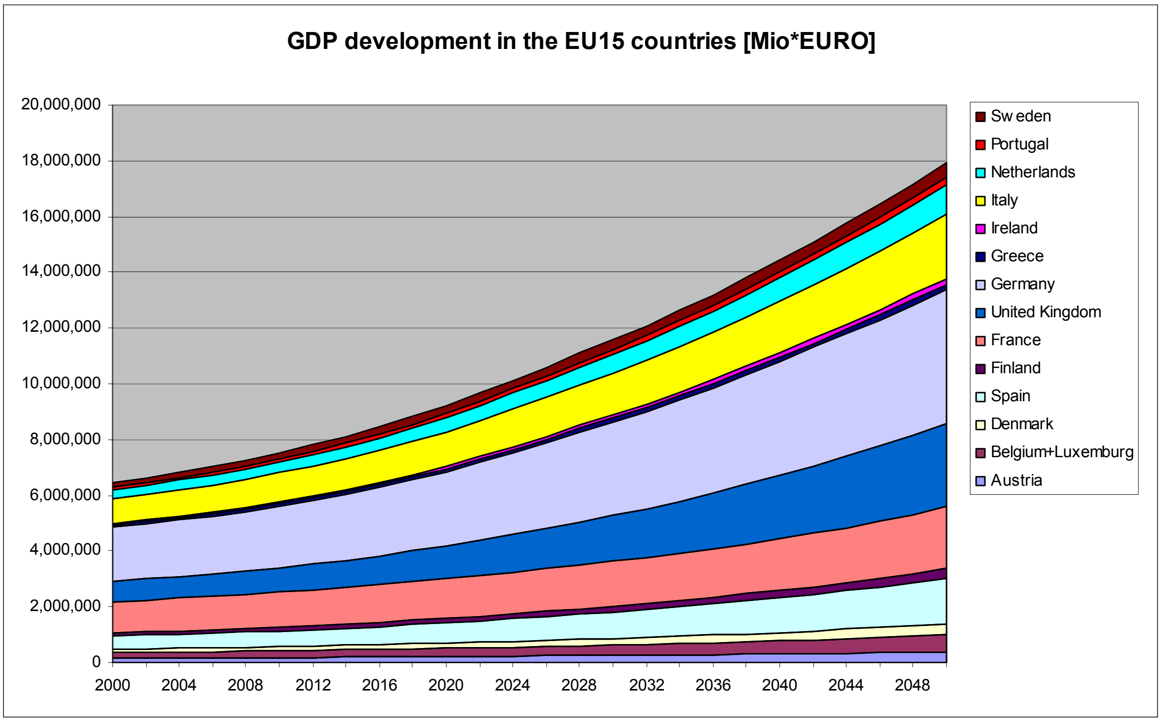

Figure 62: GDP trajectories for the individual EU15 countries

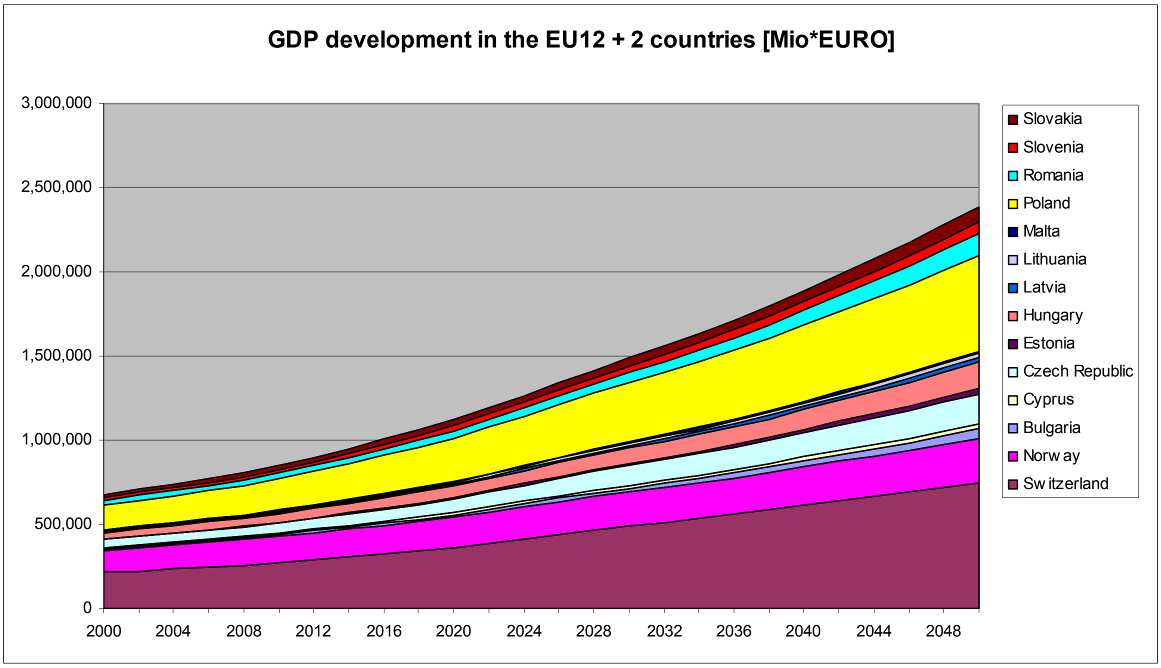

Figure 63: GDP trajectories for the individual EU12+2 countries

Exports constitute one of the most important drivers of economic growth. Figure 64 presents the growth of exports from goods sectors of the EU27 and Figure 65 the growth of the service sectors. In particular the growth of the goods sectors is relevant as it generates freight transport in ASTRA, though one has to take into account that these are monetary values, which do not directly translate into volumes of goods transport. The four strongest export sectors of the EU27 remain in their ranking with vehicles being the largest export sector and then chemicals, electronics and industrial machinery. In terms of growth percentages between 2010 and 2050 the ranking is different: communication services grow strongest followed by computers, electronics and catering services, the latter reflecting the growth in tourism.

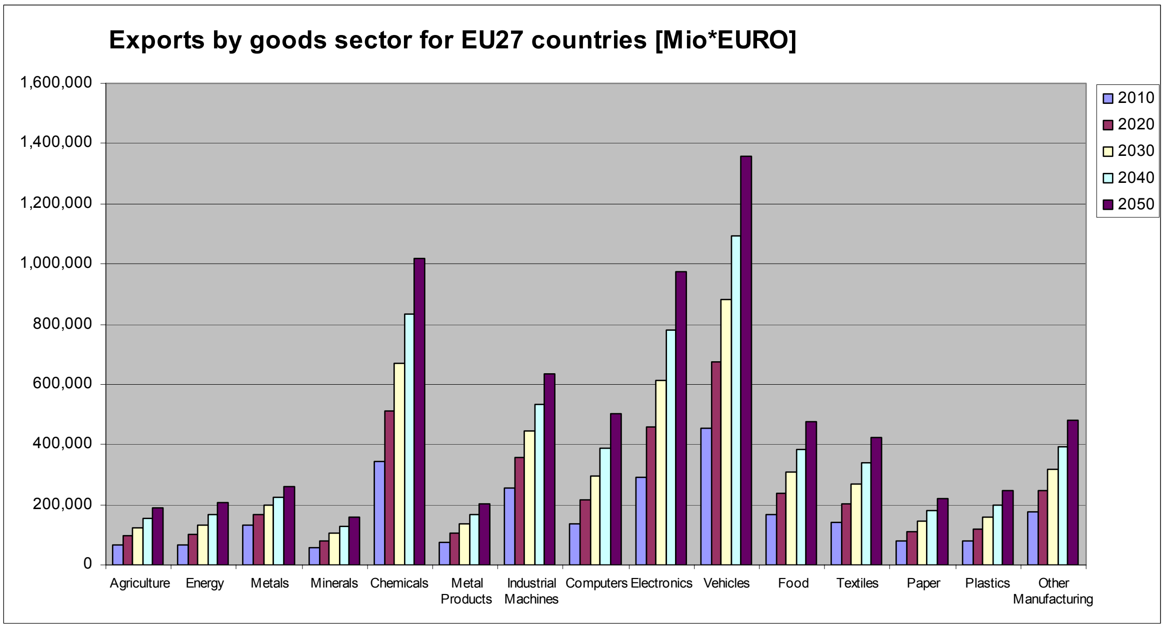

Figure 64: Change of exports of goods sectors for the EU27

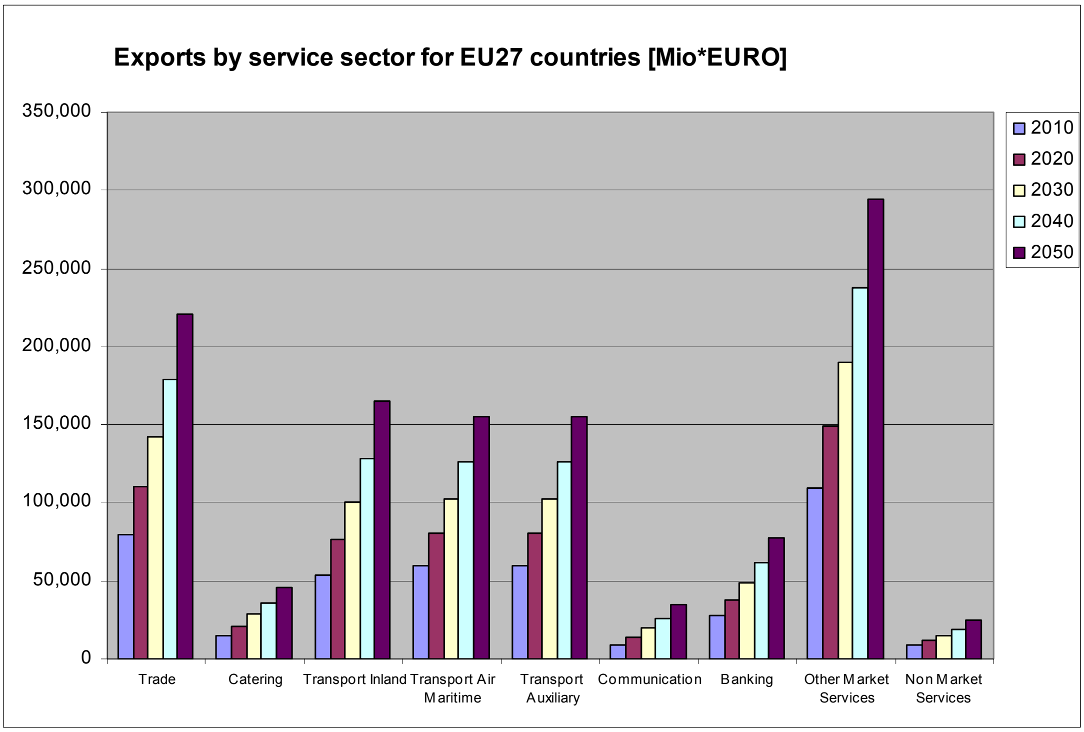

Figure 65: Change of exports of service sectors for the EU27

Another economic indicator that is driving freight transport is the production value of the goods sectors, which is shown in Figure 66. The production value includes both the output of a sector that is demanded as final demand (i.e. consumption, investment, exports and government consumption) and the output of intermediate products that is used as input for the production of other sectors. As also intermediates have to be transported between different production locations this constitutes a suitable indicator to drive domestic freight transport.

Obviously the largest single sector is construction, which holds for the whole period and which is also relevant for transport as this sector generates a large transport volume. But the following sectors change their rank over time. Food is the second most important sector at the beginning in 2010, but vehicles take over this role at 2020. Chemicals increase their rank and become the fourth largest sector in terms of production value after 2030. In terms of growth percentages the ranking of the most dynamic sectors is computers with over +300 % between 2010 and 2050 followed by electronics (+275 %) and vehicles (+246 %). Including service sectors two of them would also belong to the most dynamic sectors: other market services (+281 %) as well as air and maritime transport services (+245 %).

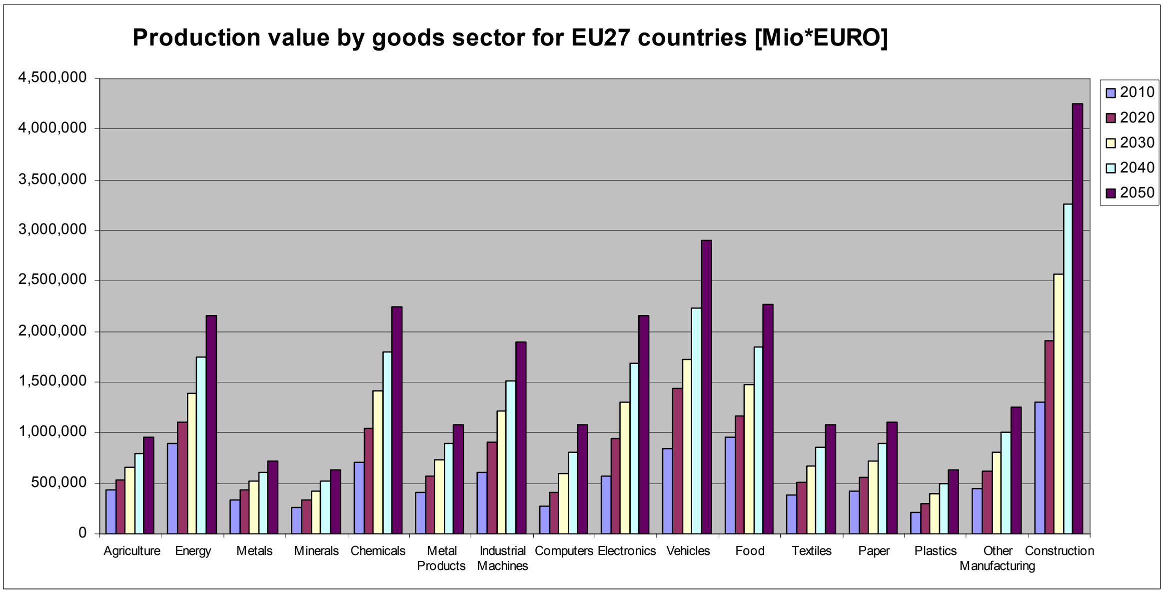

Figure 66: Change of production value of goods sectors in EU27

In terms of employment by sector the picture differs significantly from the one of production value as shown in Figure 67 for goods sectors and in Figure 68 for service sectors. The main similarity is that other market services constitute by far the largest sector. But in contrast to production value only for a few sectors dynamic growth can be observed, and is all cases this is not maintained over the whole period between 2010 and 2050. Employment in other market services grows until 2040 and then reduces; trade, after 2030 the second largest sector, remains more or less stable, while non-market services (i.e. mainly public authorities and public services) decline and loose their second most important position in 2030. For construction, the fourth most relevant sector for employment, growth can be observed until 2030 and afterwards employment reduces. Agriculture looses employment until 2020 and then stabilizes. The most dynamic and relevant sectors are vehicles with a growth of +39 % and food with +32 % between 2010 and 2050.

