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

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Paper presented to the European Transport Conference 2007, Leeuwenhorst

1 INTRODUCTION

The use of hydrogen as energy carrier for the transport system has been discussed and tested in research niches since many years. High oil prices and the growing awareness that this will not be a temporary but a permanent situation fosters the search for alternative fuels and new technologies to propel the transport system, which, so far, in Europe depends to more than 97% on fossil fuels. Two of these alternatives would be hydrogen and biofuels that both can be generated from a number of different sources including a number of non-fossil and renewable sources. Hence, large research networks like the European Hydrogen and Fuel Cell Technology Platform or the US California Fuel Cell Partnership have been set up to overcome the barriers that currently hinder the widespread use of hydrogen for transport, which are especially the fuel cell itself and the hydrogen storage system. However, shifting transport towards hydrogen and biofuels is not at all only a technical issue. Instead, it would induce structural economic changes developing a large-scale industry producing hydrogen, trade flow changes reducing trade of fossil fuels and increasing trade of feedstock for hydrogen and biofuels production, offer new employment opportunities and reduce environmental impacts of transport e.g. in the case of hydrogen produced from renewable energy sources.

This paper draws on work undertaken in the TRIAS project that is co-funded by the European Commission 6th Research Framework Programme (http://www.isi.fhg.de/trias/index.htm). In TRIAS a number of scenarios is developed for Europe describing the diffusion of biofuels into the transport markets as well as a shift of the transport system towards hydrogen until 2030 and 2050. TRIAS integrates the four models POLES, ASTRA, VACLAV and Regio-SUSTAIN that together cover the multi-facetted impacts of such a large scale change of the transport and energy system.

The paper is briefly describing the overall project structure, the four models, the base scenario and a number of alternative scenarios on how to foster and manage a shift towards the new fuels in Europe: a carbon tax funded shift, a shift subsidised by funds from general budget and an accelerated shift where Europe would be the first world region to introduce hydrogen for transport on a large scale. For these scenarios an integrated sustainability impact assessment is carried out providing results for the transport system in terms of changing demand, cost changes, structural change of the vehicle fleets and environmental impacts, for the energy system in terms of energy prices and demand for different energy carriers, for the economic system in terms of growth implications, sectoral shifts and changes of trade flows and for employment.

2 TRIAS PROJECT OBJECTIVES

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 gained knowledge on the harmonisation of an interdisciplinary selection of models and the improvement of the 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.

3 TRIAS PROJECT STRUCTURE AND ACTIVITIES

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 to use 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 1.

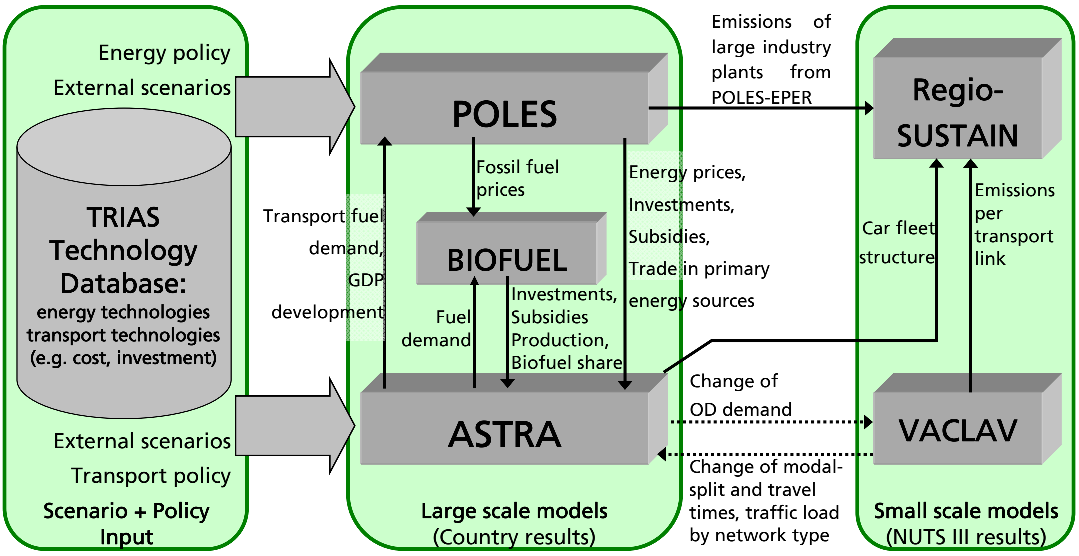

Figure 1: linkage and interaction of models in TRIAS

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 (WP) 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 eight different scenarios.

4 OVERVIEW ON APPLIED MODELS

This section gives a brief overview on the logic and role of the four applied models of TRIAS.

4.1 ASTRA

ASTRA (=Assessment of Transport Strategies) is a System Dynamics model generating time profiles of variables and indicators needed for policy assessment. Details of the ASTRA model are described in Schade (2005). Originally ASTRA was developed on the base of existing models that have been converted into a dynamic formulation feasible to be implemented in System Dynamics. Among these models have been macroeconomic models and classical four stage transport models (SCENES, ME&P 2000). ASTRA runs scenarios for the period 1990 until 2050 using the first twelve years for calibration of the model. Data for calibration stems from various sources with the bulk of data coming from the EUROSTAT (2005) and the OECD online databases (2005).

