# TRIAS

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

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# TRIAS
# Publishable Final Activity Report
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**TRIAS**

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

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# 1 Publishable Final Activity Report

The TRIAS project is performing a quantitative "Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios" for the European Union. The project objectives to fulfil this task 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.
- Base the assessment on an integrated model-based approach looking at environmental, economic and social impacts (sustainability impact assessment).
- Provide an open field for both external scenarios and scenarios developed in TRIAS.
- Consider the life-cycle implications of all strategies investigated.

The challenge of the project is to describe and model the symbiotic development of both the energy and transport system. Such a development has to overcome a number of "hen-and-egg" problems where one action only appears to happen, after another action has happened, which in turn required the first action to have happened. In particular, this is valid for the introduction of new transport technologies that require adapted energy supply technologies like the introduction of hydrogen as a fuel for transport.

## 1.1 TRIAS Team

The project lasts from April 2005 until June 2007 with some completion work running until end of August 2007. TRIAS is co-funded by the European Commission DG Research. It 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, Trasporti e Territorio (TRT), Milan, and the Institute for Prospective Technological Studies (IPTS) of the European Commission DG JRC, Seville. The four partners have distributed the major tasks amongst them: Fraunhofer ISI is responsible for providing bottom-up technological data and working on the economic impact assessment. IWW is responsible for transport and environmental impact assessment. TRT works on scenario framework and transport impact assessment. IPTS is focusing on the analysis of the World energy markets and the European energy system. All partners contribute to scenario analysis and the development of the methodology of Sustainability Impact Assessment (SIA).

## 1.2 TRIAS contact details

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## 1.3 TRIAS objectives and state-of-the-art

The TRIAS project perfomed a quantitative "Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios" for the European Union. The project objectives to fulfil this task are:

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The challenge of the project is to describe and model the symbiotic development of both the energy and transport system. Such a development has to overcome a number of "hen-and-egg" problems where one action only appears to happen, after another action has happened, which in turn required the first action to have happened. In particular, this is valid for the introduction of new transport technologies that require adapted energy supply technologies like the introduction of hydrogen as a fuel for transport.

Furthermore, even if one is able to solve the hen-and-egg problem then it emerges the next difficult questions: since energy and transport systems constitute two of the basic systems of today's societies, what would be the consequences for the economy, for the society and their mobility, for the role of Europe as a consumer of energy on the world market and an exporter of technology?

The complexity of these issues leads to the fact that analyses of the best strategies to adapt the transport and energy system in a symbiotic way in many cases only result either into:

- a qualitative description of scenarios for changing the two systems lacking the consistent checking of involved quantities, or
- a mere technology description explaining the feasibility of various technologies without consideration of economic or other limitations, or
- a model-based analysis applying partial models either on the technology side, the energy side or the economic side where mutual inputs of the other sides are taken exogenously without responding to feedbacks between the different sides.

This state-of-the-art is enhanced by TRIAS in three main ways

- **Quantification**: TRIAS incorporates both the qualitative elements of scenario design and technology foresight as well as the full quantification of relevant aspects related to the transformation of the energy and transport systems.
- **Model integration and consistency**: TRIAS links models for the energy system, the transport system, the environment and the economy. The models mutually exchange their results and replace inputs that otherwise would have been exogenously assumed, which enables to analyse the dynamic feedbacks of and between the involved systems. The need for comprehensive quantification increases the consistency of the full scenarios.

- **Sustainability Impact Assessment** (SIA): TRIAS improves the applicability of SIA to policy analysis as it provided a case of a complex SIA having at hand a broad palette of indicators to measure sustainability impacts.

Besides these rather scientific objectives, TRIAS intended to give answers to policy driven questions in particular on what will be the impact of this transition of energy and transport on economic growth in Europe? How does it affect security of supply for the Europeans? And will the environment be improved especially with respect to the threat of climate change? Can we expect an increase in employment from this transition or will the increased employment demand become visible at a time when the labour force decreases due to ageing in Europe?

As one of the major challenges of TRIAS is the integration of models this is elaborated on further. Figure 1 presents the state-of-the-art of model integration, which can be characterized by two dimensions: firstly, the way different models are integrated (e.g. separate models, network linked models, integrative coded models), and secondly, the frequency the integrated models exchange results. The state of the art is characterized as separate models that exchange results only once e.g. like in the European IASON project or twice like in the European TIPMAC project (bottom left corner of Figure 1). TRIAS is now moving towards the top right corner with linking POLES and ASTRA, though remaining separate models, interact in a way that exchange of results occurs iteratively such that model results converge and become consistent (similar as recently in the STEPs project), and with linking ASTRA and VACLAV such that they become network linked models exchanging their results at any point of time relevant in terms of policy changes. However, this last issue could not be achieved within the TRIAS project duration.