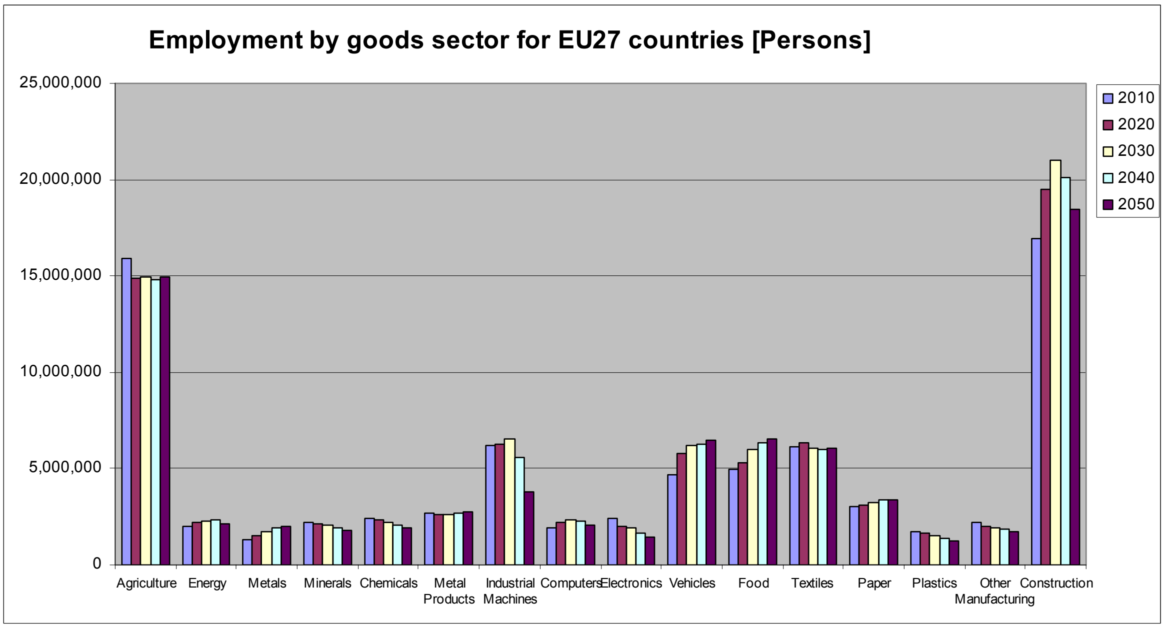

Figure 67: Change of employment in goods sectors of EU27

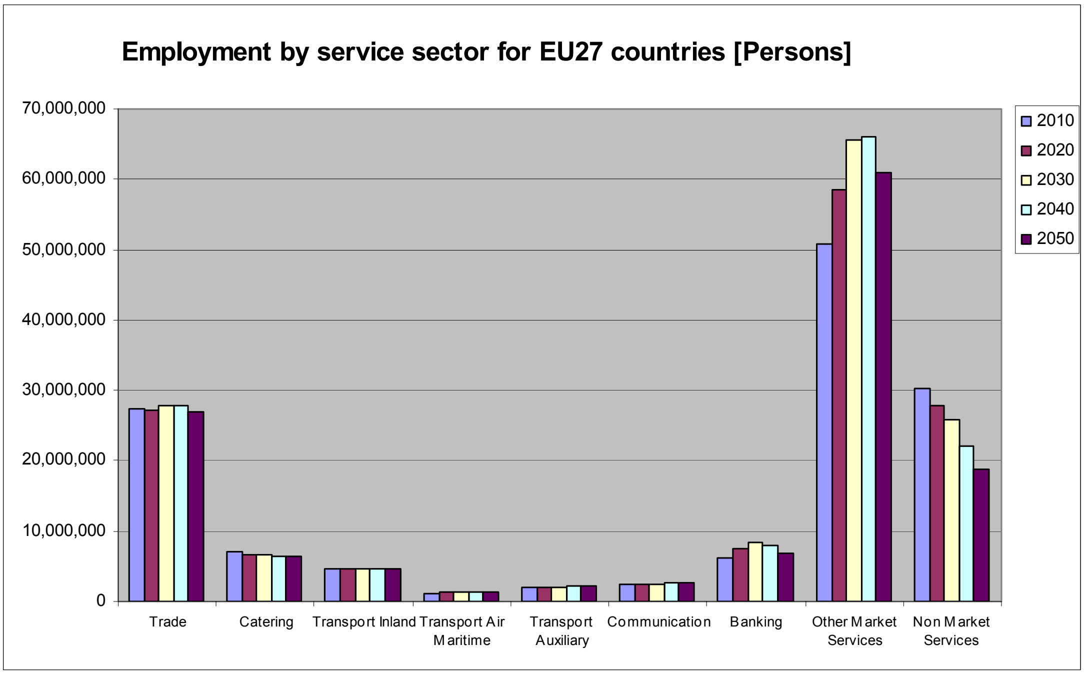

Figure 68: Change of employment in service sectors of EU27

Figure 69 presents a different view on the trajectories of employment by sector in the EU27 countries. In this view the strong reduction of agricultural employment until 2020 due to the restructuring of agriculture in the new EU member states of the years 2004 and 2007 becomes obvious. Also the continuous decline of employment in the government sector is apparent, which is fostered by concepts like the lean state and the continued privatisation of former governmental activities like health care (e.g. hospitals) or education. Also the two large sectors construction and other market services experiencing growth until 2030-2035 and afterwards decline can be identified easily.

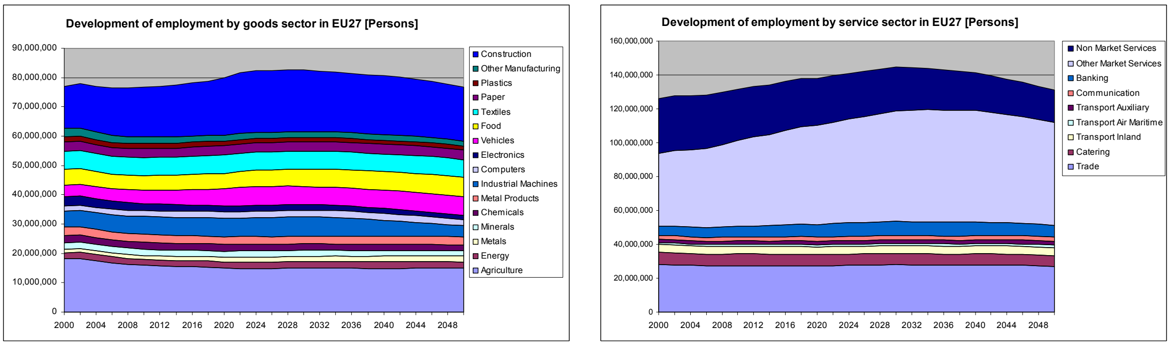

Figure 69: Trajectories of employment by sectors in EU27

Another element of the economic system that is related to transport is investments into transport infrastructure and into vehicles. These are presented in Figure 70 differentiated into EU12 and EU15. The total of all curves represents total transport investment in EU27. It is important to notice that investment into vehicles grow much stronger than into infrastructure. Investments into vehicles increase only slightly slower than the total investments in these regions, while transport infrastructure investments for EU15 grow at a similar pace as EU15 GDP, while for the EU12 the transport infrastructure investments grow even significantly slower than GDP. In other words, for EU15 the share of transport infrastructure investments on GDP remains more or less constant, while this share is declining for EU12 countries.

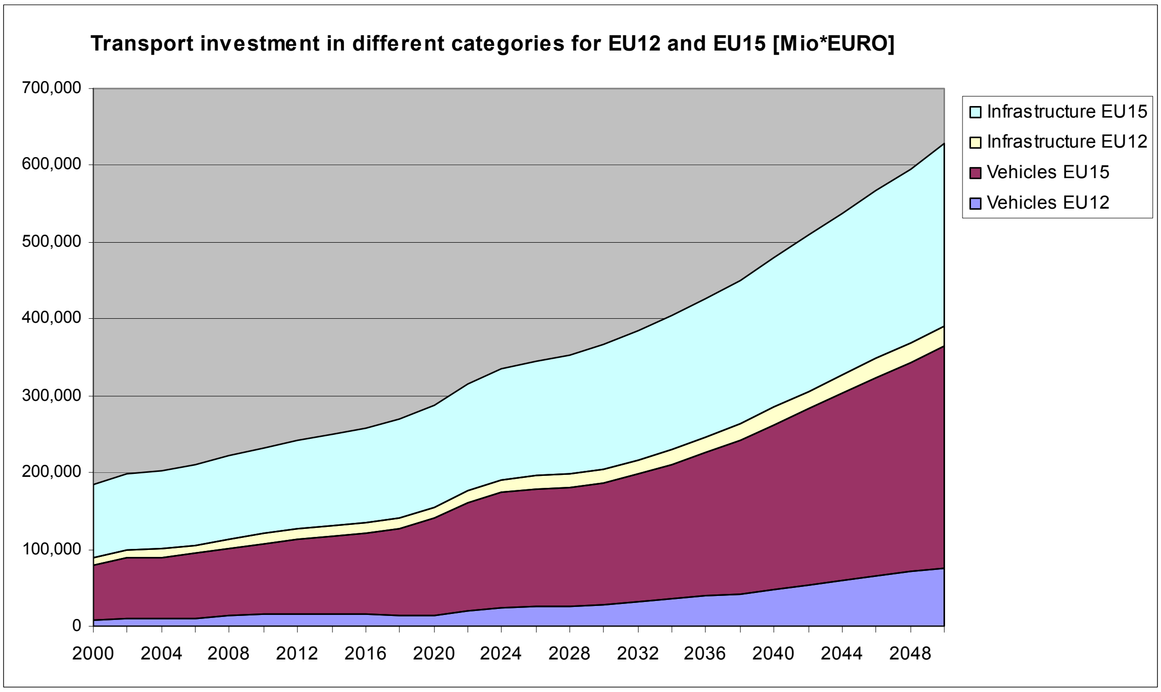

Figure 70: Trajectories of different transport related investments in EU12 and EU15

5.4 Transport System Trends

The following graphs summarise the base trend of the passenger, freight traffic and vehicle fleet composition in the baseline scenario.

ASTRA Transport System Trends

The trend of personal mobility shows an increment at different speed when EU15 and more recent EU Member States are considered. The latter are forecasted to grow faster in the near future as impact of higher incomes and motorisation rates. However, the expected decreasing of population in the Eastern Europe countries partially offsets these determinants resulting in a diminished growth rates and finally also in a reducing mobility in absolute terms with respect to the maximum level reached before 2040. Even if the path is different, at the end of the simulation period the same relative increment is forecast for both areas: 50% more passengers-km, which means an average growth rate of 0.8% per year. In the recent years passenger traffic has grown by 1.8% per year[1], therefore the TRIAS baseline forecast a slow down of personal mobility.

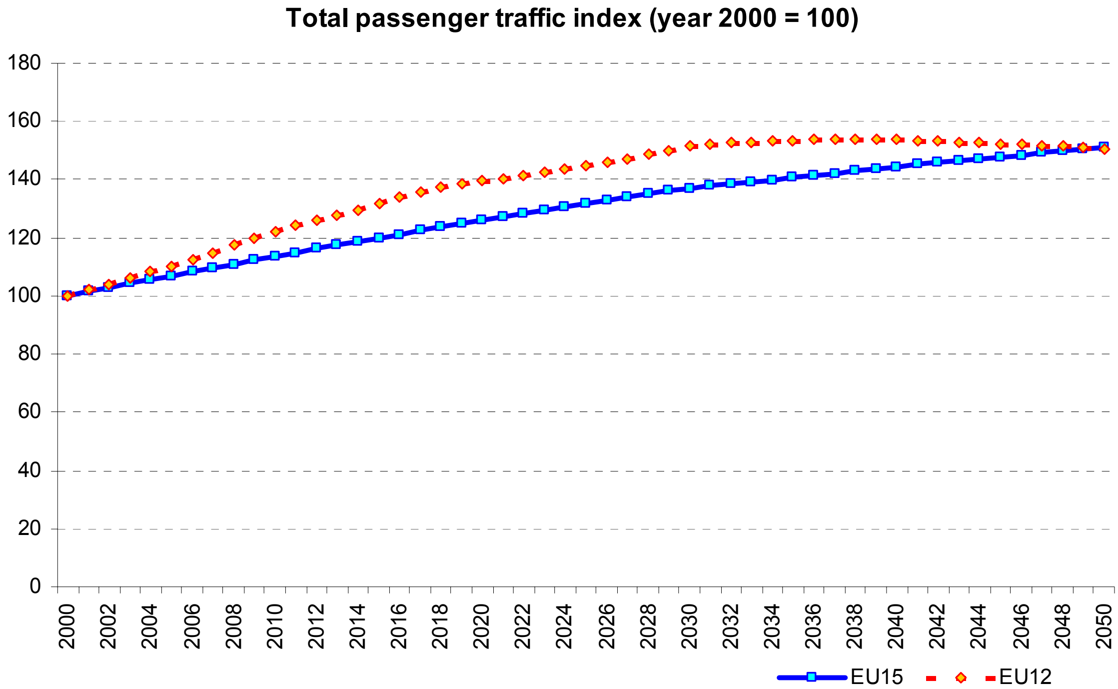

Figure 71: Baseline trend of total pkm

The difference between the two groups of countries is more significant looking at the mobility of goods, which in the Eastern Europe countries is expected to increase more significantly due to the higher economic development rates. For the EU15 countries, the TRIAS baseline foresee that in the year 2050 the amount of tonnes-km will be tripled with respect to the year 2000. This forecast corresponds to an average growth rate of 2.2% per year, which is in

1 Source: EU Energy and Transport in Figures – Statistical Pocketbook 2006. All observed data quoted below in this paragraph is drawn from EU Energy and Transport in Figures unless diversely specified.

line or a bit lower than the trend observed in the recent past (the growth rate of tons-km in the EU15 countries from 1990 to 2001 has been of 2.5% per year). For the EU12 countries, the growth rate of freight transport in baseline is 3.0% per year, which means that in the year 2050 the freight traffic should more than quadruple than in the year 2000.

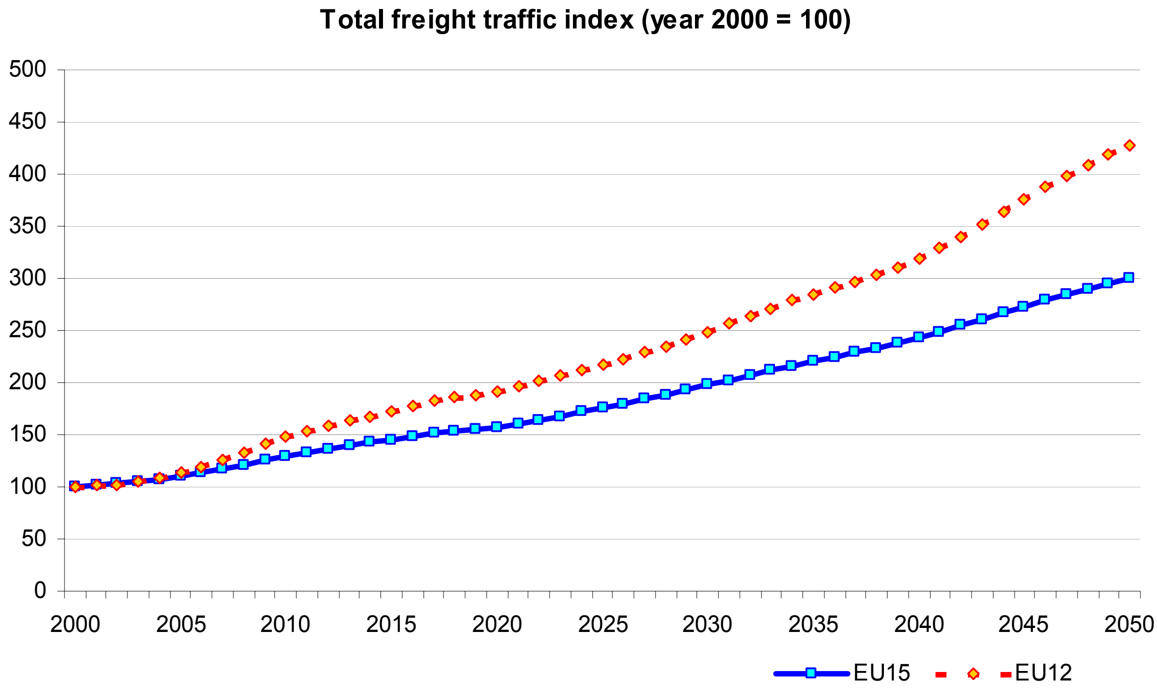

Figure 72: Baseline trend of total tkm

Looking at the trend of the passenger transport modes, the following figure shows that for the whole European Union, air is expected to grow more than any other mode doubling the total number of passengers-km at horizon of the year 2050. Also the growth rate of private cars is expected to be higher than the average (0.9% per year), while for bus and coaches a negative trend is expected, with about 25% passengers-km less in total at the end of simulation period. For rail the baseline reports a moderate growth (0.5% per year). If compared to the recent trends, the hierarchy between modes is confirmed: air has the fastest growth, while bus and coaches has grown less than any other mode in the period 1995-2004.

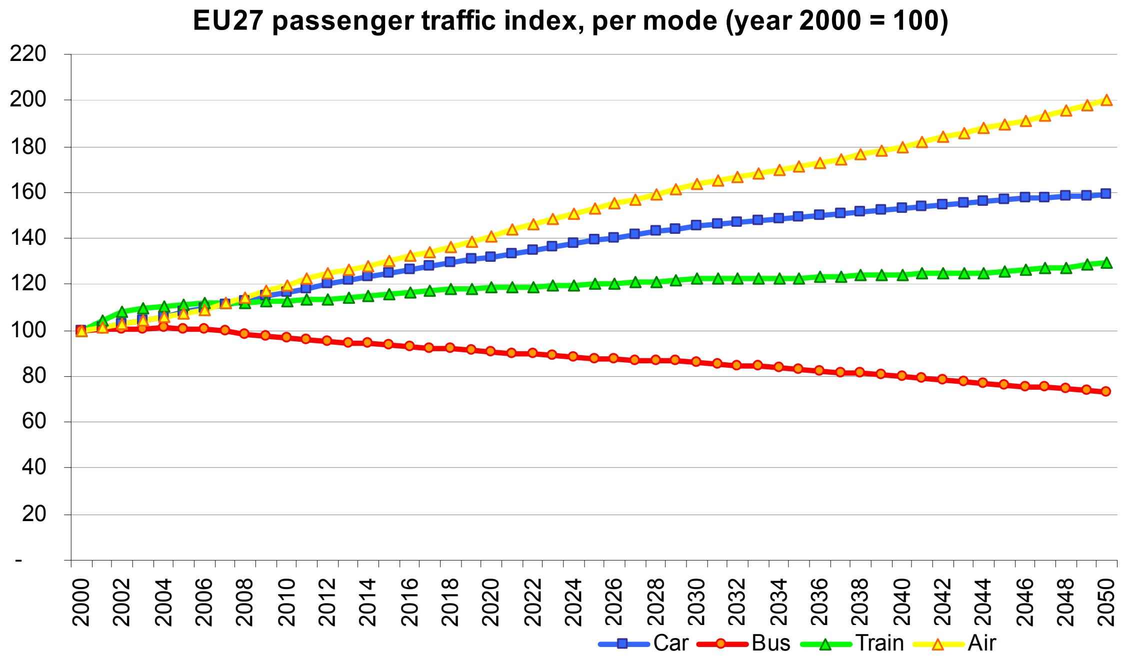

Figure 73: Baseline trend of Pass-km by mode of transport

The different trend of the modes brings to a modification of the mode split. Figure below illustrates how the mode shares evolve in the baseline for the EU27.