The ASTRA model consists of eight modules and the version presented in this paper covers the 27 Western European Union countries (EU27) plus Norway and Switzerland, (EU29). The major interlinkages between the eight modules are shown in Figure 2. Purposes of the modules are:

- Population module (POP) calculates the population development and population structure for the EU29 countries with one-year age cohorts.
- Macroeconomics module (MAC) provides the national economic framework. The MAC combines different theoretical concepts as it incorporates neo-classical elements, Keynesian elements and elements of endogenous growth theory. Of particular relevance for this paper is the sectoral structure of investments and consumption within the MAC enabling detailed consideration of changes due to penetration of hydrogen vehicles and renewable energies.
- Regional economics module (REM) describes spatial changes and the generation of transport on the level of sub-national functional zones.
- Foreign trade module (FOT) estimates trade flows by sector by country combination e.g. trade of vehicles from Sweden to Spain etc.
- Transport module (TRA) provides the modal-split of transport demand and calculates the transport performance by mode for passenger and freight transport as well as vehicle kilometres travelled.
- Vehicle fleet module (VFT) delivers the composition of the road vehicle fleets differentiated into different vehicle sizes, engine types and emission standards.
- Environment module (ENV) calculates the fuel consumption for the different fuels and the emissions of transport. Based on the fuel consumption also fuel tax revenues are calculated.
- Welfare measurement module (WEM) provides aggregate indicators like transport intensity, investment multipliers or cost-benefit ratios of policies.

The strength of the ASTRA model is that the eight modules are not connected in a linear way e.g. the economy drives transport and this leads to emissions, but that various feedbacks are implemented between the modules, such that inventions in the vehicle fleet (e.g. hydrogen cars) or new energy supply systems (e.g. renewables) feed back into the economic system through changes of investments or cost changes.

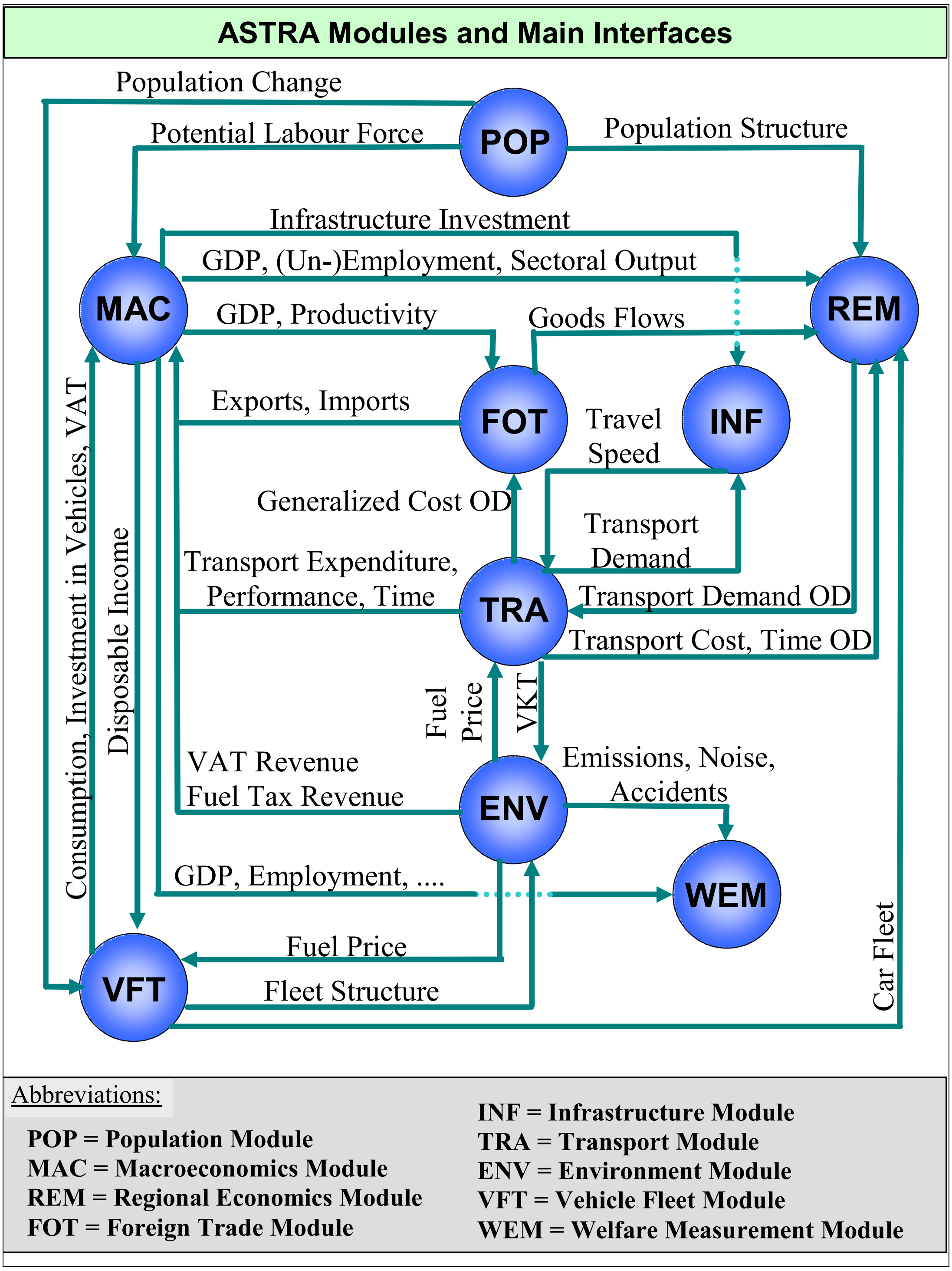

Figure 2: overview on the ASTRA model

4.2 POLES

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. The development of the model intends to fulfil four 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 CO2 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 CO2 sectoral emissions.