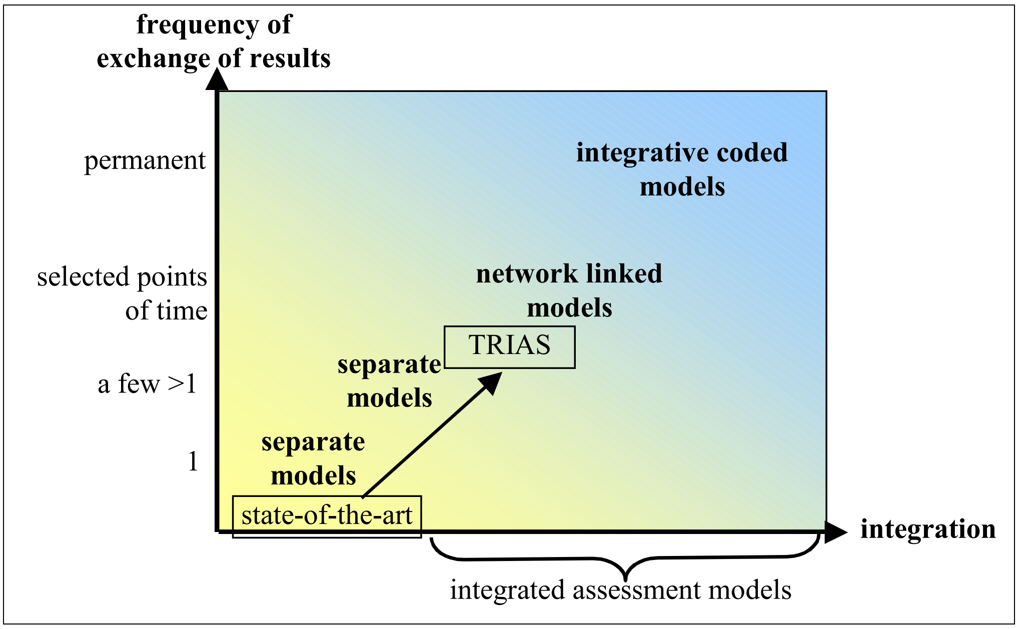

*Figure 1: state-of-the-art and classification of model integration*[1]

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[1] Adapted from Schade/Rothengatter (2005): "Research Issues in Transport Economics: Dynamics, Integration and Indirect Effects". In: Böhringer C, Lange A (eds): *Applied Research in Environmental Economics*, pp 155-184.

In agreement with the EC, an additional objective was added during the project, which concerned a software re-engineering of the ASTRA model. Given the size of the ASTRA model and the fact that a trans-national group of modellers is involved in the ASTRA development it was suggested by the TRIAS team to work on a split of ASTRA into separate files, each containing one or more models of ASTRA, and to use an existing tool to merge the separate models into one integrated model again. This is pushing the state-of-the-art of modelling large scale System Dynamics Models as well as integrated assessment modelling significantly further.

## 1.4 Project work

TRIAS is not the solely project working on scenarios for the development and transformation of the energy and transport systems in the medium- to long-term. Hence, the project started with a thorough analysis of existing scenarios and assumptions for such transformations. Eleven of these studies prepared by major Institutions active in the energy and transport field have been selected for in-depth analysis. Their findings concerning world energy supply, energy demand, economic development, transport demand of passenger and freight and potential technological development are taken into account to develop a scenario framework for TRIAS. Basically, the scenario framework is constituted by:

- a growing world economy driven by high growth rates in China and India, lower growth rates in the US and Japan and modest rates in Europe.
- a stabilizing or in some parts even declining population in Europe, which is part of the reasons for slowed down growth in Europe.
- a constrained supply of fossil fuels due to geological limitations of extraction and resources.
- an accelerated development of new fuels e.g. fuels that can be based on biomass (e.g. biofuels or hydrogen) or on the production from electricity (e.g. hydrogen).
- an accelerated development of new technologies for both production of new fuels and propulsion of transport vehicles.

### *1.4.1 Scenario development*

Given the above described framework TRIAS developed a reference scenario freezing the current technological level of using conventional fossil fuel for transport and a business-as-usual (BAU) scenario with slow penetration of new technologies into the transport market. The BAU-scenario in particular considered biofuels. The reference developments of the BAU-scenario are compared with eight contrasting scenarios, which would either foster accelerated market penetration of biofuels, of hydrogen or of both biofuels and hydrogen for transport.

Four scenarios foster either biofuels or hydrogen by implementing either subsidies funded by general government budget or subsidies financed by a carbon tax. One scenario combines all these measures to promote both biofuels and hydrogen for transport. Based on this scenario three extended variants were developed to cover a number of currently debated policy issues. (1) One particular scenario investigates the different outcome if Europe would choose the first-mover strategy in terms of hydrogen introduction for transport. (2) Another variant assumed mandatory quotas for blending biofuels into fossil fuels (gasoline and diesel). The quotas are oriented at European policy objectives. (3) The final variant focussed on another current policy debate, which is on setting $CO_2$ emission limits for cars.