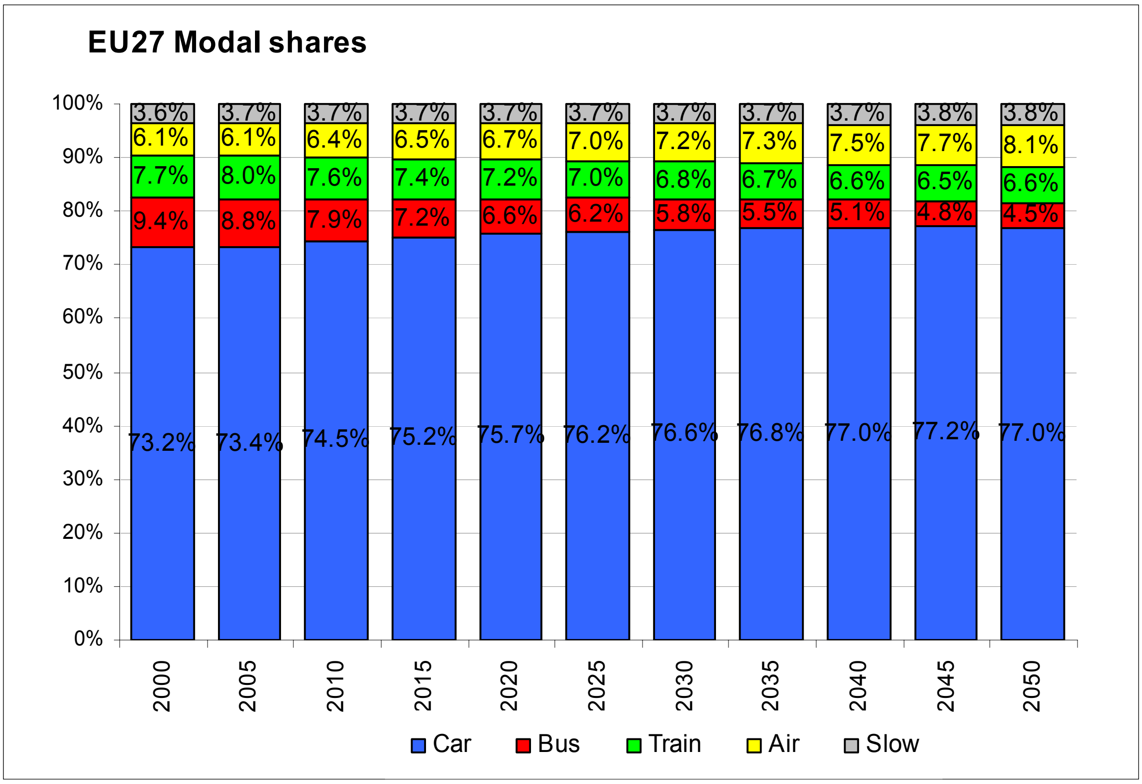

Figure 74: Baseline trend of passenger mode split in the EU27 countries

The mode share of car and air is expected to grow. In particular, air becomes the second transport mode in terms of passengers-km, overtaking bus and train. The former is the major loser as its mode share is more than halved. Again these forecasts are reasonably consistent with observed data. For instance, bus share was about 10% in the year 1995 and less than

9% in the year 2004, and in same period, rail share slightly fall from a bit more than 8% to less than 8%.

Looking at the role of car on motorised land trips (i.e. excluding air trips), table below shows that in all EU countries the share of passengers-km performed by car is expected to increase, but in EU12 countries, where the share of car and the motorization rate at the year 2000 are generally lower than in the EU15 countries, the growth rates are higher. It is remarkable that this trend occurs even if the car cost is supposed to grow more than costs of other modes in the simulated period (see chapter 3).

Table 42: Change of car share(1) in the EU27 countries in the baseline

Country	2000 (2)	2050	Var% 2000 - 2050
AUT	76%	86%	13.0%
BLX	82%	89%	9.1%
DNK	79%	88%	11.6%
ESP	81%	89%	10.0%
FIN	82%	89%	9.5%
FRA	85%	90%	6.1%
GBR	87%	87%	0.1%
GER	84%	90%	6.8%
GRC	76%	84%	10.5%
IRL	72%	86%	18.9%
ITA	83%	90%	7.8%
NLD	85%	88%	2.9%
PRT	82%	86%	5.7%
SWE	80%	89%	10.5%
BLG	27%	55%	99.7%
CYP	48%	75%	54.9%
CZE	73%	84%	15.0%
EST	76%	86%	12.9%
HUN	65%	75%	15.3%
LAT	73%	80%	9.4%
LTU	84%	88%	5.0%
MLT	74%	87%	18.2%
POL	78%	87%	12.1%
ROM	22%	42%	87.0%
SLO	85%	92%	8.1%
SVK	69%	81%	18.7%

(1) Share computed on the car traffic measured in passengers-km with respect to total traffic of motorised land modes (i.e. excluding air and slow modes)

(2) The data for the year 2000 concerns modelled shares not observed ones.

Also for freight transport, the foreseen baseline growth of modes is different (see figure 8). Road is expected to grow faster than its competitors – rail and maritime – at a pace of about 2.7% per year. Rail growth should be slower than road's but faster than maritime's. In the recent past maritime has actually shown larger growth rates than rail, so from this point of view the TRIAS baseline introduces a break in the series. An explanation for this break is that in the ASTRA model, only intra-Europe transport demand is considered. In the model, the economic development of the EU countries gives rise to an increment of transported goods. Actually, part of the generated demand concerns trades with overseas countries and maritime statistics are affected by this trades, while ASTRA deal with the impact on intra-Europe demand only.

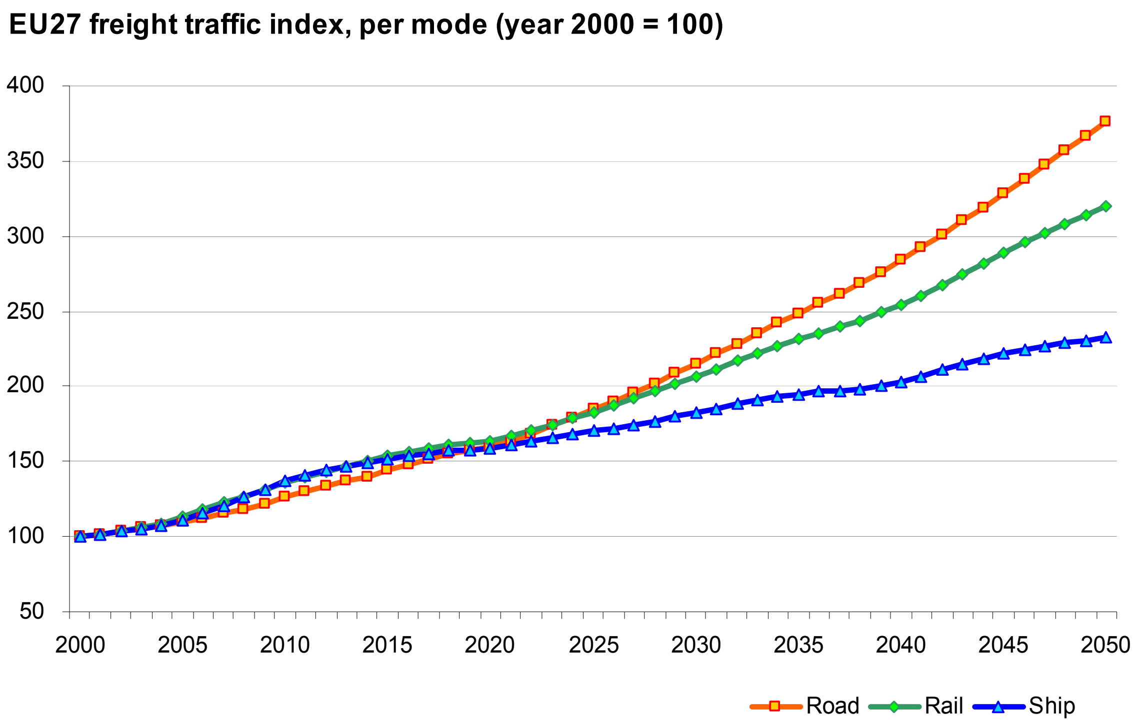

Figure 75: Baseline trend of Tonnes-km by mode of transport

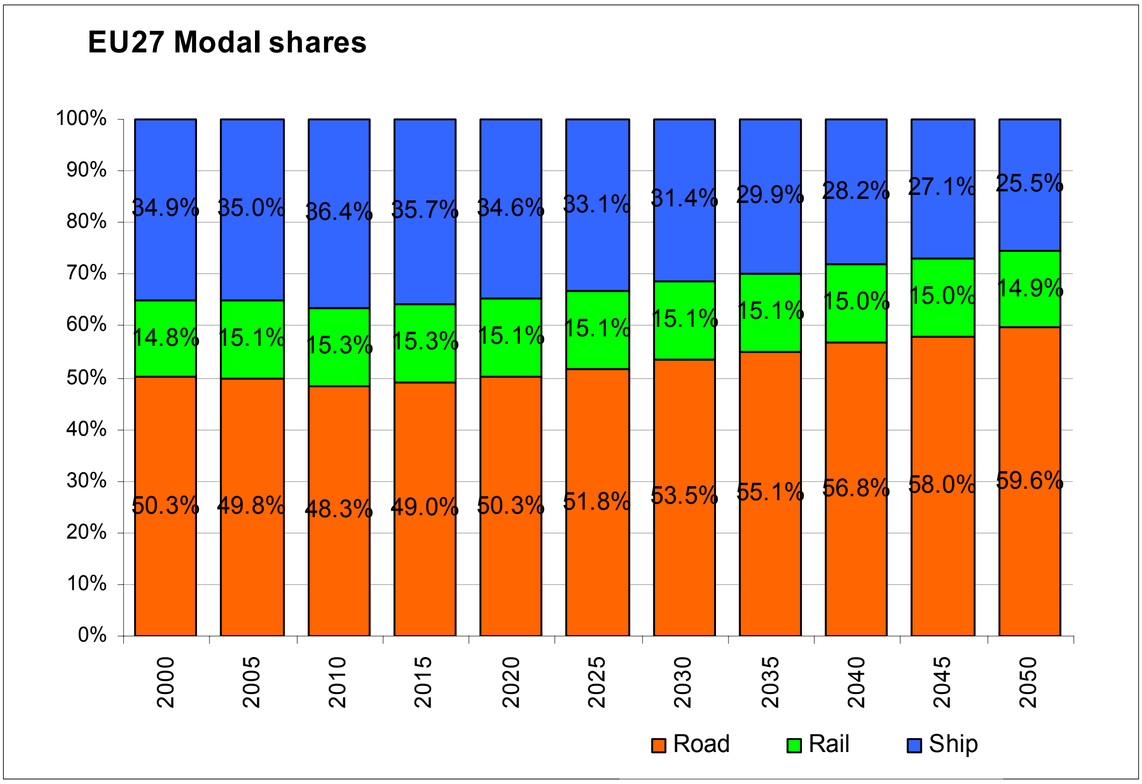

Figure 76: Baseline trend of freight mode split in the EU27 countries

As a consequence of the different trend of the transport modes, mode shares change over time in the TRIAS baseline as shown in figure 9. Rail maintains is share even if the road freight grows much faster. As road and maritime usually are not direct competitors (road is used on shorter distances and for smaller loads), the evolution of mode shares suggests a double shift: from rail to road and from ship to rail. At the basis of this mode shift there is the different development of the economic sectors. Coastal ships are mainly used for bulk goods (oil products, irons, cereals, etc.) whose relevance on the intra-EU trade is decreasing over time. Container ships are especially used to and from overseas, while within EU rail is an alternative mode for this share of traffic, which is the fastest developing one. Therefore, the TRIAS baseline suggests that the future freight demand will be larger and differently composed, higher value goods will be a higher share of total traffic and therefore modes like rail and especially road will be preferred to ship.

ASTRA Vehicle Fleet Trends

In comparison with results from previous ASTRA simulations the TRIAS baseline scenario simulation comprise five new alternative car technologies in addition to five conventional car categories. The following figures demonstrate the baseline scenario trends estimated by ASTRA for car, bus and goods vehicle fleets and highlight the assessed technological development in EU27.

Figure 77 provides an overview on the estimated vehicle fleet development in EU27 until 2050. Analysing the projections one has to take into account the different modelling mechanisms for car, bus and goods vehicle fleets. In contrast to new bus, light and heavy duty vehicle registrations the number of new registered passenger cars depends mainly on factors like demographic trends, development of average income, variable and purchase costs. New registered buses are mainly induced by growing demand in terms of passenger-km resulting from the modal split stage in the ASTRA transport module. Monetary goods flows stemming from the ASTRA foreign trade module and resulting physical goods flows impact the ASTRA freight performance in terms of ton-km. Finally this indicator is used to assess the additionally required light and heavy duty vehicles.

The ASTRA car fleet model estimates a growth of EU27 passenger car fleet of +44.7% until 2030 and +73.5% until 2050 compared with the year 2000. Spoken in absolute numbers this means that the 27 member states of the EU will have 274 Mio registered cars until 2030 and 329 Mio cars until 2050. A moderate average yearly car fleet growth rate of +1.11% and a more detailed look on country results indicate that the car fleet increases most significantly in EU12 countries while most EU15 are already characterised by only slight car fleet growth rates. In comparison with Western European countries EU12 countries like Romania, Slovakia and Hungary are still lacking behind regarding the motorisation and therefore have a higher demand for new cars and faster growth of motorisation. Together with a declining population of –3.4% until 2050 this results in an increasing average motorisation in EU27 of 555 cars per thousand inhabitants until 2030 and nearly 697 cars until 2050 compared with 418 cars per thousand inhabitants in the year 2000.

The transport performance results presented in the previous chapter show the difference between passenger and freight transport. The development of bus vehicle fleets in EU27 showed in Figure 77 reflects the decreasing modal share of bus transport from 9.2% down to 4.4% in 2050. ASTRA assesses a reduction of –18.9% buses until 2030 and –33.2% buses until 2050 due to the modal shift and the falling transport demand.

In contrast ASTRA assesses heavy and light duty vehicle fleets to grow significantly. This trend follows obviously the high growth rates estimated for freight transport with +2.2% yearly growth of ton-km for EU15 respective +3% yearly growth in EU12. The projections show +2.45% yearly growth of light duty vehicle fleets and +2.37% yearly growth of heavy duty vehicle fleets in EU27. Both fleets are doubling until 2034 and even more than tripling until 2050.

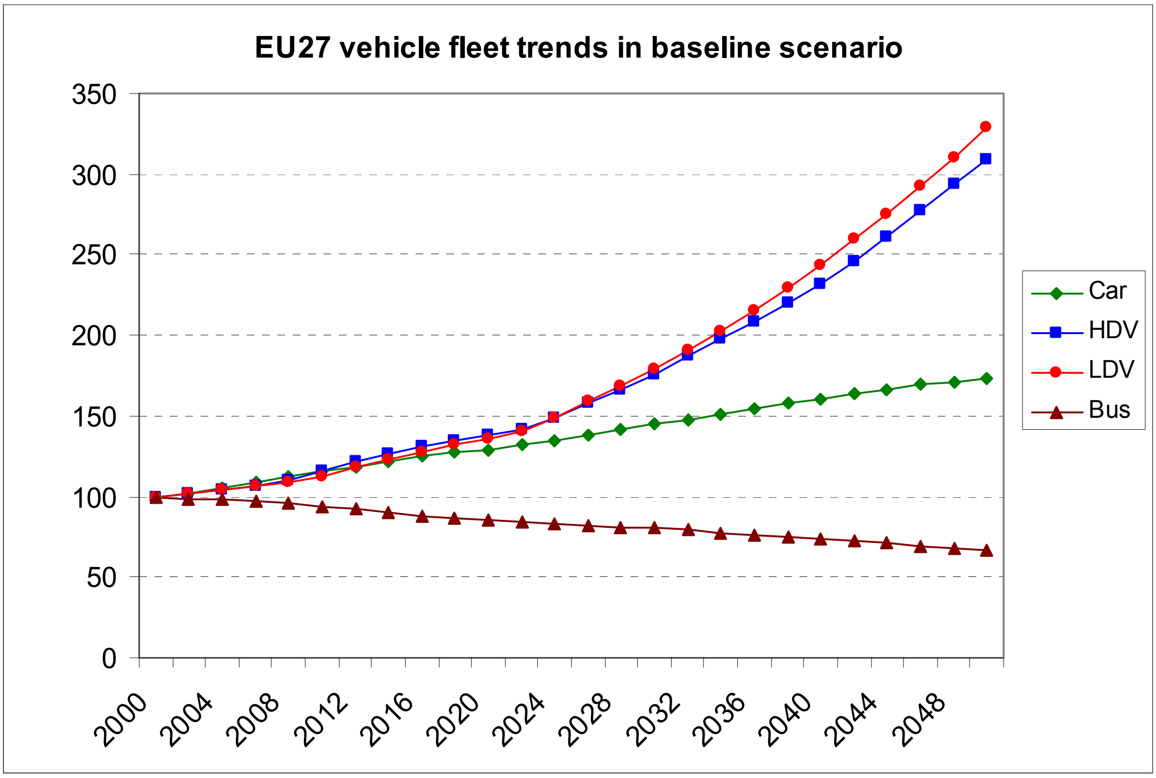

Figure 77: Overview on vehicle fleet trends in EU27

Besides the illustrated trends showing the development of motorisation and size of EU27 vehicle fleets the technological composition of car fleets is of major concern for the scenarios assessed for TRIAS. The ASTRA module responsible for the simulation of the car technology diffusion is the car purchase model. As described in the chapter 3 the car purchase decision is based on variable, fixed and fuel procurement costs depending on the density of filling station network. The results of the calibration and the scenario simulation showed that fixed and variable costs influence the decision for one technology only slightly stronger than filling station infrastructure. Hence, the displayed results are affected by fuel costs provided by POLES, the assumed development of car purchase prices per car technology and the establishment of filling station infrastructure for alternative fuels.