The main exogenous variables are the GDP and population 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 has been provided by the CHELEM-CEPII database, in the framework of the LETS network of the JOULE II program.

In the current version of the model, 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.

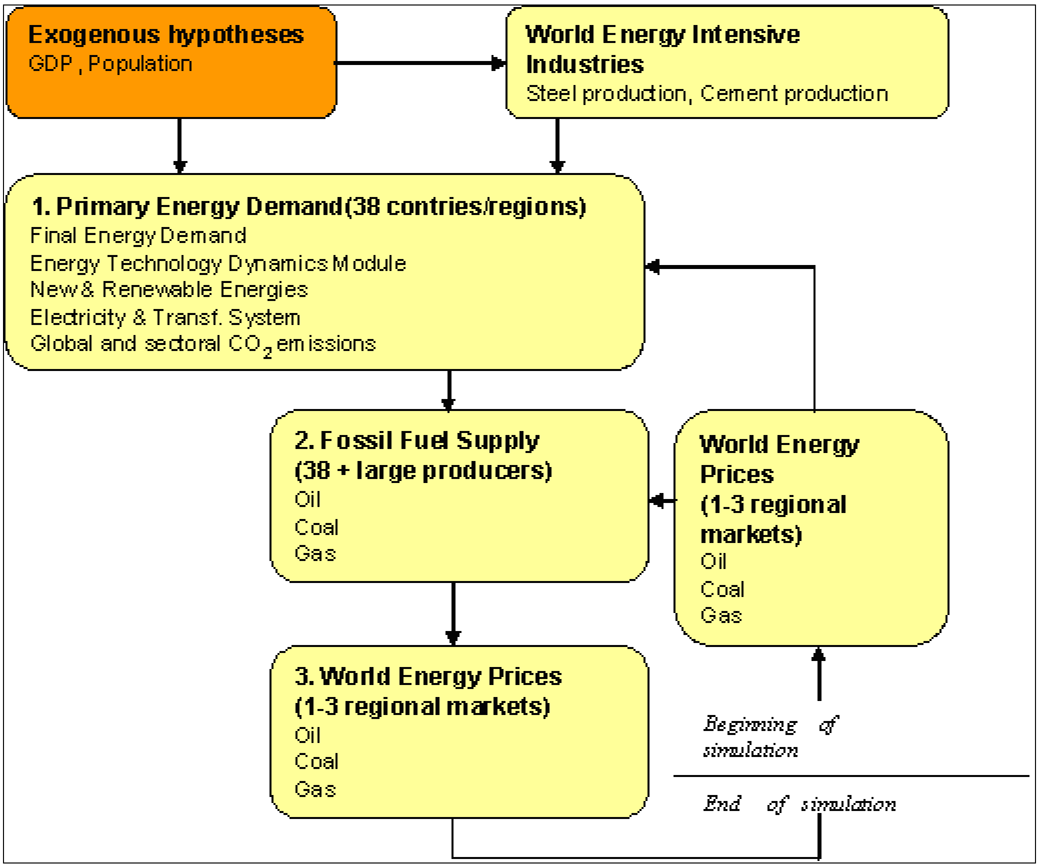

Figure 3: POLES five modules and simulation process.

4.3 VACLAV

Originally based on a transport network model for Germany VACLAV is enlarged to a European-wide forecasting model for long distance passenger and freight traffic in a series of European research projects. The heart of VACLAV is constituted by a network flow model, which follows the classical four-stage transport modelling approach of trip generation, trip distribution, modal choice and trip assignment. The level of detail for passenger and freight transport differs with full four-stage approach for passenger transport and a reduced approach for freight transport. For passenger transport the generation/distribution part and the modal split/assignment part are modelled by integrated approaches, taking into account the close feedbacks between these stages.

The extension of VACLAV to Central- and Eastern Europe is implemented within a study on the traffic forecast for the so-called Helsinki corridors in which country partners from each CEEC participated. Therefore it was possible to extend and refine the databases for traffic and socio-economic data with the help of domestic organisations. The latest refinements to VACLAV are made in the European project TEN-STAC (EC DG-TREN) in which the updated plans for the Trans-European Transport Networks (TEN) are evaluated with VACLAV.

Spatially VACLAV is differentiated into NUTS III zones amounting to a number of more than 1300 zones. VACLAV covers all interzonal transport with transport distances of at least 50km. Passenger demand is segmented by three trip purposes and four modes. In the assignment step common assignment of freight and passenger road vehicles is implemented. The road assignment procedures are capable to estimate also local traffic volumes. Therefore VACLAV can be calibrated on the base of link-related data on traffic counts.