### 1.4.2 Technology assessment

In parallel to the definition of scenarios analyses of promising technologies for energy supply and propulsion of the future transport system have been undertaken. The analyses concluded that the most promising new technologies for in-depth technology assessment and application in scenarios for sustainable transport would be biofuels and hydrogen using technologies. This is already reflected in the definition of the TRIAS scenarios.

In-depth technology assessment then covered the biofuels and hydrogen related technologies for the supply-chain of transport fuels, which include the sub-systems production of raw materials, distribution, conditioning, storage and refuelling, as well as for conversion, which could occur in conventional propulsion systems (i.e. internal combustion engines), in fuel cells and electric engines or in hybrids thereof. This results into so-called well-to-wheel analysis for the different fuels and technologies. In such a well-to-wheel analysis each combination of different technologies at each stage of the fuel supply-chain for a specific fuel represents a possible pathway that could be chosen for future development depending on the techno-economic characteristics that are identified for the pathway as a whole.

The analysis for biofuels identified eight major pathways starting from different types of crops producing the input of biomass into the fuel production i.e. sugarbeet, rapeseed, sunflower, wheat, miscanthus, woody biomass and straw. Other crops like sugar cane or maize seem to be inferior for use as energy crops compared with the ones linked to the eight major pathways such that these pathways provide the pre-selection of technologies for biofuels. However, even for these pre-selected pathways the price of such biofuels would be about 50%-100% higher compared with fossil fuels in 2005. Only the pathways involving ethanol production from lignocellulosic biomass (e.g. wood or straw) may come close to the cost of fossil fuels. Of course, this statement bears two uncertainties: the cost development of crude oil and the technological progress concerning cultivation and production of biofuels.

The analysis for hydrogen as transport fuel revealed that the number of technically feasible pathways is much larger then for pure biofuels since the "raw material" to produce hydrogen could on the one hand be biomass, similar as described for the biofuels, but on the other hand it could be produced from fossil fuels or from electricity, which could in turn be generated from renewables, fossils or nuclear. Furthermore, hydrogen can be used in vehicle engines in two different physical conditions: liquid or gaseous with compression.

In general, the possible hydrogen pathways show an obvious trade-off between cost of fuel and $CO_2$ emissions per unit of fuel. Pathways that generate cheap hydrogen produce high amounts of $CO_2$ emissions and vice versa. This also holds for the 12 most promising and hence pre-selected pathways for TRIAS, of which four lead to liquid hydrogen and eight to gaseous hydrogen. Two of the pathways generate hydrogen on-site at the fuelling station either by electrolysis or by steam reforming of natural gas, while the other 10 pathways require the built-up of large scale production and distribution systems producing hydrogen by large scale coal and lignite gasifiers, steam-reformers or electrolysers, which then require input of either coal, lignite, natural gas or electricity and, in the case of fossil inputs, facilities for carbon capture and sequestration (CCS). Compared to gasoline the most obvious pathway for hydrogen as transport fuel would be hydrogen as a by-product of chemical processes, which e.g. in Germany would be sufficient to fuel about 500.000 cars annually. This pathway would be slightly more costly then gasoline but would also slightly reduce the $CO_2$ emissions. In terms of cost also those pathways based on natural gas would be close to gasoline, while in terms of $CO_2$ emissions especially the pathways based on electrolysis from renewables or nuclear would strongly reduce $CO_2$ emissions.

Of course, the different pathways can not be seen as independent. Investing into one pathway and neglecting another one would bring cost down of the selected pathway and its related technologies due to economies of scale and technological progress from learning-by-doing as well as what concerns biomass there is competition of the different sources of biomass for a limited amount of land and between the different ways to use biomass e.g. heating or electricity instead of as transport fuel.

The interdependency of the different pathways is taken into account by further working steps of TRIAS. These steps included the implementation of the different pathways in terms of their techno-economic characteristics within a set of models, which then optimize the selection of pathways under the given constraints and estimate the impact for the energy system and subsequently the transport system. The applied models were POLES for the world energy system and BIOFUEL, a newly developed model estimating production cost and production of biofuels in Europe. With these models it will was feasible to grasp the impacts for the energy system e.g. the changes of prices for the different fuels and to provide these to the other TRIAS models calculating the impacts for the transport system e.g. changes of modal-split, the impact on the environment e.g. changed $CO_2$ emissions and the economic impact e.g. changes of GDP growth.

The TRIAS work on the scenarios and technology assessment was complemented by the organisation of a cluster workshop on the *Sustainability of a hydrogen economy* (Feb. 21st 2006 in Frankfurt) at which the TRIAS planned scenarios and the technology assessment were presented and discussed by TRIAS and other participants. In the course of the workshop a group discussion concluded that the sustainability of hydrogen depends to large extent on characteristics of the feedstock to produce hydrogen, where the unambiguous sustainable option would be to use renewables while for nuclear and fossils with CCS doubts were raised about their sustainability.