Figure 78 and Figure 79 present the projected technological trends until 2050 in absolute and relative numbers for each of the eight technologies considered in the TRIAS baseline scenario. At a glance the most significant trend concerns the rise of diesel cars. Since the beginning of the 1990ies the share of diesel cars on EU27 car fleets grew strongly. Innovative new diesel technologies like common rail or unit injector system made improved the efficiency of diesel cars and made them more and more attractive in the context of rising fuel prices. Despite 13% higher CO2 emissions per litre fuel than gasoline modern diesel cars are at least currently characterised by higher fuel efficiency and therefore on average less CO2 emitting than gasoline cars. The projections show that EU27 vehicle fleets consist of more diesel than gasoline driven cars for the first time in 2022. The development of diesel and gasoline cars reverse in the year 2040 which is mainly induced by stagnating or even reducing gasoline prices. Regarding mineral oil scarcity and increasing efforts on exploiting oil resources a decrease of gasoline prices seem to be astonishing. Having a closer look on the fuel production technology clarifies this development: the POLES-TRIAS model assumes gasoline to be blended with lignocellulosic ethanol starting in 2030. As the production process of lignocellulosic ethanol is characterised by low costs (see Table 43), gasoline prices decline with increasing shares of this kind of ethanol. The observed reversing trend is enabled by the car purchase model structure even if it is controversial that old technologies might return in the focus as a kind of renaissance. The observed positive development of LPG car registrations in Germany and many other countries are an example for old technologies - LPG cars entered the first markets already in the 1970ies – that rebound as alternatives to other conventional car technologies. Finally the assessment provides a share of diesel cars in EU27 car fleets of 39.6% in the year 2050.

Another interesting outcome of the baseline scenario is the estimated substitution process from gasoline car with high cubic capacity to powerful motorised diesel cars, which is already ongoing since the end of the 1990ies. The originally unattractive old diesel technology became competitive to high-powered cars.

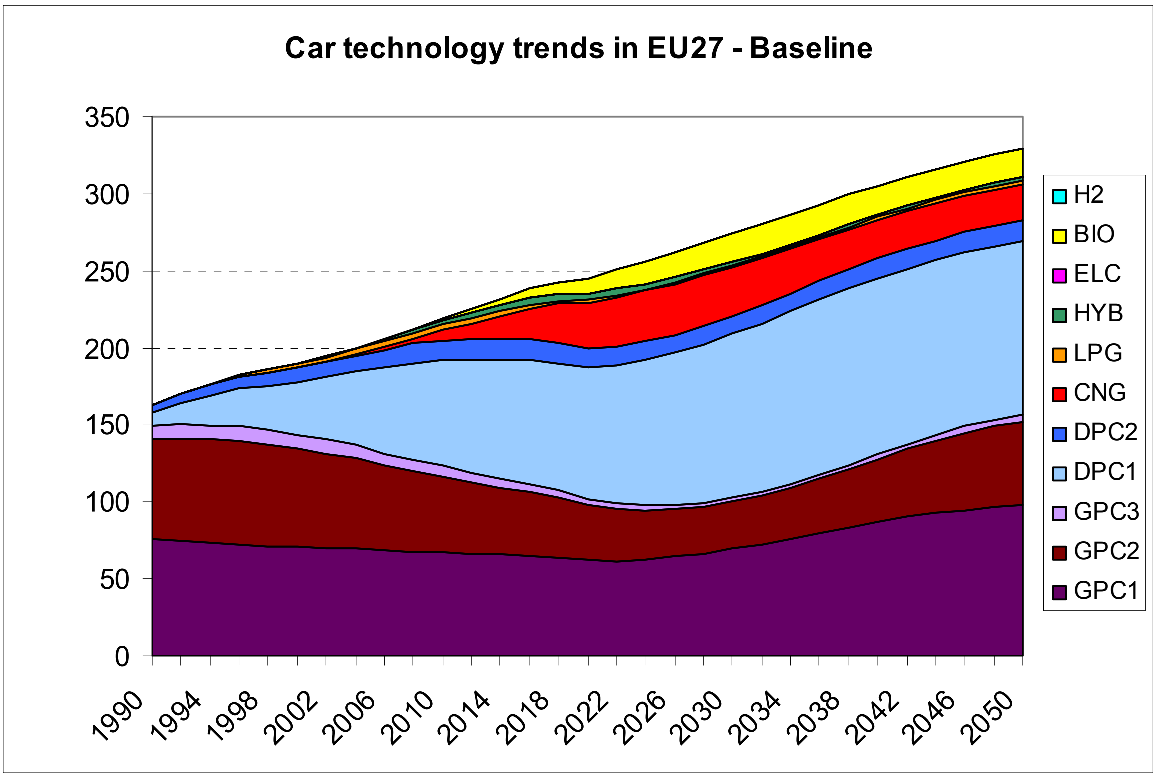

Figure 78: Passenger car technology trends in EU27

The baseline scenario identifies NGV (natural gas vehicles) as the most attractive alternative car technology to car buyers in the mid term. Countries like Germany, Italy, Sweden, Austria and UK currently support the diffusion of CNG cars into the markets and the improvement of filling station infrastructure via action plans. This results in an EU27 share up to 12.9% in the year 2024. In the following years CNG cars are estimated to lose share and end up at 7.2% in 2050. The declining share from 2024 onwards is mainly caused by increasing natural gas prices computed by the POLES-TRIAS model. Compared with other technologies like bioethanol or conventional technology NGV loses attractiveness and the share declines. Regarding the fleet share development of LPG one can say that the modern CNG technology is substituting the older LPG technology. The ASTRA model assesses a reduction of LPG share from 1.4% in 2005 to 0.8% in 2050. Cars driven with bioethanol (BIO) or E85 are projected to have the second highest share of all alternative fuel cars in the baseline scenario. The market share of bioethanol cars in EU27 is increasing and reaches a peak in the year 2032. In the following decades the share is stagnating and ending in 5.4% in the year 2050.

The stagnating or even reversing trend observed for CNG and bioethanol driven cars is mainly caused by increasing efficiency of gasoline cars. Caused by stagnating gasoline prices estimated in POLES the fully developed technology attracts buyers and lead to a slightly recovering share of at least small and partially medium sized gasoline cars. Nevertheless the share of gasoline cars in EU27 declines with -28.2% significantly from 75.8% in the year 2000 down to 47.6% in the year 2050.

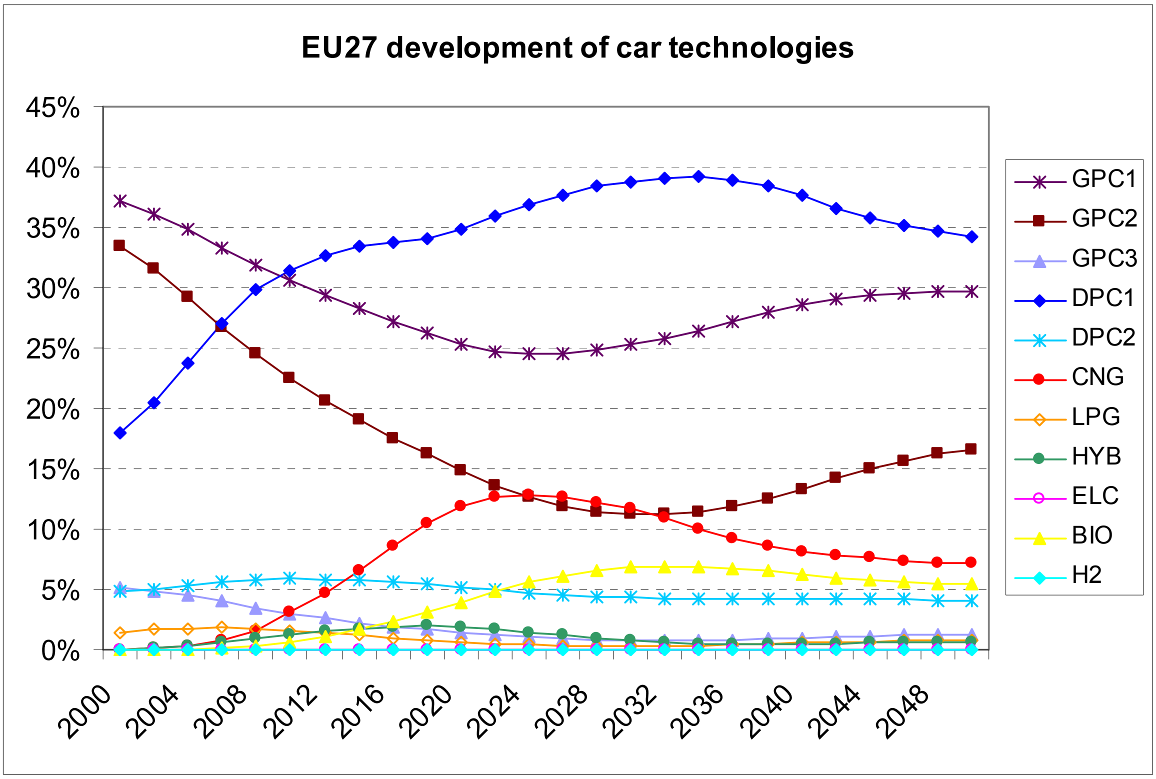

Figure 79: Share of passenger car technology in EU27

5.5 Energy System Trends

POLES Energy Demand

Without taking electricity and transformation system sector into account, the total energy demand in EU27 can be expected to increase by a factor of 1.4 during the period 2006-2050, which means 0.75% increase per year. Transportation is the most energy intensive sector, of which the share of total demand increases from 39% in 2006 to 41% in 2050. Residential sector share decreases from 23% in 2006 to 18.8% in 2050 while service sector share increases from 10% in 2006 to 17% in 2050 (Figure 80).

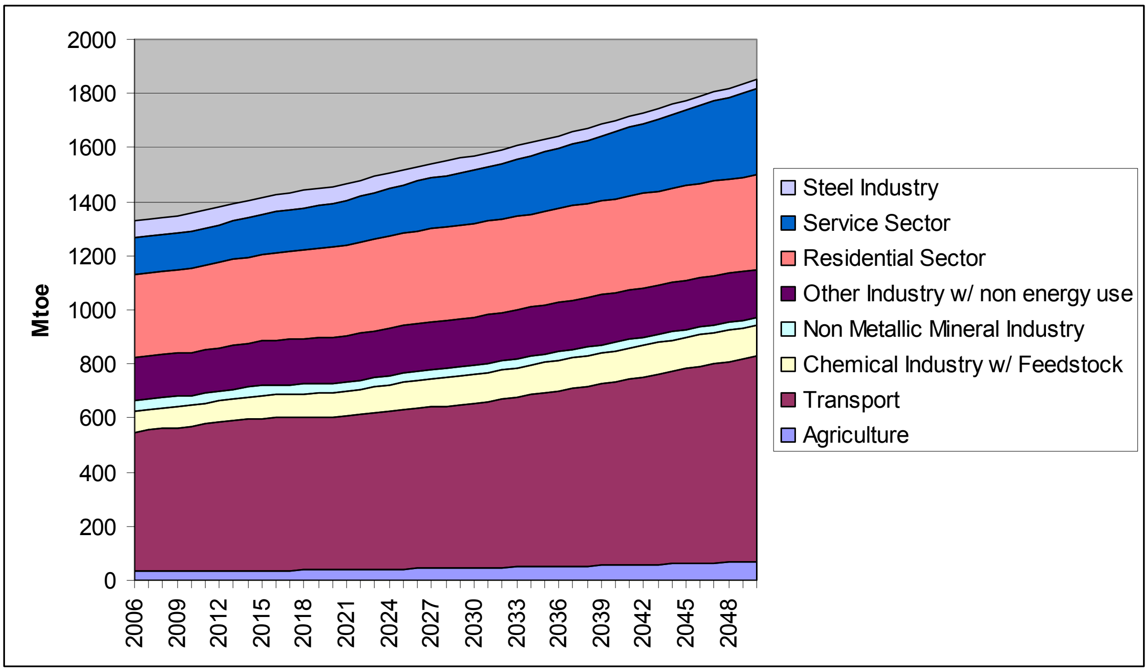

Figure 80: EU27 total energy consumption (without electricity and transformation sector)

The fuel consumption of the industrialised countries (including CIS) can be expected to increase by a factor of 1.4 during the period 2006-2050. The share of Europe in the world total energy consumption will decrease from 27% to 22% during this period. In the developing world, energy consumption will increase by a factor of 2.5 during the same period (Figure 81). China's share, which is the biggest among the developing world, will increase from 17% in 2006 to 22% in 2050. In 2006, two-third of the consumption comes from the industrialised countries while the remaining one-third comes from the developing world. By 2050, the share of the consumption can be expected to reach a ratio of 50:50.

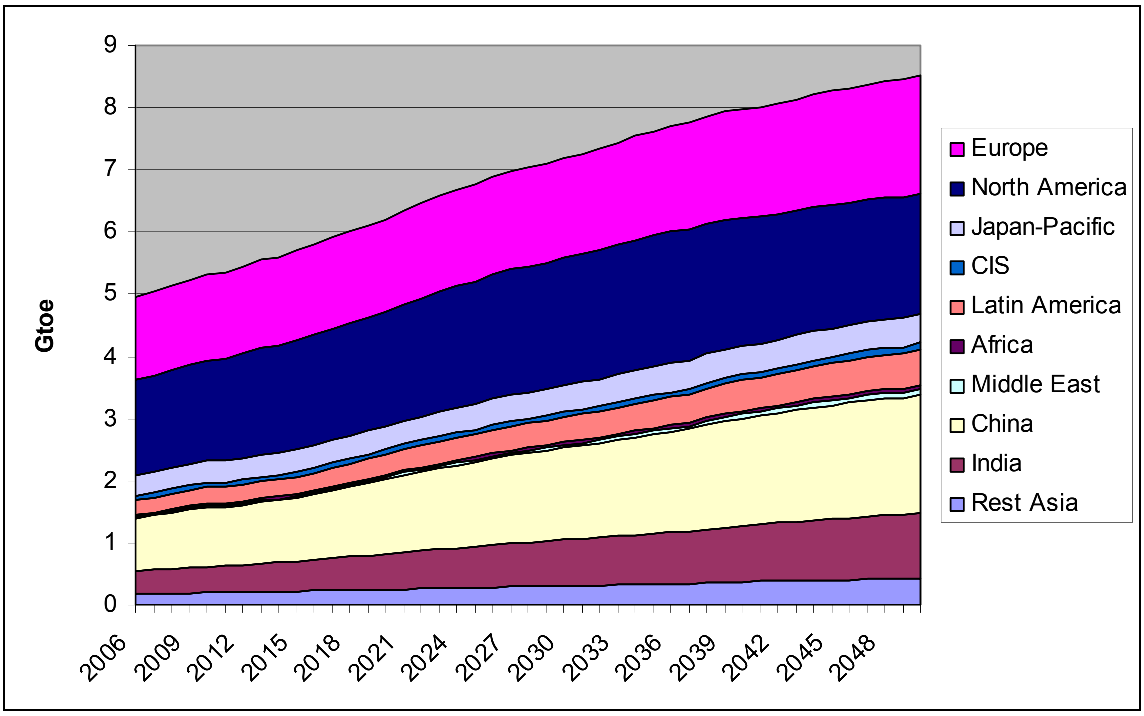

Figure 81: Total world energy consumption by region (without electricity and transformation system)

Biofuels

The production costs increase for biofuels of the 1st generation and decline for biofuels of the 2nd generation (Table 43). Production costs rise due to increasing feedstock costs, which are not compensated by learning effects. A decrease in production costs of first generation biofuels due to the learning effect was not taken into account as they are considered limited and lie within the range of uncertainties. Biodiesel production is a mature technology and even though bioethanol production in Europe is lagging behind biodiesel in terms of production volumes, the technology can be considered mature as well, especially when taking into account the global deployment of bioethanol. Besides, economies of scale due to larger plant sizes will be counteracted by more complicated logistics and increased transport costs.