VACLAV is based on the four-stage approach of traffic modelling because the aggregate type of approach includes a number of standard routines, which have been calibrated and provide a reliable basis for forecasting of traffic flows. To include the interaction between traffic demand and the situation on the supply side (e.g. congestion on links) the assignment model is organised as an incremental procedure and as such can take account of capacity restraints. Main outputs of VACLAV are aggregate traffic volume and traffic performance as well as the traffic load per link. The latter can be presented by GIS-tools on maps.

4.4 RegioSUSTAIN

Core of Regio-SUSTAIN is a huge database that is collecting data for local pollution modelling from various sources and routines that enable to calculate e.g. concentrations of pollutants or noise levels. For these calculations partially external tools are used e.g. a software to calculate noise levels. Input data for the calculations comprises:

- Emission quantities from any kind of source presupposing that the co-ordinates of the source are available. In TRIAS these would come from VACLAV where the road transport emissions are connected with the road network and from POLES-EPER (European Pollutant Emission Register) concerning the emissions of power plants or other relevant point source.
- Population data.
- Land cover data (Corine).

- Digital elevation model.
- Climate and weather data.

Regio-SUSTAIN will not be applied for the whole area of Europe since this would involve too huge calculations such that selections are made for two locations in Europe where critical pollution situations are expected and which cover some different aspects of European regions. For TRIAS the Ruhr area in Germany with a high density transport network and significant industrial emissions and Andalucia in Spain with the transport corridor Cordoba-Sevilla-Huelva have been chosen.

5 BASELINE SCENARIO

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 4 shows three different groups of indicators for the TRIAS baseline scenario. 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.

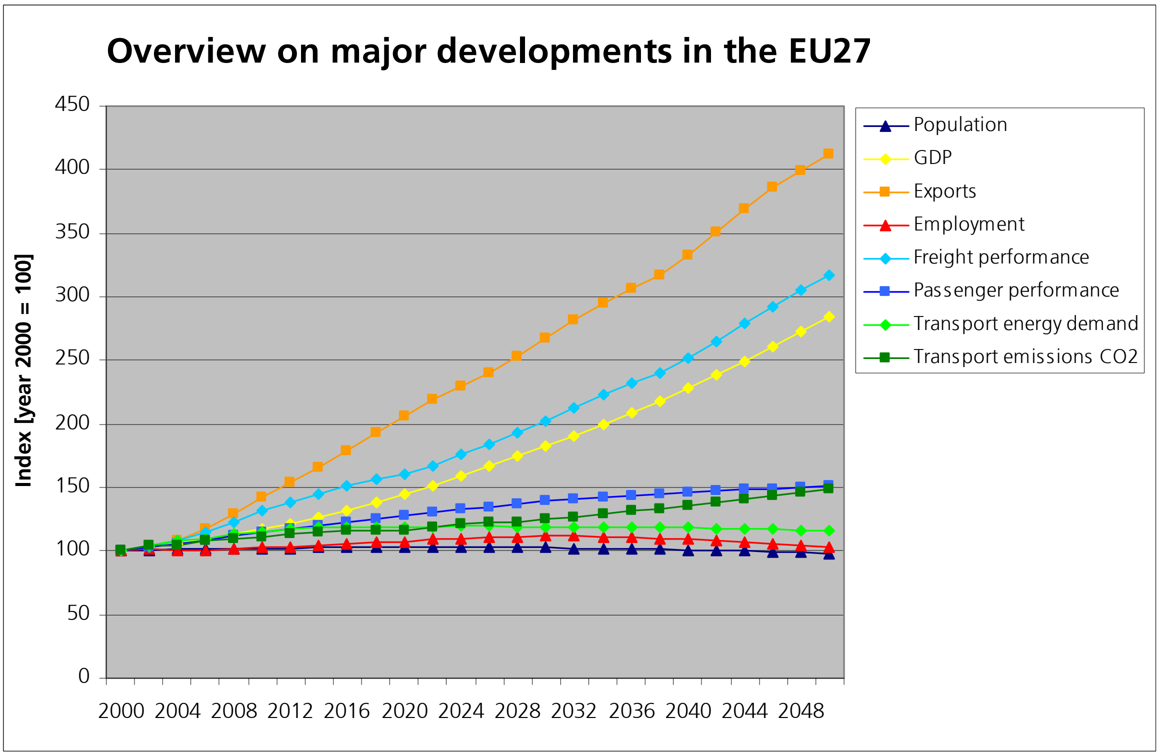

Figure 4: major developments in the transport-energy-economic system of the EU27

Taking a closer look at indicators of the transport and energy system in Figure 5 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 continues to grow 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.