### *1.4.3 Modelling work*

A very significant part of TRIAS concerned the update of the applied four models ASTRA, POLES, VACLAV and Regio-SUSTAIN to incorporate new elements that are required to model market entry and diffusion of the new technologies in the energy and transport sector as well as to assess their economic and environmental impacts. For POLES a new module was developed to model biofuels prices and production, the so-called BIOFUEL model. This is implemented as separate module with connections and overlap to both POLES and ASTRA. For ASTRA, the vehicle fleet module was updated to include besides gasoline and diesel vehicles also hybrids, electric vehicles, CNG, LPG, bioethanol and hydrogen vehicles. Also all fuel consumption and emission factors for the different vehicle types are updated. Further the cost model of the transport model was significantly extended both to consider separately the different fixed and variable cost elements of the different modes, in particular road mode, and to reflect the cost of the new technologies. For the economic model the linkages from the new technologies to consumption and investment are established, the fuel prices and taxes on the new fuels are considered and the GDP trends for the European countries and the nine rest-of-the-world regions distinguished in ASTRA have been adapted to GDP trends used also in the MATISSE and ADAM projects. For Regio-SUSTAIN the linkage with POLES and the EPER database is established and the new CEMOS2 model (chemical exposure module for spot-sources) was developed as part of Regio-SUSTAIN.

During the course of the project it was felt that the ASTRA model would grow too strong to maintain it as one single file. Hence, in agreement with the EC an approach was conceived to split ASTRA into a number of separate stand-alone models that on request could be merged together using either all or only selected models. Since the first conceived attempt to use an available tool for this split-and-merge process failed, TRIAS developed its own tool, the so-called ASTRA-Merger, with which it was then possible to merge the ASTRA model and obtain again a fully operational integrated transport-economy-environment model.

Further work in TRIAS concerned the linkage of the different models such that they could exchange results between each other. The link between ASTRA and POLES where a large number of variables is exchanged in both directions could be implemented successfully both in terms of logic (i.e. meaning and usability of variables) and technology (i.e. file system and protocol for data transfer, which involved the setup of a repository system). The same holds for the linkages from POLES, ASTRA and VACLAV to Regio-SUSTAIN. These were designed as soft-linkages with manual exchange of data, since the number of points of times at which data was to be exchanged is limited and no feedback from Regio-SUSTAIN to the other models is required. The most difficult to handle was the link between VACLAV and ASTRA, which could not be completely developed as hard link during the project duration of TRIAS due to technical difficulties. Instead, most of the simulations used the internal transport model of ASTRA making reference to basic VACLAV results.

### 1.4.4 Scenario analysis

Applying the newly calibrated and interlinked models the baseline scenario of TRIAS could be developed successfully. In terms of broad economic development, the ASTRA and POLES model followed the GDP trends of the ADAM and MATISSE projects. Concerning transport developments, the trends foresee a strong continuous growth of freight transport, while for passenger transport only moderate growth until about 2030 is expected and afterwards nearly a stabilisation. In terms of energy consumption growth is slower than the total growth of transport, which implies moderate improvements of efficiency of transport. New technologies will enter the transport vehicle market with different time horizons. In the medium term, in particular bioethanol and CNG vehicles will achieve significant market shares, while hydrogen will not enter the market without policy support, which is in line with results of the European HyWays project.

After the business-as-usual scenario was completed this could be used as basis from which the policy scenarios could be derived. Hence, the scenario levers were implemented into those models, which were appropriate to handle a specific policy. On this basis the scenario runs could be undertaken and provided the results for the indicators that should be used within the sustainability impact assessment. For this purpose, the quantitative indicators from the models were combined with qualitative analysis on specific aspects e.g. the biomass potentials to produce biofuels and the related question on food versus energy and meat versus energy, respectively. A summary table is developed to easily provide an overview on the scenario results for policy-makers.

A further invention were the linked sensitivity runs of the ASTRA and POLES model. For these runs the POLES model assumed reasonable ranges for reserves of fossil fuels (crude oil and gas) and ranges for the GDP growth in China and India. The result were reasonable ranges for fossil fuel prices that could feed into a sensitivity analysis of ASTRA together with the same GDP growth ranges for China and India and ranges for the imports of fossil fuels of the European countries in monetary terms. ASTRA then produced ranges for results of economic variables (e.g. GDP, employment), of transport variables (e.g. transport performance, energy demand) and of environmental variables (e.g. $CO_2$ emissions, $NO_x$ emissions).

## 1.5 Project results

The project results achieved were an update of the POLES, ASTRA, VACLAV and Regio-SUSTAIN models with new model elements required for the specific scenario analysis in TRIAS e.g. extending to the time horizon 2050, adding new technologies to the vehicle fleets, modelling of biofuels for the energy and transport markets as well as the new development of the BIOFUEL model. In particular, the ASTRA model made a large step ahead as during the course of the project it was agreed to actually modularize the software and to develop a tool that would merge it back to the integrated System Dynamics model that incorporates the most important feedbacks between transport, energy, technology and the economy. A further achievement was the improved linkage between ASTRA and POLES that enabled fast running of scenarios in an iterative manner and achieving convergence between the two models.