Table 43: Biofuel production costs

Pathways	Production costs [€/toe]				
	2010	2020	2030	2040	2050
Bioethanol from Wheat	628.0	705.2	731.5	750.0	764.7
Bioethanol from Sugarbeet	642.4	721.3	748.3	767.1	782.2
Biodiesel from Rapeseed	726.8	700.7	739.9	762.4	809.7
Biodiesel from Sunflower	713.4	696.1	733.8	756.7	802.4
Lignocellulosic ethanol (straw)	928.6	818.5	736.1	733.2	743.7
Synthetic diesel (farmed wood)	1118.5	1014.7	924.6	894.2	891.5

Contrarily, the production costs of the 2nd generation of biofuels decrease. For 2nd generation of biofuels, technology learning plays an important role for the market introduction. These are expected to be technically available on commercial scale between 2010 and 2020, although their commercial viability will depend on how competitive their prices will be. Important cost reductions can be expected both in terms of the production process due to economies of scale and more mature technologies and in terms of the feedstock, as current crops are not yet optimised for their energy content.

With the above cost reductions, production costs of 2nd generation ethanol reach that of conventional ethanol between 2020 and 2030, while synthetic diesel (BtL) remains more expensive with about 900 €/toe.

In the base scenario, production costs of biofuels remain above costs of fossil fuel, which is around 500 €/toe in 2010 and is assumed to be around 700 €/toe in 2050. Therefore, biofuels enter the market due to the quota set on a Member State level. In the base scenario, the quota for the country groups 1 and to 2 is assumed to be 5.75%, respectively 2.35% for the countries of country group 3 and 4.

The biofuel production increases very rapidly until around 2012 and remains than on this level until 2030 (Figure 82). This is due to the assumption that the incentive for investors to build additional production capacity decreases the closer they come to the equilibrium point. After 2030 a further increase is expected due to the introduction of 2nd generation biofuels.

In the case of biodiesel, for example, the model predicts reduced growth rates already around 2012, while this occurs for bioethanol only about one decade later. Up to today, biodiesel dominates the EU biofuel market with a share of more than 80% (unlike the US and Brazil where ethanol clearly dominates [F.O. Licht, 2006]). In the base scenario the biodiesel production increases from 3.4 mill toe in 2006 to 8.5 mill toe in 2010.

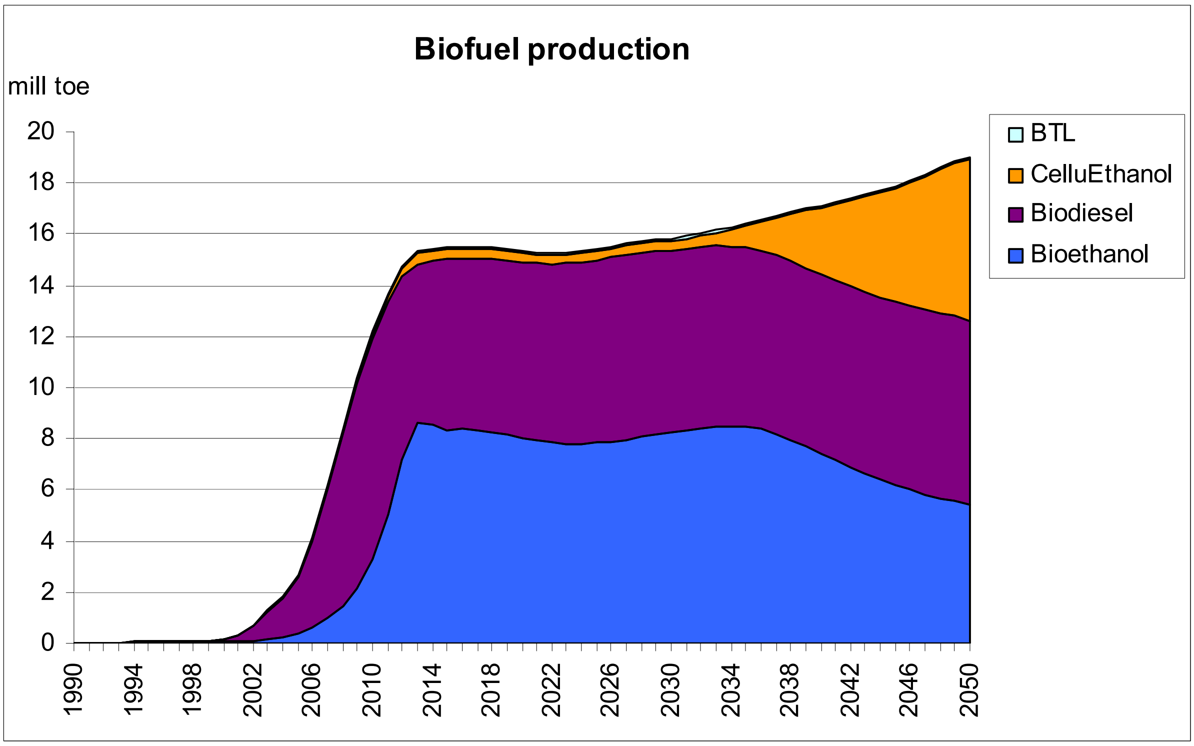

Figure 82: Biofuel production in the base scenario

The base scenario project that the trend of an increase of biodiesel production is likely to not continue in the longer term. Due to lower production costs and in particular lower feedback on feedstock prices, bioethanol production is projected to increase at a much faster rate than biodiesel. The fast uptake of ethanol will slow down once additional distribution and adaptation costs are required due to problems in blending ethanol above a certain low share, but cannot reverse the trend.

2nd generation biofuels are projected to enter the market after 2030 when production costs of ligno-cellulosic ethanol drops below than that of bioethanol from the 1st generation. At this time, ligno-cellulosic ethanol is competitive and replaces bioethanol from wheat and sugar beet. Synthetic diesel doesn't enter the market as its production prices remain above the prices of biodiesel from rapeseed and sunflower.

Overall 2nd generation of biofuels reaches a rather limited share below 0.3% in total transport fuel demand by 2030. Beyond 2030, their penetration accelerates, due to the effect of learning, to reach 6% (Figure 83) of the demand of gasoline. The rise in lignocellulosic biofuels will by then have become a main driver for the continued growth in biofuel production. The scenarios also seem to indicate that conventional and 2nd generation biofuels are likely to co-exist for a long time rather than replacing each other in this scenario.

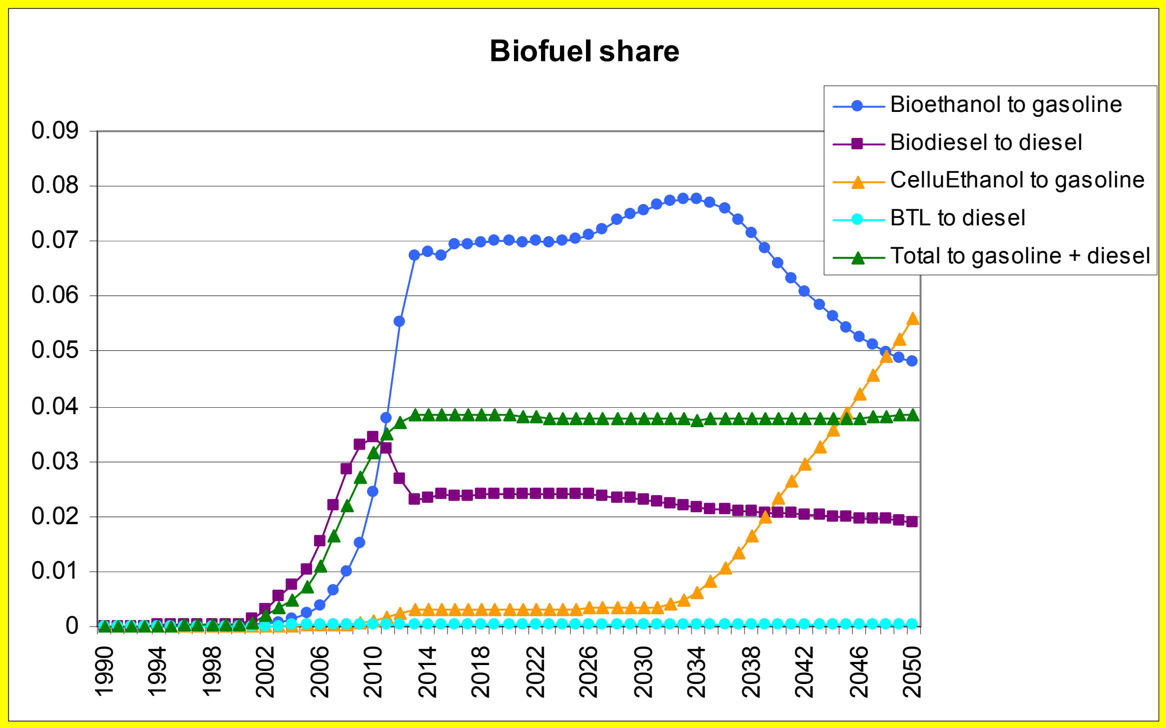

Figure 83: Share of biofuels to fuel demand

The share of all biofuels together compared to fossil fuels follows a logistical curve (Figure 83). All biofuels amount to 4% of total fuel demand (gasoline and diesel).

ASTRA Fuel Consumption

Following the structure of the TRIAS model and the interaction between ASTRA and POLES fuel demand for each considered fuel type is relevant for the estimation of future fuel prices. Figure 84 demonstrates the development of fuel demand for the simulation period in the baseline scenario for each fuel type. Regarding diesel the figure differentiates between car diesel, truck diesel, van diesel, ship diesel and train diesel. Furthermore electric current consumption is separated into the modes train and car and gasoline is consumed by car or van.

Total fuel consumption translated into million-tons-of-oil-equivalent (Mtoe) continuously increases from 2000 until 2050. Starting from 420 Mtoe for EU27 in 2000 the maximum transport fuel consumption reaches 649 Mtoe in 2050, which amounts to an increase of +54% over this period. Excluding truck transport the overall development of fuel consumption shows a growing trend until the year 2026 where a maxim fuel consumption of 351 Mtoe will be reached. Afterwards fuel consumption excluding trucks is estimated to stagnate or even slightly decreases resulting in 347 Mtoe in 2030 and 340 Mtoe in 2050. Influenced by the technological development of the vehicle fleets, especially the car fleet, the demand curves per fuel type show different trends. Figure 84 reflects increasing shares of diesel cars leading to a strong growth of diesel fuel demand for cars until 2025, with an even stronger decline of gasoline demand. The high growth rates of freight transport are reflected in particular in the strongly growing demand for diesel fuel for heavy and light duty vehicles. The projections show that diesel fuel consumption for road transport will increase until 2050 reaching a share of more than 72% compared with 46% in the year 2000. As opposed to this trend gasoline consumption reduces to 14% until 2050 compared with 45% in 2000.

Concerning the diesel fuel demand it has to be taken into account that ASTRA is not yet considering alternative fuels for freight vans (<3.5t) and trucks. At least for the former the introduction of alternative fuels can be expected.

CNG demand grows until 2024 and reaches a level of 19.1 Mtoe ending up at 13 Mtoe in 2050. In 2028 Bioethanol passes CNG as most important alternative fuel besides the conventional fuel types and results in 20.8 Mtoe in 2050. Together with biodiesel, electric current, LPG and hydrogen the alternative fuels are estimated to have a rather moderate share of only 12% of total fuel consumption by cars in 2050 in the baseline scenario.

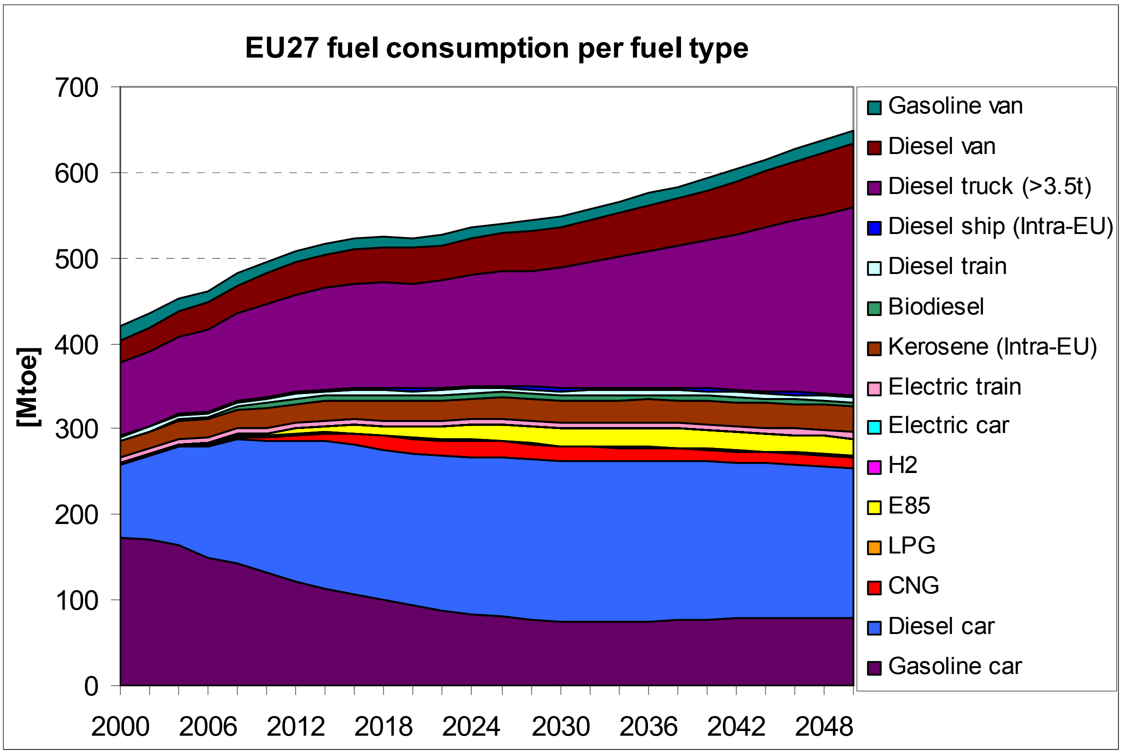

Figure 84: EU27 fuel consumption per fuel type

Since biofuels play a role in climate mitigation strategies of the EU and concerning the security of supply, in particular considering a medium term time horizon, these are presented in more detail in the following paragraphs concentrating on bioethanol. One should consider that no specific policies are considered in the TRIAS baseline scenario, which means that the most recent policies to define quotas for biofuels, which are motivated by climate policy, are not considered. I.e. the requested quotas are not achieved by the EU as at maximum a share of 5% biofuels is reached around the year 2030.

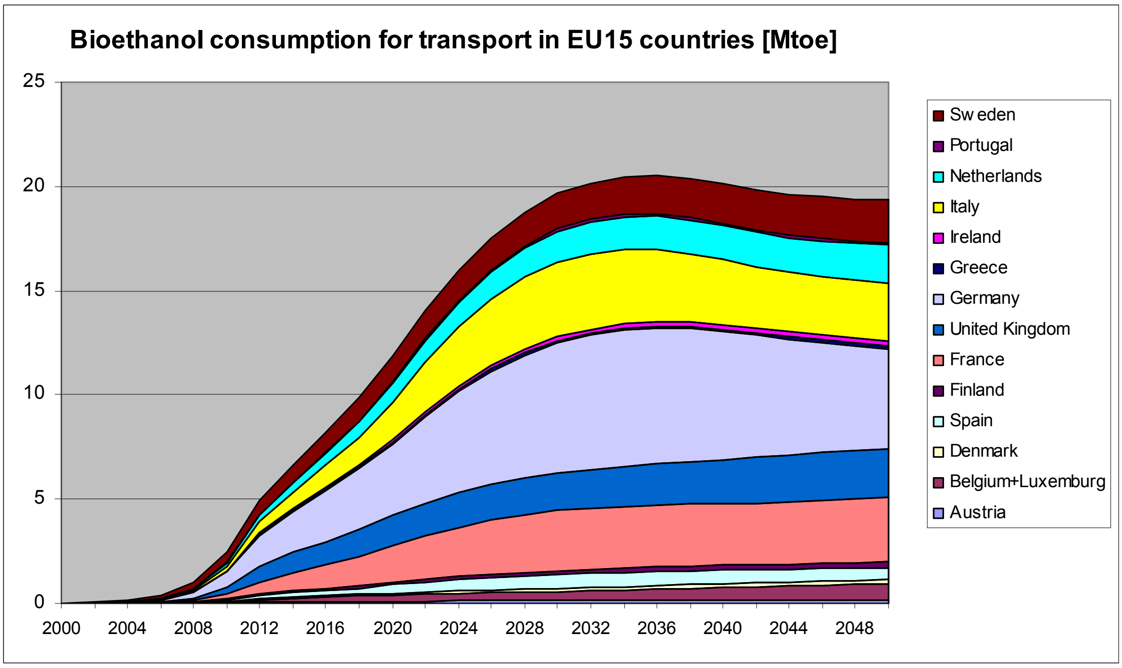

Figure 85: Consumption of bioethanol in EU15 countries

Looking more closer at the bioethanol consumption at the country level we can observe for most of the countries and in particular for Germany and Italy that bioethanol consumption peaks around 2030 and then is slightly reduced, which is driven by the cost development of bioethanol and the competing fuels. However, for some other countries e.g. with better growth potentials for bioethanol related plants continuous growth until 2050 can be observed e.g. France, United Kingdom (see Figure 85 and Figure 86).