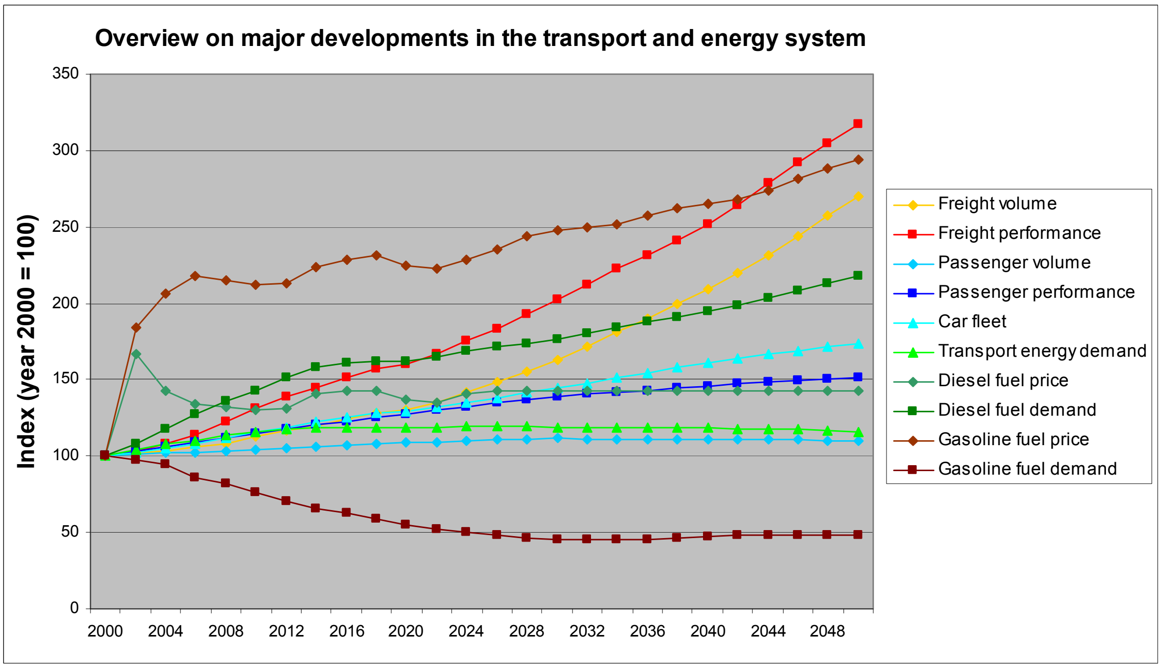

Figure 5: major developments in the transport and energy system of the EU27

6 POLICY SCENARIOS

TRIAS has defined in total ten scenarios including a reference scenario, a baseline scenario and eight policy scenarios. The reference scenario represents a virtual scenario excluding any new technologies, which was used for a number of comparisons with the baseline scenario, which e.g. included biofuels. Briefly the ten scenarios are:

1. Reference Scenario with no new technologies at all.
2. Baseline scenario with slow diffusion of biofuels (max 5.75%) and no market entering of hydrogen into transport. The latter seems reasonable as for hydrogen large projects like HyWays (2006) as well as the TRIAS stakeholder workshops concluded that hydrogen will not enter the transport market if it is not supported e.g. by subsidies at the beginning. This is because the entry barriers e.g. in terms of cost of the first fuel cells would be too high.
3. Carbon tax scenarios to foster biofuels, which implements a carbon tax on fuels and uses the revenues for subsidisation of biofuels.
4. Carbon tax scenario to foster hydrogen which implements a carbon tax on fuels and uses the revenues for subsidisation of hydrogen.

5. Subsidies scenario to foster biofuels, which pays subsidies on biofuels from the government budget increasing the debt.
6. Subsidies scenario to foster hydrogen which pays subsidies on hydrogen from the government budget increasing the debt.
7. Combined carbon tax and subsidies scenario to foster new technologies i.e. both technologies biofuels and hydrogen receive policy support.

On top of the combined scenario:

8. First mover scenario for hydrogen use for transport presupposing that the EU becomes the first world region to produce and use hydrogen cars affecting especially trade of vehicles.
9. Mandatory biofuels quotas resulting in higher penetration rates of biofuels.
10. CO2 emission limits for cars defining maximum emission standards of the average car fleet in Europe, which is to some extent equal to regulate fuel consumption.

The policies were introduced earliest in 2008. Some measures like the first mover approach for hydrogen become effective with some delay i.e. policies are introduced around 2012, but impacts are measurable only 4 to 8 years later. In general the picture of all the policies is quite positive, due to a number of synergistic effects.

Looking at GDP of EU27 compared with the baseline development (see Figure 6) the impacts in 2050 lies in the range between close to +0.2% and +1.6% increase of EU27 GDP compared with the baseline scenario. Positive impacts occur for a number of reasons:

1. All policies stimulate additional investments. The stronger the stimulus for investments the more positive is the long-term impact on the economy. Depending on the policies additional investments may occur in:
   - plants to produce biofuels,
   - plants and infrastructure to produce and distribute hydrogen,
   - R&D and manufacturing plants for new type of vehicles (e.g. bioethanol, hydrogen) or improvements of existing technologies (e.g. efficiency of gasoline vehicles to cope with CO_2 emission limits).
2. The counterfinancing of the additional investments by carbon taxes or government subsidies (affecting government debt) leads only to minor cost increases and thus has limited dampening impacts. E.g. average

cost of passenger car transport increases by +1 to +2% only in nearly all policies (see Figure 7).

3. Imports of fossil fuels can be reduced, which improves the trade balance of the European countries.
4. In the first mover scenario additional exports of hydrogen vehicles stimulate the economy, as Europe becomes the technology leader and due to this competitive advantage increases its exports of such vehicles to other parts of the world.

Figure 6 reveals that both setting a CO2 emission limit and trying to get into the first mover position for hydrogen vehicles (presupposing that the technical barriers of fuel cells can be overcome) would be the most promising options. Both policies belong to the policies with the highest investment requirements, but it seems that these could pay-off.