Applying the improved models and using the newly established linkages between the models the eight scenarios could be tested and compared with the business-as-usual scenario. The main conclusion is that all scenarios showed a positive impact on the economy, though in most of the scenarios the improvement remained quite limited. The two most effective scenarios were the first mover scenario for hydrogen and the introduction of $CO_2$ emission limits, because the main driver for making scenarios positive were the additional investments induced by the policy and these were the scenarios with the highest investments. A further stimulus was the reduction of fossil fuel imports. It has clearly to be noticed that all scenarios were comprehensively specified such that e.g. to increase investments always either increased cost, increased taxes or government expenditures are specified that would keep the economic system closed.

Looking closer at the results for GDP and $CO_2$ emission from transport (Figure 2and Figure 3) it seems that European policy making goes into the right direction. In the shorter term setting $CO_2$ emission limits will provide economic stimulus as well as it will reduce $CO_2$ emission. This can be enforced by fostering biofuels, though it should be taken into account to limit the use of biofuels, because (1) overdrawn use of biofuels would lead to strong conflicts between the use of biomass for food and the use for energy, which seems not to be reasonable considering (2) that the impacts on economy and $CO_2$ emissions of the biofuels policies remain limited. In the longer term, hydrogen seems to be a suitable option to foster economic growth and to significantly reduce $CO_2$ emissions and other environmental impacts of transport. However, this presupposes that this hydrogen is mainly produced from renewable sources. Finally, two issues should be taken into account: (1) the policies analysed in TRIAS are designed rather conservative, and in particular concerning $CO_2$ reduction targets until 2050 the policies have to be designed more ambitious, and (2) the recent technology development of batteries, which was not considered in the TRIAS scenarios, could make that battery-electric vehicles will play a more important role than in the TRIAS scenarios.