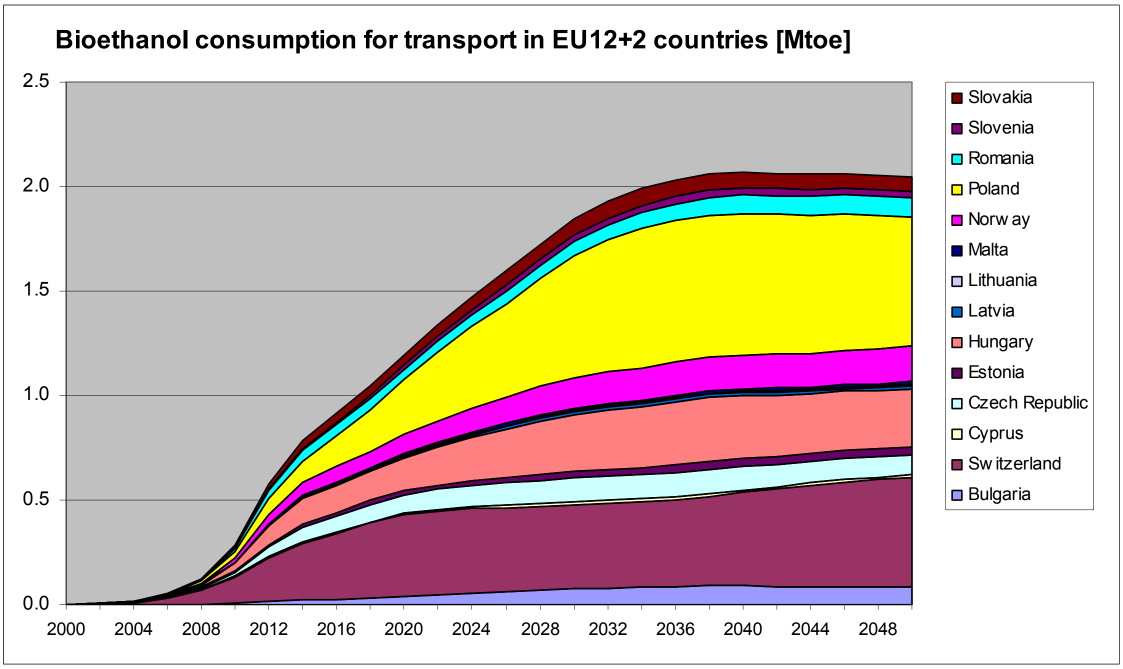

Figure 86: Consumption of bioethanol in EU12+2 countries Figure

5.6 Environment

The following chapter describes the observed environmental trends in the TRIAS baseline. The presented figures and graphs were extracted from ASTRA showing national emission trends, from POLES-TRIAS demonstrating upstream emissions from electricity and from Regio-SUSTAIN analysing regional immissions for two case study regions.

ASTRA Emissions

The displayed graphs in the following chapter summarise the observed trends for air emissions and fuel consumption in EU27 in the TRIAS baseline scenario. Figure 87 opposes estimated transport performance and air emission trends for the period from 2000 to 2050. The figure highlights passenger transport trends in terms of passenger-km and freight transport trends in terms of ton-km. As described in the chapter on transport results, passenger-km are growing only slightly influenced by stagnating or even declining population in EU27 by +38.9% until 2030 and rather moderate +51.3% until 2050. As opposed this freight transport is impacted strongly by high foreign trade and national production value growth rates. Ton-km are assessed to double until 2030 and even more than triple until 2050 in EU27.

Against the background of increasing passenger and especially freight transport the illustrated CO_2 emission projections show that business-as-usual measures implemented in the baseline scenario Euro 6 are by far not sufficient concerning the greenhouse gas emission reduction targets. Carbon dioxide reduction targets like the agreement of EU member states on overall –30% reduction until 2020 compared with 1990 require stronger incentives for the transport sector. The baseline scenario simulation considering the changing technological improvements of vehicle fleets in EU27 illustrate positive growth of CO_2 emissions from transport until 2050. Due to the baseline simulation CO_2 emissions are expected to increase by +25.3% until 2030, +35.5% until 2040 and +48.6% until 2050 compared with the base year 2000. Technological improvements cannot balance increasing transport performance and growing motorisation.

In contrast NO_x emission projections demonstrate the impacts of significant technological improvements. ASTRA assesses NO_x emission reductions by –54.8% in 2030, -53.2% in 2040 and –50.2% in 2050. In the last two decades NO_x emissions stagnate in EU27 mainly due to growing importance and share of freight transport. Besides CO_2 and NO_x ASTRA considers also CO and VOC emissions caused by the transport sector. The baseline projections estimate –24.3% decline of CO emissions until 2030 and –7.6% reduction until 2050 compared with 2000. VOC emissions increase until 2030 by +11.2% and even +32.6% until 2050.

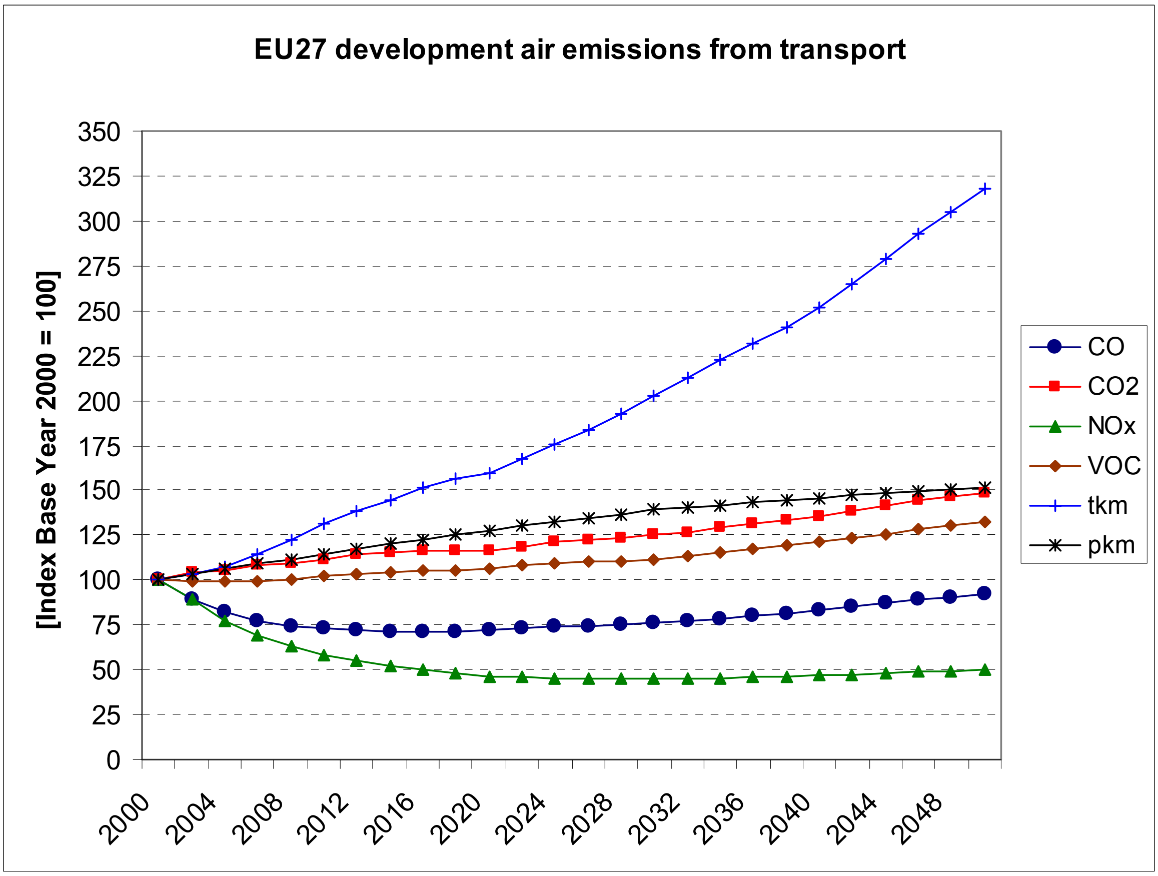

Figure 87: EU27 air emission trends versus transport performance

Figure 88 allows a more detailed analysis of CO_2 emissions in the baseline scenario. The figure differentiates CO_2 emission trends per origin respective transport mode. Having the significant freight transport growth in mind the high emission growth rate for CO_2 produced by freight transport is not astonishing. Freight transport CO_2 emissions grow by about +1.9% yearly and until 2050 by +153.7% compared with the base year. As opposed passenger transport CO_2 emissions increase only slightly by +12.6% until 2016 and decline afterwards reaching with a small plus of + 2.9% nearly the same level as in base year. Strongest growing freight transport mode in terms of CO_2 emissions is with distance heavy duty vehicle transport increasing nearly by +249% until 2050. Compared with the emission trends observed for heavy duty vehicles CO_2 emissions from light duty vehicles reflect a slight saturation of EU27 markets with LDVs and a less strong increase as for HDVs.

Regarding CO_2 emissions from passenger transport the expanding modal share of air transport is of growing importance and results in +45.6% growth until 2050. ASTRA assesses stagnating or even reducing CO_2 emissions from all other passenger transport modes: car, bus and passenger train. Passenger car emissions stay on nearly the same level as in the year 2000 while emissions from bus and passenger train transport are estimated to be reduced by –37.3% respective -18% until 2050.

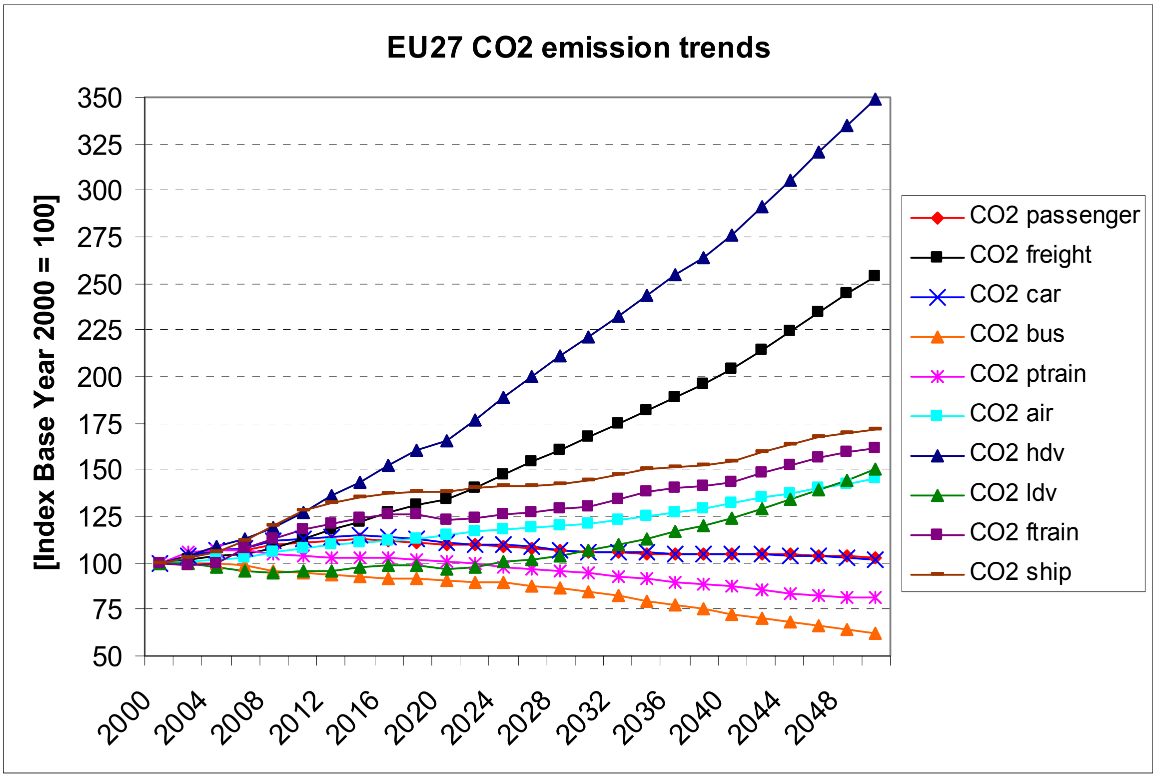

Figure 88: EU27 CO2 emission trends per mode

Figure 89 substantiates the relative emission trends for CO_2 demonstrated in the previous figure. The depicted absolute emission values clarify the importance of growing heavy duty vehicle transport for strategies facing the problem of global climate change. Comparing the situation in the year 2000 and in 2050 there is a significant trend visible: in the base year heavy duty freight transport produced about 17.6% of all transport CO_2 emissions while passenger car transport was the main polluter with a share of 54.7%. In 2050 cars will be responsible for 36.2% of all transport CO_2 emissions while heavy duty transport reaches even a share of 39.8%.

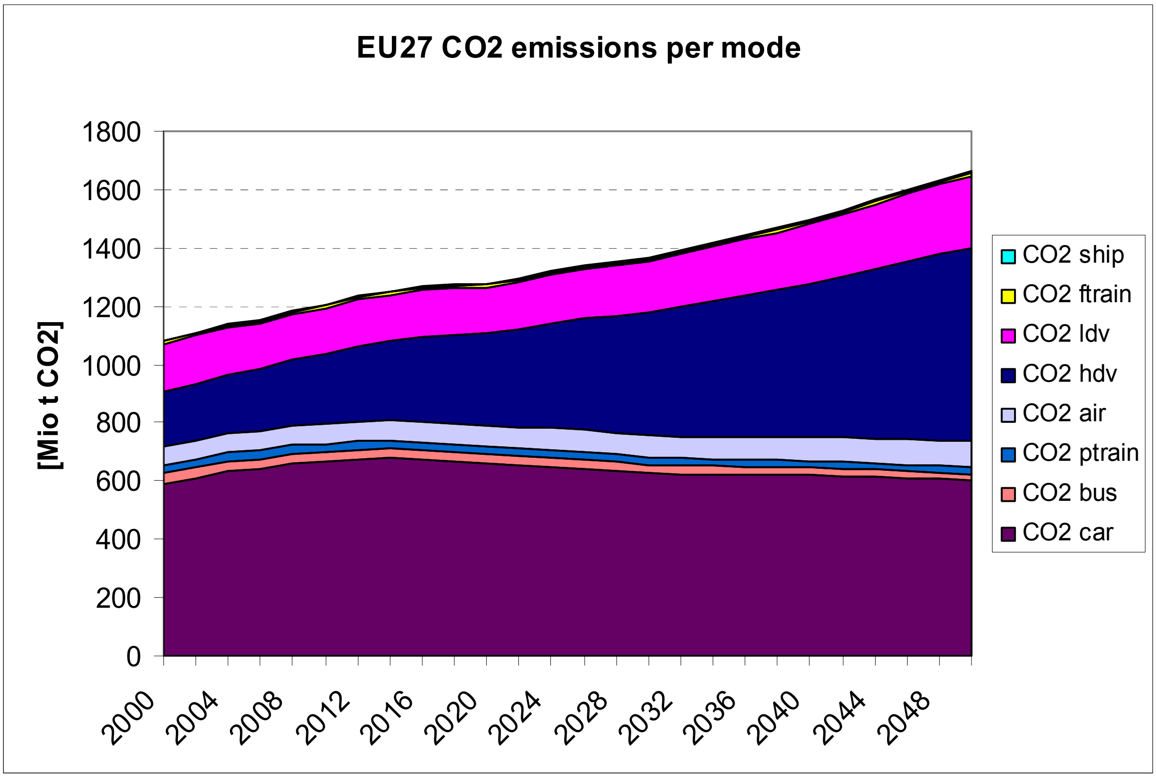

Figure 89: EU27 absolute CO2 emissions per mode

The following figures demonstrate the development of NO_x emissions caused by transport activities in the baseline scenario. In the context of climate change debate the pollutant NO_x took a back seat compared with CO_2. Regarding the dangers caused by NO_x emissions like acidification, health problems, increasing smog and ozone appearance, the simulated trends are not subordinate and have to be analysed critically as well.

Figure 90 presents NO_x emission indices based on the year 2000 showing the prospective emission trends per transport mode respective transport sector. Results of the baseline scenario confirm that NO_x emissions caused by passenger transport can be reduced significantly by –62.1% until 2030 and -58.8% until 2050. The strong decrease of NO_x emissions is mainly caused by car technology improvements like the introduction of three-way catalytic converters or NO_x storage catalysts and the disappearance of cars with old technologies. ASTRA projects a slower substitution of old NO_x intensive by modern NO_x reducing technologies for freight transport. This is mainly influenced by the high share of diesel heavy and light duty vehicles. Most modern gasoline cars or light duty vehicles are equipped with catalytic converters while still not all diesel cars or trucks are equipped with NO_x storage catalysts. Despite the slower technological diffusion NO_x emissions caused by freight transport decrease by –65% until 2030 and –56.6% until 2050. In contrast to CO_2 emission trends NO_x emissions increase most significantly by passenger air transport with +53.6% until 2030 and +81.6% until 2050 followed by ship (inland waterway) with +28.5% until 2030 and +52.6% until 2050. Passenger car and light duty vehicle motor technology enable a decline of NO_x emissions by –91.8% respective –87.9% until 2030 and –92.5% respective –80.8% until 2050.