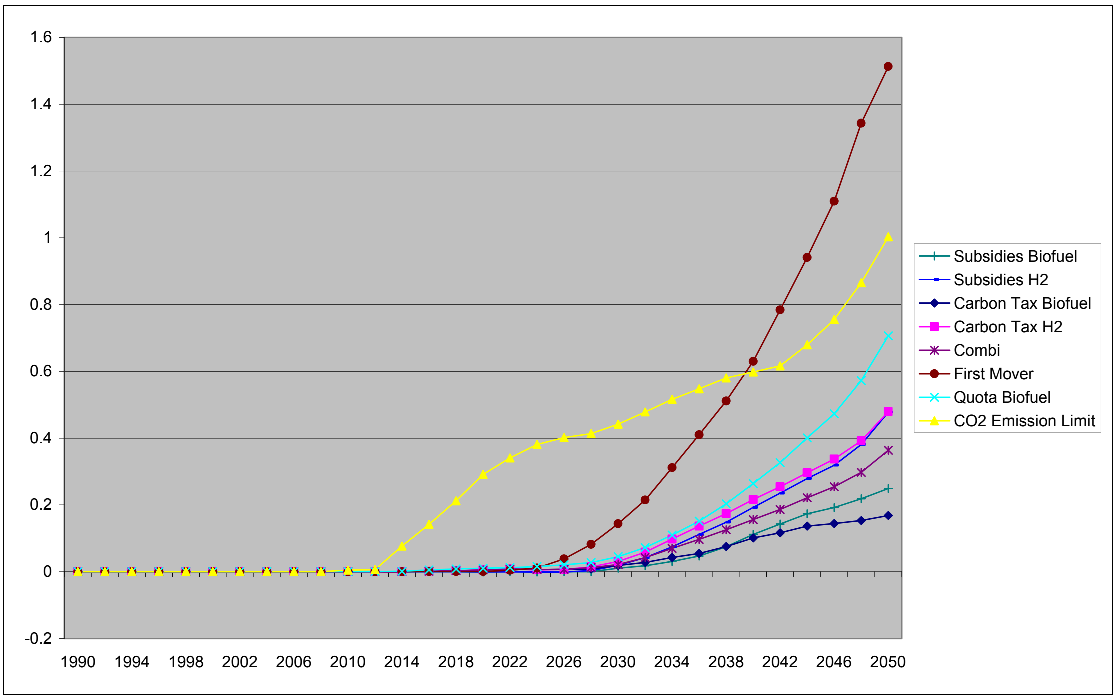

Figure 6: Impact on GDP of EU27 as percentage change to baseline

An interesting aspect to notice for the CO2-emission limits is that these constitute the only policy in which average cost of car transport decrease (see Figure 7). The reason is the significant improvement of fuel efficiency that overcompensates the cost increase induced by the carbon taxes as well as the higher prices of vehicles. The side effect is that modal-share of car transport in this policy can even increase.

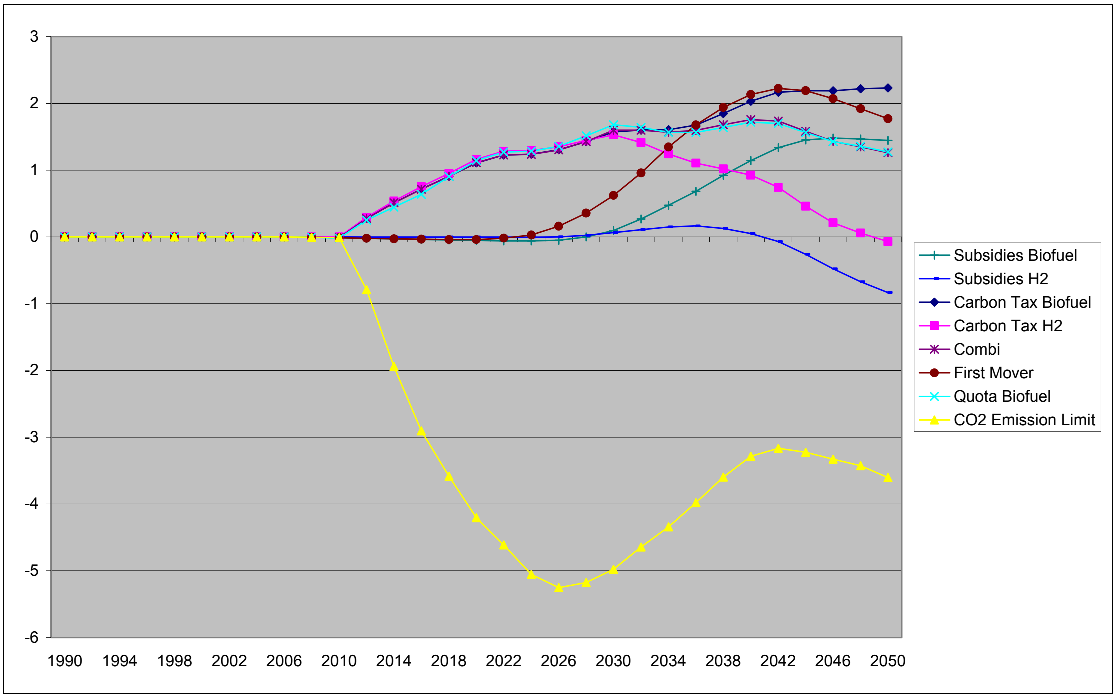

Figure 7: Impact on average cost per pkm by car for EU27 as percentage change to baseline

Figure 8 presents an example how the diffusion of new vehicle technologies is affected by the different policies. Besides cars fuelled with compressed natural gas (CNG) the bioethanol option is the most promising one for the medium term to reduce CO_2 emission and improve security of supply. This already holds for the baseline scenario. The reactions of the policies confirm this evaluation, since all policies are designed in the direction to support these two policy goals they stimulate the diffusion of bioethanol for car compared to the baseline in the medium term (2010 to 2030) by +3% to +10% (besides the pure hydrogen focussed scenarios), while in the long-term their importance is reduced below the baseline scenarios, because alternative technologies (in particular hydrogen but also electric vehicles and highly efficient gasoline cars) increase their market share.