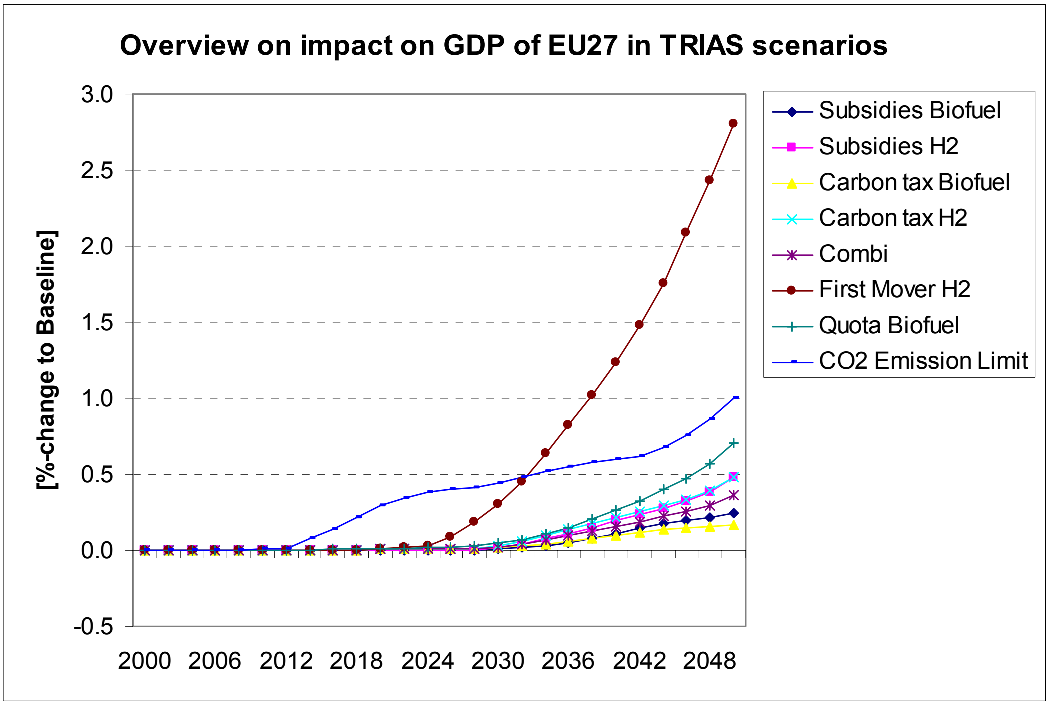

*Figure 2: Impact on GDP in the eight TRIAS scenarios*

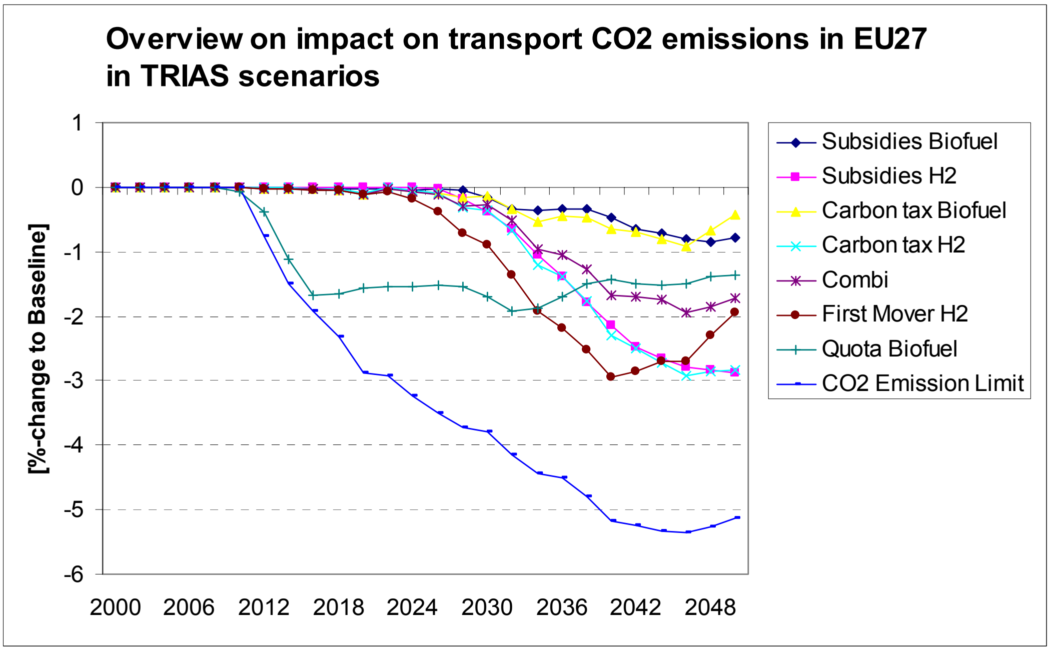

*Figure 3: Impact on transport $CO_2$ emissions in the eight TRIAS scenarios in EU27*

Besides the technical work and the resulting findings, the TRIAS project was also the main organizer of two cluster workshops, of which the latter was also the projects final conference. First, the cluster workshop on the *Sustainability of a hydrogen economy* was hold in February 2006 in Frankfurt, and, second the cluster workshop and TRIAS final conference titled *Running transport on hydrogen and biofuels* was hold in Frankfurt in June 2007. Both workshops were co-organized with the European research projects HyWays and MATISSE and for the first workshop the ENCOURAGED project was the fourth co-organiser.

## 1.6 Project dissemination

Three elements constitute the strategy for dissemination of TRIAS: (1) the website explaining the project, disseminating results, providing deliverables for download and distributing information e.g. about the two cluster workshops (http://www.isi.fraunhofer.de/TRIAS/), (2) the participation at a number of conferences to present TRIAS (e.g. World Conference on Transport Research 2007 in San Francisco, EC-DG-JRC International Conference on Transport and Environment: A global challenge Technological and Policy Solutions 2007 in Milan, European Transport Conference (ETC) October 2007 in Leeuwenhorst) and (3) the organization, participation and web-hosting of the TRIAS-HyWays-MATISSE cluster workshops in Frankfurt.

Further, an abstract has been submitted and is accepted for the European Transport Research Arena (TRA) in Ljubljana in 2008 and it is planned to submit two papers to scientific journals. One paper on the results of the stakeholder interaction at the first cluster workshop has been submitted to a Journal already.

## 1.7 Overview on published deliverables of TRIAS

The following table presents the list of deliverables. All deliverables are provided for download as PDF-Files from the TRIAS website at http://www.isi.fraunhofer.de/TRIAS/.

Table 1: Deliverables List

| Deliverable no. | Deliverable name | Work package no. |
|---|---|---|
| **1** | Scenarios for the socio-economic and transport-energy systems | **1** |
| **2** | Technology trajectories for transport and its energy supply<br>This report is extended by:<br>▪ Hydrogen Technology Database (EXCEL)<br>▪ Biofuels Technology Database (EXCEL) | **2** |
| **3** | TRIAS outlook for global transport and energy demand | **4 , 3** |
| **4** | Alternative Pathways for Transport, Technology and Energy to promote sustainability in the EU | **5** |
| **5** | Final Report of the TRIAS Project | **7** |

# 2 Annex – Final plan for using and disseminating the knowledge

## 2.1 Exploitable knowledge and its use

Four major exploitable results can be expected from TRIAS: firstly, the results of the scenarios can be used for comparison with other scenarios and can finally contribute to policy-making; secondly, the extended models both as stand-alone or in combination can be applied for further research and policy advising projects; thirdly the split-and-merge concept can be applied to other large System Dynamic Models (e.g. POLES), and fourthly the experience of establishing model interactions via a repository can be used in other European projects (e.g. ADAM project, HOP! project). Table 2 presents the list of exploitable results of TRIAS, which is followed by brief explanations for each item.