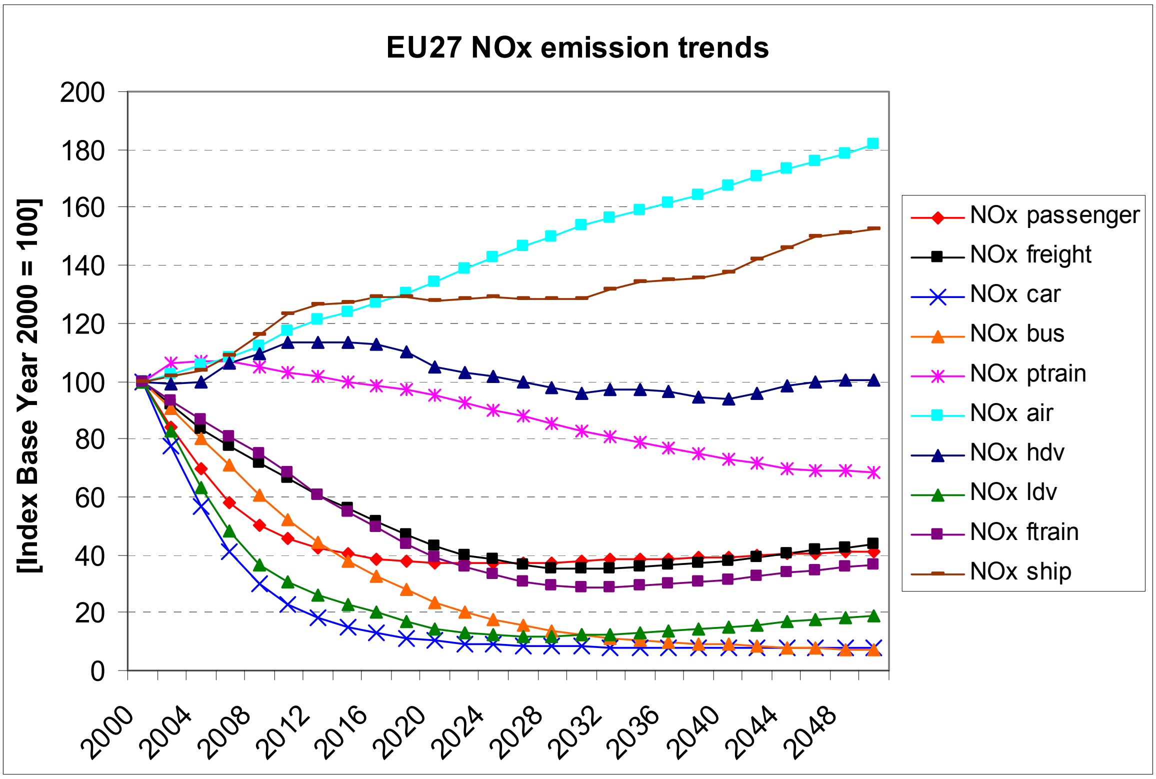

Figure 90: EU27 NOx emission trends per mode

Figure 91 shows the development of absolute yearly NO_x emissions per transport mode. The graphs highlight the growing responsibility of air transport for EU27 NO_x emissions from transport. Due to the fast decline of emissions from car the plane is already from the year 2010 onwards the most significant polluter of NO_x in EU27. The model assesses a share of NO_x emissions of 55.3% for air transport while for example car transport is emitting only 9.4% of all transport related NO_x emissions. Due to the model results the second important polluter in the transport sector will be freight train with a share of 16.3%. Higher shares of diesel locomotives compared to passenger trains, technological lags in terms of NO_x emissions and higher freight transport growth rates compared with passenger transport are the main drivers for this trend. Overall the model estimates declining transport related NO_x emissions and 2.11 Mio tons of NO_x in 2030 and 2.39 Mio tons of NO_x in 2050.

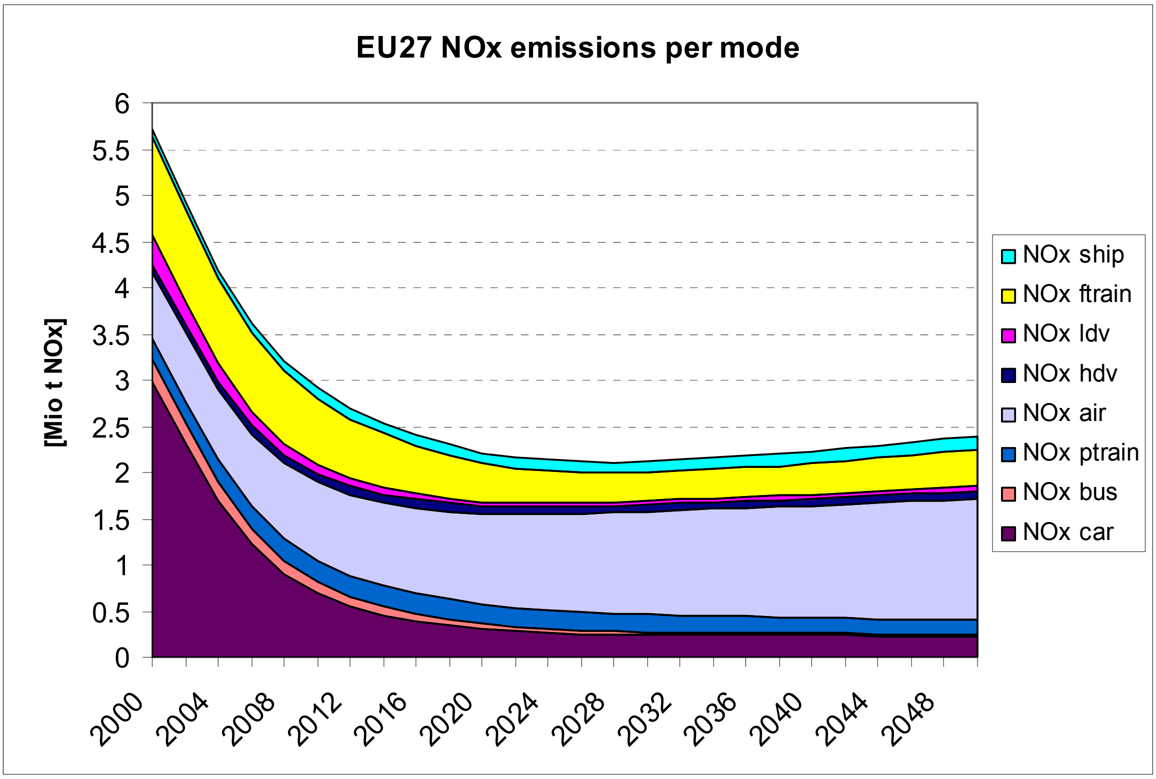

Figure 91: EU27 absolute NOx emissions per mode

POLES-TRIAS Emissions

POLES-TRIAS Upstream Emissions Electricity

In EU-27 countries total carbon dioxide emissions from electricity production increases constantly by an average of 1.2% from 2006 until 2041 when it reaches around 2033 MtCO2. Beyond 2041 this total emission can be expected to undergo slight decrease. In term of share of the total CO2 emission from electricity production in the world, EU-27 is estimated to contribute around 15% in 2006 and 12% in 2050.

Figure 92 below shows how electricity production by solid fuel (coal) has the lion share of the total CO2 emission between 2001 and 2050. This share oscillates between 65 to 75% of the total emission during the period. The share of CO2 emission from electricity production by natural gas increases steadily from 18% in 2006 to 31% in 2050 while the share of CO2 emission from production by liquid (oil) fuel remains the lowest with 6.1% in 2006 decreasing to 2.8% in 2050.

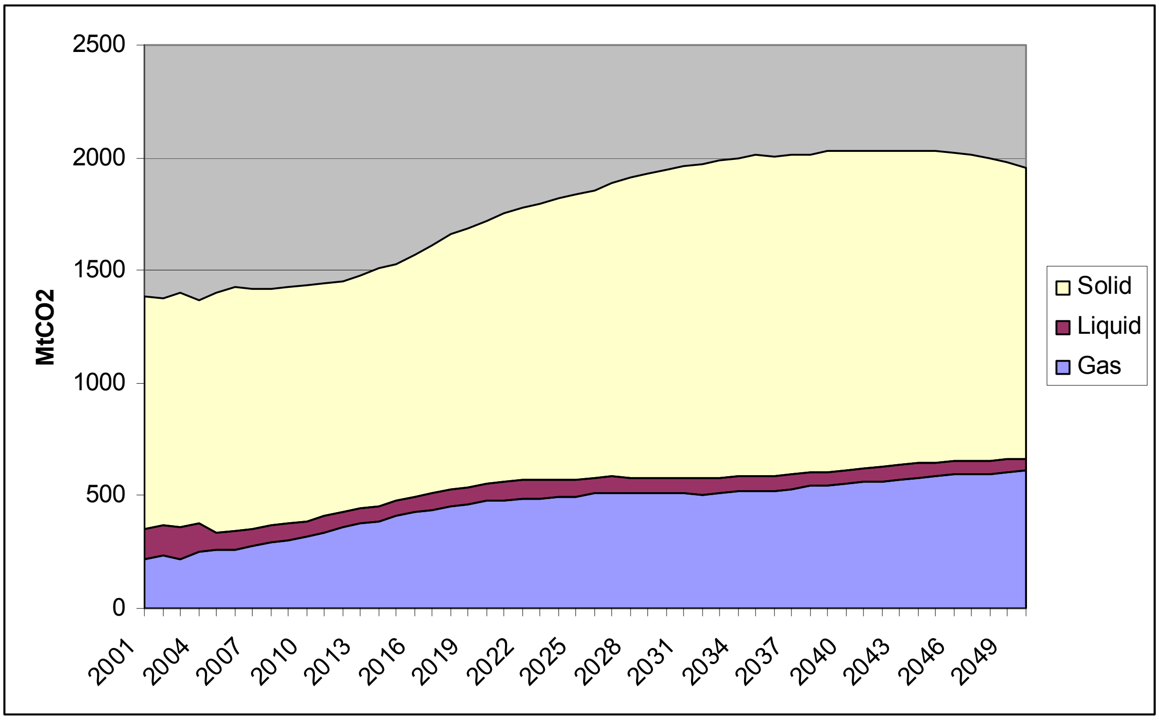

Figure 92: Share of CO_2 emissions from electricity production in EU-27 countries

Regio-SUSTAIN: Analysis of regional immissions

The Regio-SUSTAIN model has been developed for the analysis of regional impacts. During the TRIAS project it has been expanded and updated for the objectives of the project. The following chapter describes the results of Regio-SUSTAIN for the Reference scenario in 2000. First, the two investigations areas are defined. Second, the major roads of the areas and the considered substances are described. Finally, the results for the Reference scenario 2000 are displayed and explained.

Areas under consideration

Regio-SUSTAIN has been developed for regional analyses. It is based on a huge database, which could not be applied for the whole area of Europe. Regio-SUSTAIN provides regional and local indicators depending on transport activity and energy use. The consortium decided to analyse the development of local pollution in two case-study regions, namely the Ruhr area and the South of Spain. Boundaries for the two regions are based on the Nomenclature of Territorial Units of Statistics (NUTS). The NUTS III classification has been applied for the TRIAS project. Table 44 displays the regions under consideration.

Table 44: NUTS III regions under consideration for the regional environmental assessment

Ruhr area			South of Spain	
NUTS III classification	**Name of region**		**NUTS III classification**	**Name of region**
DEA11	Düsseldorf		ES613	Cordoba
DEA12	Duisburg		ES615	Huelva
DEA13	Essen		ES618	Sevilla
DEA16	Mühlheim			
DEA17	Oberhausen			
DEA1C	Mettmann			
DEA31	Bottrop			
DEA32	Gelsenkirchen			
DEA51	Bochum			
DEA52	Dortmund			
DEA55	Herne			
DEA56	Ennepe-Ruhr-Kreis			
DEA5C	Unna			

The analysed Ruhr area has a West-East elongation of approx 80 km and a North-South elongation of approx 50 km. The region has been chosen for analysis because of its great population density and the major road axis which passes the area, namely the German motorways A1, A2 and A3. Furthermore, the Ruhr area consists of a number of large industrial cities, which have been dependent on coal mining and steel production. Nowadays, steel production still plays an important role in the area but the introduction of engineering industries as well as the service sector shows the structural change of the area. For the assessment of emissions from stationary facilities (e.g. steel industry, etc.) and its future development the Ruhr area serves as a good example. Figure 93 maps the area under consideration.

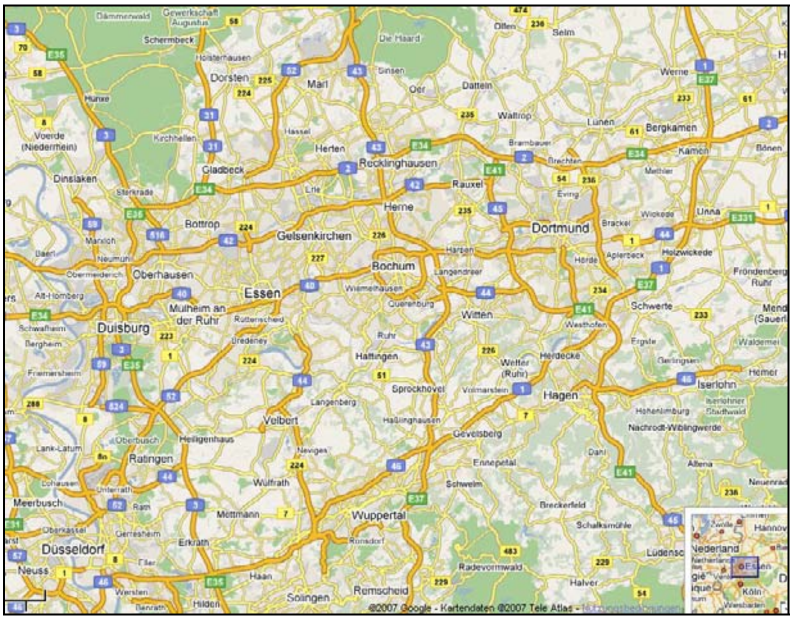

Figure 93: Ruhr area (Germany) as assessed in the TRIAS project (GoogleMaps, 2007)

The second area under consideration for the regional assessment of emissions is Andalusia in Spain. Andalusia has a total population of around 8 million and covers an area of approx 87,000 km² (Junta de Andalucia, 2007). The cities of Seville, Granada, Cadiz and Malaga belong to the autonomous community of Spain. The economy of Andalusia is based on the three pillars: industrial production (mining, chemistry and shipbuilding), agriculture and service sector. Especially the development of the industrial sector has been of major concern for the TRIAS project. Emissions from stationary facilities coming from the industry as well as transport exhaust emissions are considered in the assessment. Figure 94 shows the area of Andalusia, which has been analysed for the TRIAS regional environmental assessment.

Figure 94: Andalusia (Spain) as assessed in the TRIAS project (GoogleMaps, 2007)

Major roads and emission facilities

The location of stationary facilities has been provided by the Poles model for both investigation areas. Poles considers the five industry sectors which have been implemented into Regio-SUSTAIN:

- Chemical industry (CHI),
- Service sector (SER),
- Steel industry (STI),
- Non metallic mineral industry (NMM) and
- Other industries (OIN).

For the objective of analysing emission and immission concentrations the major polluting sectors are chemical, steel and non-metallic mineral. In the Ruhr area a concentration of chemical and steel industry can be found whereas in Andalusia steel and non-metallic mineral companies are mainly represented. In total over 70 stationary facilities are considered for the TRIAS project.

The major roads for both investigation areas are national motorways and national highways. VACLAV has provided data for the trunk roads, including location of the links and their traffic loads. In the Ruhr area a large number of national motorways exist. The area is densely populated and can be classified as urban. The cities are connected by highways as well as motorways. Three of the most congested German motorways are located in this area, namely the motorway A1 (E37[2]), A2 (E34[3]) and A3 (E35[4]). Other motorways that have been considered are A40 (E34), A42, A43, A 44, A45 (E31), A46 (E37), A52 and A59. Furthermore, the largest federal highways are included in the immission calculation.

With a population density of around 90 persons per sqkm, Andalusia can be classified as a rural region with some major urban settlements. These cities are linked by motorways, which have been introduced into the model. The main motorways of Andalusia are A4 (E5), AP4 (E5) and A49 (E1). Also smaller motorways and highways, such as A45, A66, A92, N420 and A432 have been considered for the TRIAS project.

Analysed Substances

Regio-SUSTAIN analyses regional impacts of the transport and energy sector. Therefore, substances have been chosen which have local impacts on the environment. The focus of the analysis has been placed on Particulate Matter (PM) and Nitrogen Oxides (NO_x).

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2 The European E-network consists of roads which cross national boarders and which have been defined as important roads for Europe by the United Nations Economic Commission of Europe. The E37 is located in Germany. It is a North-South axis starting in Delmenhorst (Federal state of Lower Saxony) and terminates in Cologne.