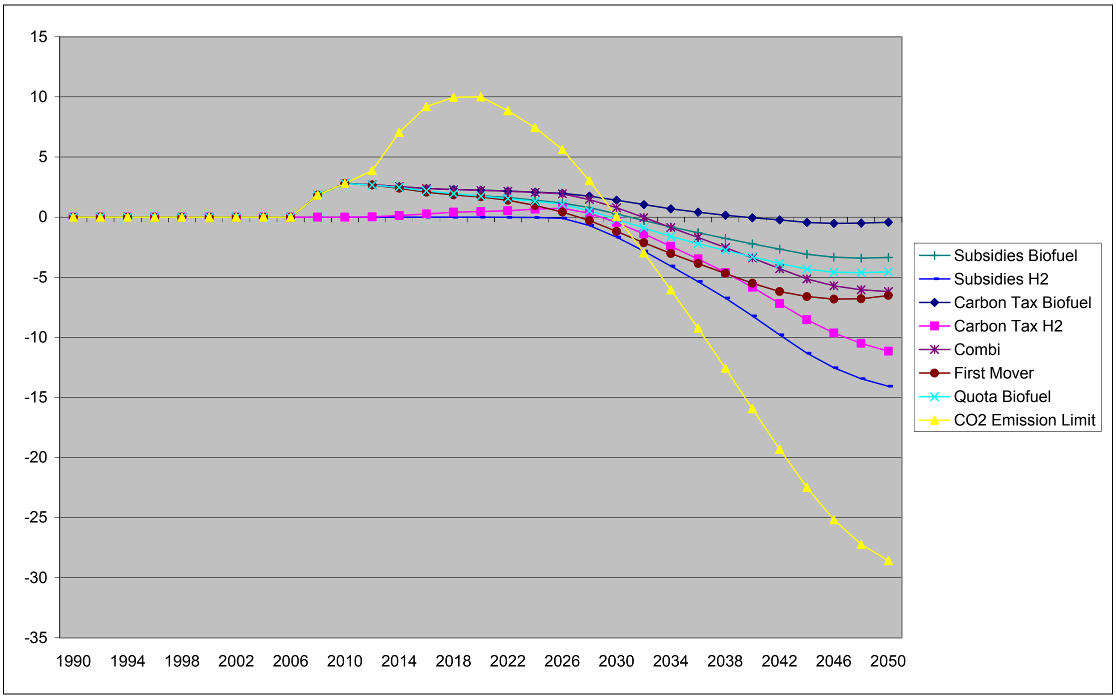

Figure 8: Impact on share of vehicle technologies as percentage change to baseline: example of bioethanol cars in Germany

In terms of CO_2 emissions of transport all policies lead to a decrease (see Figure 9) though the decreases remain in the range of -1% to -5%. Policies with stronger regulation (biofuel quota, CO_2 emission limit) are more effective then those based on technology shift and the moderate price signals, only.