Table 2: Exploitable results of TRIAS

| **Exploitable Knowledge** (description) | **Exploitable product(s) or measure(s)** | **Sector(s)** of application | Timetable for commercial use | Patents or other IPR protection | **Owner** & Other Partner(s) involved |
|---|---|---|---|---|---|
| Scenarios | Data | Energy and transport policy analysis | 2007/2008 | Public | TRIAS |
| Deliverables | Reports | Energy and transport policy analysis | 2007/2008 | Public | TRIAS |
| Linked POLES-ASTRA models | Mathematical models | Energy and transport policy analysis | >2007 | IPR of modellers | IPTS for POLES, ISI-TRT-IWW for ASTRA |
| Linked ASTRA-VACLAV models (only when completed after TRIAS) | Mathematical models | Transport policy analysis | >2008 | IPR of modellers | ISI-TRT-IWW for ASTRA, IWW for VACLAV |
| ASTRA | Mathematical models | Economic and transport policy analysis | >2007 | IPR of modellers | ISI-TRT-IWW |
| POLES | Mathematical models | Energy policy analysis | >2007 | IPR of modellers | IPTS |
| Regio-SUSTAIN | Mathematical models | Environmental impact analysis | >2007 | IPR of modellers | IWW |
| Split-and-merge-concept for SDM models | Concept (but linked with ASTRA-Merger) | large System Dynamic Models | > 2007 | Concept free, Software IPR of modellers | ISI for ASTRA-Merger |
| Concept of repository usage for model linking | Concept | Integration of models for policy analysis | > 2007 | Public | Free |

The TRIAS consortium proposed a similar approach for another European project for DG TREN involving the linked ASTRA and POLES models as well as the TRANS-TOOLS and TREMOVE models. The proposal became successful and continued the TRIAS line of thoughts since May 2007 (iTREN-2030 project funded by EC DG-TREN).

ISI will apply the extended ASTRA model in the MATISSE project to improve the extended concept of Integrated Sustainability Assessment (ISA) running a hydrogen case study and using the experiences gained from TRIAS in the second half of 2007.

Furthermore, the extended ASTRA model is applied by ISI for the ADAM project to analyse policies both to mitigate climate change and to adapt to climate change. In ADAM, ASTRA will cover the economic and the transport analysis of Europe. Also, ISI will apply ASTRA in the HOP! project to analyse the economic impacts of high oil prices.

IWW intends to use the combined ASTRA-VACLAV models in further transport demand projections e.g. for Turkey. Regio-SUSTAIN is further developed to become a well-known tool for regional environmental analysis.

IPTS expects that the improvements of the energy model through the update of the techno-economic database and the incorporation of the EPER data will result in an updated POLES model. The main focus of the POLES model will be policy support to other Commission services, and in this respect, the knowledge gained from TRIAS will allow the delivery of more integrated policy support in combined transport and energy issues. Hopefully, the results of the project will also be useful in the support of the Hydrogen and Fuel Cell technology platform.

In the shorter term, TRT will use the knowledge gained in the TRIAS project to develop the HOP! project, where the effects of high oil prices will be investigated using ASTRA and POLES. The TRIAS experience provides useful information on relevant aspects needing specific care both in theoretical terms concerning the close linkages between energy and transport development, and in working terms concerning the simulation of scenarios.

The TRIAS experience will be also of reference for future enhancements of the ASTRA System Dynamics Model of Europe, for instance to improve its connection with a network based transport model.

## 2.2 Dissemination of knowledge

The TRIAS consortium undertook a number of dissemination activities, of which the most effective were the implementation of the project website and the organisation and hosting of the two cluster workshop in Frankfurt (02/2006, 06/2007), which also involved to send out direct e-mail with the flyer explaining the workshops.

Besides presentations at its own workshop TRIAS gave five presentations at international conferences, which were accompanied by the delivery of three papers. One further paper is accepted for presentation at another conference in April 2008.

Further, the accepted deliverables of TRIAS are put on the website, such that they can be downloaded, and a summary of the deliverables is provided.

Table 3: Overview list on dissemination activities of this reporting period

| Planned/ actual Dates | Type | Type of audience | Countries addressed | Size of audience | Partner responsible /involved |
|---|---|---|---|---|---|
| since 07/2005 | Project web-site | Research, General Public | **EU** | n.a. | ISI |
| 03/2007 | International Conference on Transport and Environment: A global challenge Technological and Policy Solutions, Milan | Research and policy | **EU** | 40 | TRT / IPTS, ISI |
| 05/2007 | Flyer informing about TRIAS final conference | Research and policy | **EU, World** | n.a. | ISI |
| 05/2007 | Direct e-mailing to invite for final conference | Research and policy | **EU, World** | 400 | ISI |
| 05/2007 | 15th European Biomass Conference, Berlin | Research and policy | **EU** | 50 | IPTS |
| 05/2007 | Sustainable Neighbourhood – from Lisbon to Leipzig through Research, Leipzig | Research and policy | **EU** | 100 | ISI |
| 06/2007 | TRIAS Final Conference, Frankfurt | Research and policy | **EU** | 55 | ISI, TRT, IPTS, IWW |
| 06/2007 | Direct e-mailing to inform about summary of final conference | Research and policy | **EU, World** | 400 | ISI |
| 06/2007 | World Conference on Transport Research, San Francisco | Research focus, some policy | **EU, US, World** | 30 | ISI |
| 10/2007 | Presentation at the European Transport Conference, Leeuwenhorst | Research and policy | **EU** | 40 | ISI / TRT, IPTS, IWW |
| 04/2008 | Presentation at the Transport Research Arena, Ljubljana | Research and policy | **EU** | 40 | ISI / TRT, IPTS, IWW |
| 2008 | Papers in Scientific Journals | Research | **EU** | n.a. | All |