3 E34: Antwerp (Belgium) – Venlo (The Netherlands) – Dortmund (Germany) – Bad Oeynhausen (Germany)

4 E35: Amsterdam (The Netherlands) – Düsseldorf (Germany) – Karlsruhe (Germany) – Basel (Switzerland) – Milan (Italy) –Rome (Italy)

Particles are one of the most influential emission factors on a regional scale. Breathing fine particles have substantial adverse impacts on human health. Inhaling high concentrations over a long period may lead to asthma, lung cancer, cardiovascular issues and premature deaths. Therefore, legislation of the European Commission is aimed at reducing the concentration of particles significantly over the next decade.

Nitrogen oxides are associated with reduced lung functions, which lead to irritations and damage of the respiratory organ. Especially short-term exposure of high concentrations at a local and regional level leads to high impacts on human health. These characteristics of NO_x have been the reason to include the substance into the evaluation sample.

Results for the Reference Scenario 2000

The baseline scenario as defined in the first part of the TRIAS project displays the situation in the year 2000. No scenarios are applied and the situation as it has happened is calculated. The results of the regional immission calculation for the transport sector are displayed in Figure 95 for nitrogen oxides and in Figure 96 for particles. The major motorways with the highest transport loads in the Ruhr area can be ascertained from the figures, namely the A3 (North-South axis in the western parts of the region) and the A46, which passes over to the A1 (West-East axis starting in the south of the region). Both axis are mostly used for long distance traffic, especially HGVs coming from the Dutch ports with destinations in the South or East of Germany respectively Europe. The highest concentrations of NOx and PM are found in east direction of the analysed motorway. The reason is that a constant average wind field has been applied to the model that has been calibrated on long-term time series for the Ruhr area. The assumption is a constant wind field of 225° (South-East direction) with an average speed of 2.5 m/s. Expert interviews have shown that the assumptions are acceptable.

The interpretation of the figures should be focused on changes over time and changes with different scenarios. Absolute values of the figures are indicators for the situation in the region but the focus of TRIAS is on long-distance transport and energy pollutants only. Therefore, inner city traffic and pollutants from households go behind the objectives of the project but should be considered when analysing absolute values.

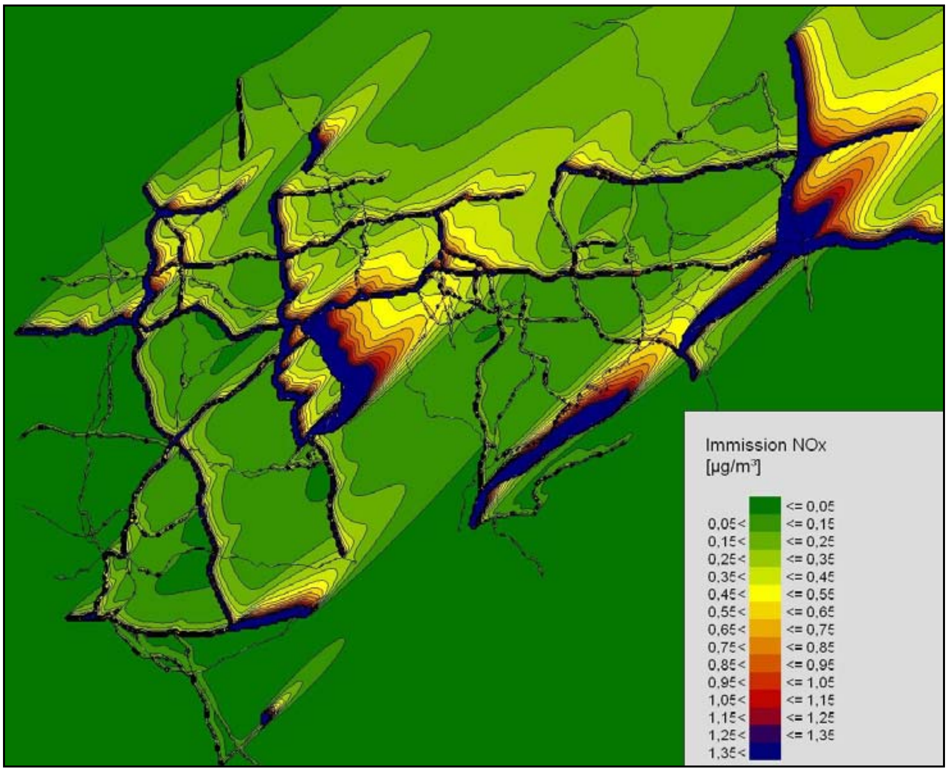

Figure 95: NOx immissions in the Ruhr area (Baseline scenario for 2000)

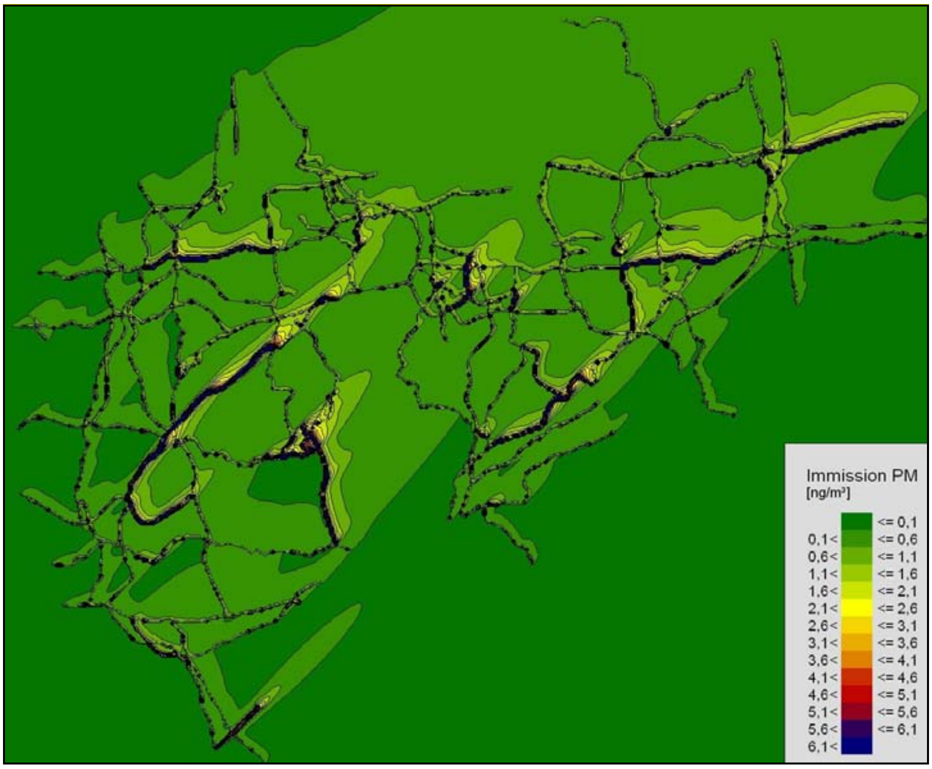

Figure 96: PM immissions in the Ruhr area (Baseline scenario for 2000)

The situation for Andalusia is slightly different as for the Ruhr area. Instead of a large number of motorways crossing the area only few major roads are available. The most important roads in Andalusia are the A49 (E1) and A4 (E5), which cross the region from West to East. This can also be observed when analysing the immission maps, especially the NOx map. The highest concentration for NOx can be found in the eastern parts of the region where the landscape becomes hilly and the major motorway crosses the foothills of the Sierra Nevada. Emissions from highways (national roads) play a secondary role when analysing regional concentrations (see Figure 97 and Figure 98) whereas on a local level (5 to 10 km along the highways) these emissions have to be considered in detail.

The same as for the Ruhr area also applies to the results of Andalusia. Interpretations of the figures should focus on comparisons over time (e.g. scenario analysis, transport and energy policies) instead of analysing absolute values.

For Andalusia a constant wind field has been applied. It is based on the regional wind called Poniente, which is a moderate West wind. Poniente blows constantly year around (except July and August) from the Atlantic to the Sierra Nevada. Therefore, a wind field of 225° and 4.0 m/s has been applied to the model.

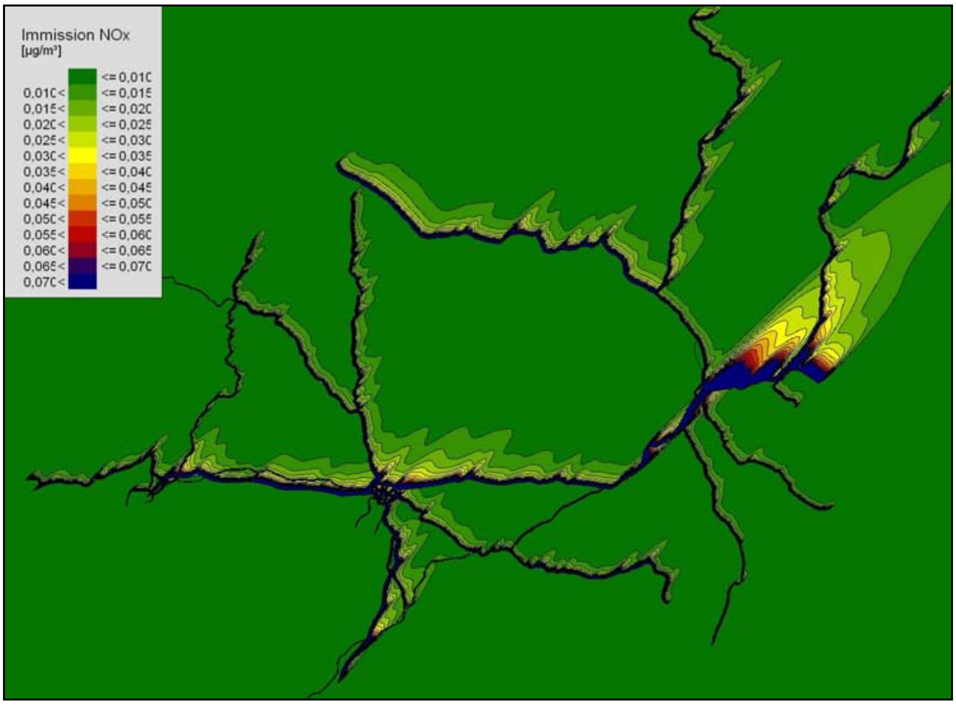

Figure 97: NOx immissions in Andalusia (Baseline scenario for 2000)

The PM concentration from exhaust emissions in Andalusia shows two centres of immissions: the AP4 (E5) and the A4 (E5), especially around Seville. The concentrations can be explained by higher volumes of heavy goods vehicles, which are the main polluter of particles. Especially in the main economic centre of Andalusia, namely Seville (e.g. production facilities of Renault and EADS), goods transport is above the average of the region, which can be observed in Figure 98.

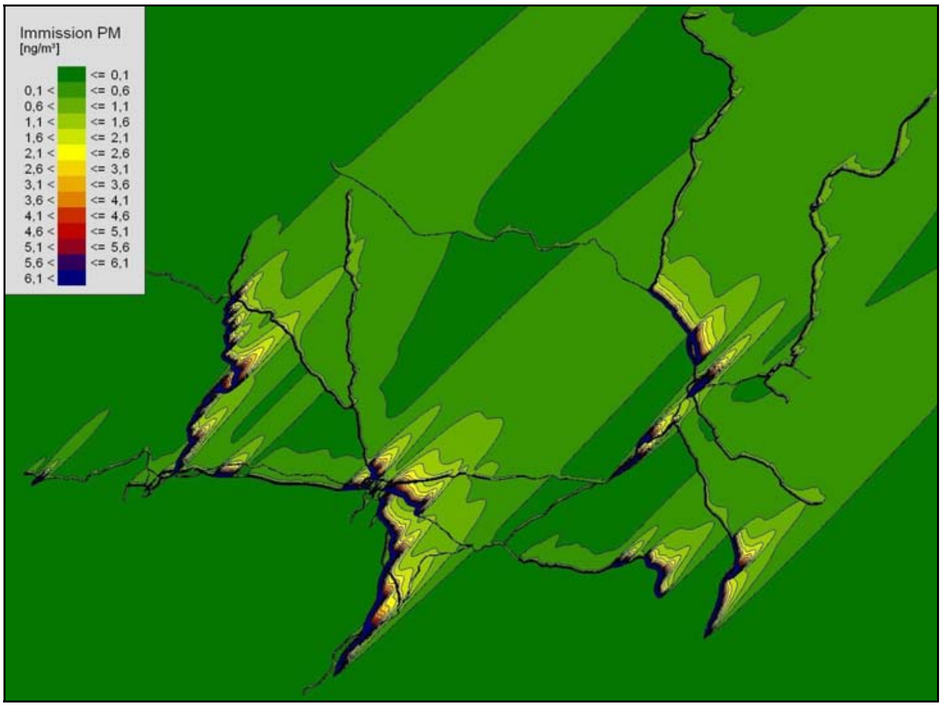

Figure 98: PM immissions in Andalusia (Baseline scenario for 2000)

6 Conclusions and Outlook

In the TRIAS project a "Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios" is performed. Considering emerging constraints of fossil energy, prospective transport performance trends, potential technology trends for alternative fuels of transport and possible policies to foster fuel switch of transport the TRIAS project assesses potential sustainability implications. This report first concentrates mainly on the description of the tools applied for assessing the potential impacts, the development and revision of these tools, their linkage and assumptions. Second the TRIAS baseline scenario is presented.

Modelling and tool development

The following five models are improved and linked in TRIAS:

- POLES and BIOFUEL display world-wide energy demand and supply,
- ASTRA simulates national economies, sectoral foreign trade and transport on an aggregate level,
- VACLAV models detailed transport network impacts on NUTSIII level, and
- Regio-SUSTAIN identifies local environmental impacts for two selected European regions.

Linking ASTRA with POLES and BIOFUEL enables to exchange endogenously calculated energy prices and energy demand from transport within a closed feedback loop that connects the world energy system with the European transport system. Integrating the transport network model VACLAV in this modelling framework represents another important value-added of TRIAS. Congestion effects and existing infrastructure can be considered with VACLAV and can be combined with ASTRA simulating all socio-economic indicators relevant for the generation of transport demand, which in turn closes the feedback loop between the transport system and the economic system. Additionally, TRIAS enables a detailed overview on scenario implications for specific case studies by integrating the regional immission model Regio-SUSTAIN into the modelling suite.

Regarding technological scenarios focussed on transport the TRIAS modelling framework demonstrated a good performance with the integration of alternative fuel technologies like hydrogen and biofuels. These technologies are represented with their implications on both side i.e. in the energy system and the transport system.

Furthermore, TRIAS developed two new concepts for integrated modelling across discipline: first, a tool that allows distributed modelling on System Dynamics Models of the ASTRA type, the ASTRA-Merger, is developed. This enables the implementation of the split-and-merge concept for ASTRA, which increases enormously the efficiency of conjoint model development by working in different teams on separate small-size files that are version-controlled by a repository. Second, TRIAS proved that the use of such a repository for soft-linking between models like POLES and ASTRA enables to create model linkages with a high number of iterations of data between the models in a fast and traceable manner.

TRIAS baseline scenario

The Baseline Scenario of TRIAS is constructed in general as a business-as-usual scenario assuming no major disruptions for the next 45 years, i.e. no strong policy changes are considered. This does not mean that we would not expect them, as for instance in the case of climate policy we would expect a rather more ambitious approach in the next decades then up to now. But it means that the baseline scenario is not including such major changes of the systems under analysis.

Hence, the TRIAS baseline scenario expects continuous economic growth, of course with different speeds by country and by world region, moderate technological improvements in terms of energy efficiency and in terms of the emergence and diffusion of new technologies in the energy and transport system as well as continued globalisation accompanied with strong growth of World and European trade. The main element where a change of development in the future compared with the past is expected by the models concerns the demography. European population will grow slightly until about 2020 and then starts to decline. The structure of the population will even change significantly with an increase of +50% of persons above 65 years of age, and a corresponding decrease of younger age classes. On country level population trends can be quite different e.g. declining earlier like in most new member states or continuing to grow like in Sweden.

One of the main conclusions of the TRIAS baseline scenario is that under such a baseline scenario transport energy demand and also CO_2 emissions are still increasing in the next decades until 2050. Nearly 50% growth of CO_2 emissions compared with the year 2000 indicates that the EU27 is miles away from climate protection targets. Passenger and freight transport performance are projected to increase further until 2050 by +50% respective more than +200%. Transport volumes grow at a lower pace, which indicates that part of transport growth is still driven by longer travel distances. This means, energy efficiency improvements in transport technology are too moderate too compensate the transport demand growth.

Regarding the technological composition of prospective EU27 vehicle fleets the diesel technology will have the highest share followed by gasoline. Since the baseline scenario does not consider subsidies for hydrogen this technology will not diffuse into EU27 vehicle markets. Instead, the ASTRA baseline scenario simulation projects that in the short to medium term technologies like CNG and hybrid will be alternatives to today's petroleum based internal combustion engines (ICE), while in the medium term bioethanol becomes more important. Interestingly, in the long-term gasoline blended with bioethanol and burned in new highly fuel efficient combustion engines recaptures part of the lost market share.

Regarding these trends and the fact that there is no revolutionary technological change expected in the baseline scenario, more radical technological shifts from fossil to alternative fuels and behavioural changes of individual mobility must be fostered to cope with scarcity of fossil fuels and with the need for ambitious climate protection. Potential scenarios that give some answers on how to reduce fossil fuel dependency of transport and contribute to climate protection targets in EU27 are presented in the TRIAS D4 report.

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