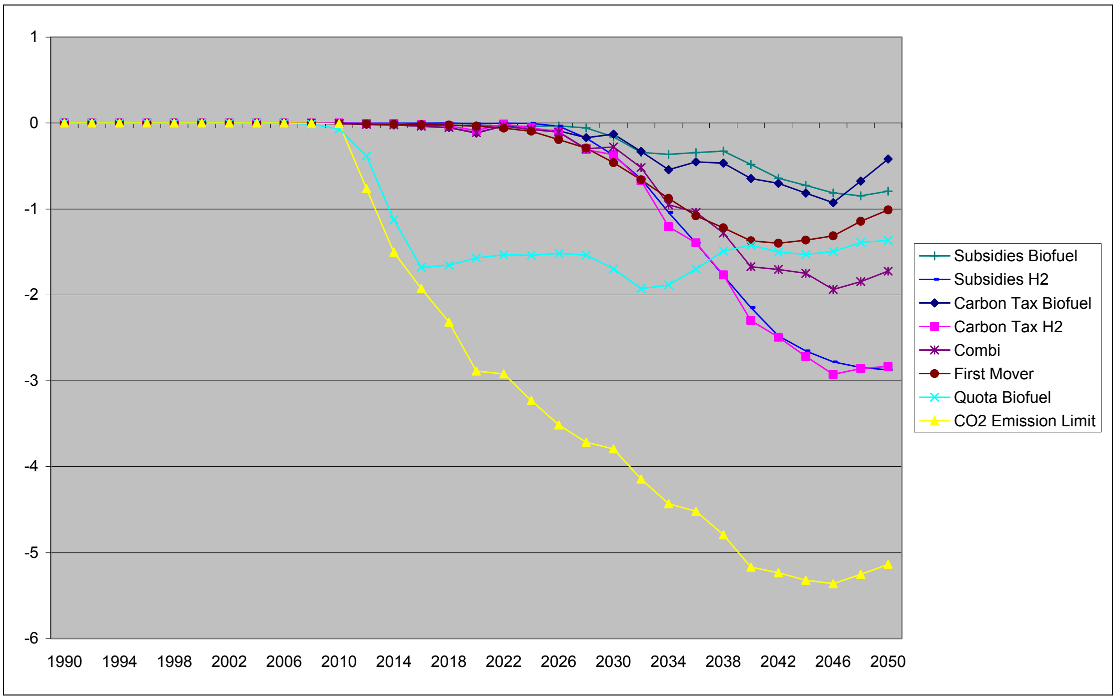

Figure 9: Impact on transport CO2 emissions of EU27 as percentage change to baseline

7 SENSITIVITY ANALYSIS

To verify the results sensitivity analyses have been carried out with the combined POLES and ASTRA models. For this analysis POLES varied the assumed resource base of fossil fuels i.e. the known and assumed reserves of oil, gas and coal. POLES and ASTRA both varied the GDP growth rates of China and India because together with the fossil fuel reserves the development of these countries are the important influencing factors on fuel prices, which in turn constitute one of the most influential factors on technological development, behaviour and policy making in the transport sector.

POLES then calculates a range for the prices of different types of fuels (fossil fuels, hydrogen and biofuels) and also a resulting range of trade of fossil fuels. With these inputs from the POLES sensitivity analysis the ASTRA model starts its own sensitivity analysis. The results for the GDP development of EU27 are shown in Figure 10. In general, also the sensitivity analysis leads to the positive stimulus of economic development as only about 10% of the more than 3000 simulations lead to a negative effect compared to the baseline.

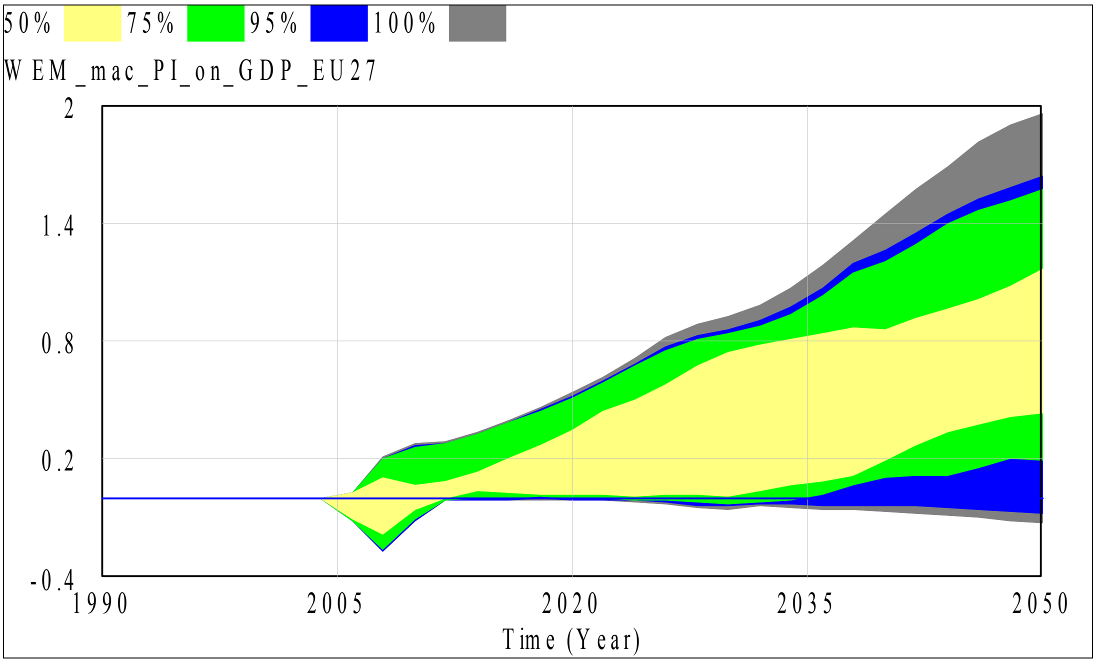

Figure 10: Sensitivity of GDP impacts in the EU27 to variations of the policies

8 CONCLUSIONS

The scenario analysis in the TRIAS project aspires to link the developments in the transport sector with the required parallel developments in the energy sector. For this purpose the analysis applies eight scenarios with the four models ASTRA, POLES, VACLAV and Regio-SUSTAIN.

The basic idea of the scenarios is to stimulate the diffusion of new technologies into the transport sector, in particular biofuels and hydrogen, with the objectives to reduce the greenhouse impact of transport and to increase the security of energy supply. Given the structure of the scenarios it is quite obvious that these two objectives are fulfilled as CO_2 emissions of transport are reduced in all scenarios and the imports of fossil fuels is also decreased both due to higher fuel efficiency and due to a fuel switch towards alternative fuels.

Less obvious but of similar relevance is the question about economic impacts. There is to note that the applied policies did only lead to a moderate cost increase for car transport, but the technological improvements in terms of efficiency and new technologies for transport required significant additional investments such that together with the reduction of fossil fuel imports the overall economic impact is positive i.e. GDP is increased above the baseline scenario.

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