## 2.3 Publishable results

The publishable results of the TRIAS project comprise the Deliverables D1 to D5 of the project, presupposed they are accepted by the European Commission (EC). Currently, two deliverables are accepted and are available for download from the website. The same holds for the technology database developed in WP2 of TRIAS. A third deliverable D3 is completed and is waiting for approval to be published on the website. When the remaining deliverables D4 to D5 have been completed and accepted by the EC they will also be posted on the website to make them publicly available. The following sections present the summaries of the already approved deliverables D1 and D2 as well as the completed deliverable D3.

### 2.3.1 TRIAS D1

**Executive Summary of TRIAS Deliverable D1 "Scenarios for the socio-economic and transport-energy systems"**

The TRIAS project will perform a "Sustainability Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios", which is coherent with the full title of the project. 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) taking the lead and collaborating with the Institute for Economic Policy Research (IWW) at the University of Karlsruhe, TRT Trasporti e Territorio (TRT) and the Institute for Prospective Technological Studies (IPTS) of the European Commission DG JRC.

The project will provide quantitative estimates of the potential of conventional and alternative vehicle and fuel technologies until 2030, 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. The applied models will act at European scale (EU25) and will include POLES , ASTRA, VACLAV and Regio-SUSTAIN.

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 years.
2. Preparation and integration of existing models to implement the scenarios: POLES covering the energy sector, ASTRA modelling transport on an aggregate level and the national economies with 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 locations.
3. Sustainability Impact Assessment of the scenarios. The scenarios will be tested with the interlinked four models and from each model indicators will be selected to provide a picture of consequences of the scenarios as broad as possible. A condensed set of indicators will be defined to make the results accessible for the public and decision-makers.

This deliverable documents the outcome of the first task, focused on the definition of the scenarios to be simulated by means of the modelling tools (WP1 of the project). The activities have been organised into three main phases:

- The survey of relevant studies at national and at international level: the scenarios proposed in each study have been classified according to the specific topic addressed (e.g. use of energy in the transport field, development of technologies for means of transport), the source (e.g. national agencies, international agencies, European RTD projects), the methodology applied (e.g. modelling, industrial trend analysis, expert interviews, Delphi surveys).
- The screening of existing relevant policy documents, including currently agreed long-term effective policy statements e.g. hydrogen and fuel cells technology platform of the EU, White Paper European transport policy for 2010: time to decide.

- The design of TRIAS specific scenarios covering a spectrum of scenarios with moderate changes and scenarios with extreme changes.

## The current trends and the policy approach

Those "Scenarios" in the energy and transport fields relevant for TRIAS are increasingly used to explore more sustainable patterns in future energy consumption. The huge amount of documents reviewed within TRIAS Work Package 1 covers the bulk of main studies completed by the *international energy community* – from national and international agencies to industry, from financial institutions to academia – to produce projections of future energy consumption consistently related to projections concerning factors that influence energy consumption. The range of options for combining model based projections with scenario techniques can be considered indicative of the fact that such links are based on both past evidence concerning trends, a good deal of assumptions about changes of trends and a manifold understanding of cause-effect mechanisms.

Far form being exhaustive, bullets shown in Table 1 are indicative of circumstances around which most official medium term projections linking economic development to energy consumption do converge.

Table 1. Basic facts

1. Demand for oil has grown steadily in the past, only marginally reacting to year-on-year price fluctuations. However, oil consumption responded very strongly to the oil price hikes of the 1970s, especially in the advanced countries that subsequently imposed high taxes on energy consumption.
2. The main consumers of oil continue to be the advanced economies; the United States, OECD Europe, and Japan together consume about half of annual oil output.
3. Consumption in the emerging markets and developing countries has been increasing at a faster pace, as these economies grow rapidly and their use of energy including oil in the transport, industry, and residential sector expands.
4. China and India contributed 35 percent to incremental oil consumption between 1990 and 2003, even though the two countries produced only 15 percent of world output over the period.
5. On average, oil intensity, or use of oil per unit of output, halved over the past 30 years in advanced countries and declined by about one third in developing countries.
6. The group of developing countries and emerging markets is less oil efficient than the advanced economies when output is measured at market exchange rates. But oil intensity is similar in the two groups when output is adjusted for differences in national price levels.
7. Proven oil reserves (i,e the oil resources that can be extracted profitably with at least 90 percent probability) are sufficient to meet world demand at current levels for over 40 years.
8. However, this figure significantly underestimates the volume of oil resources that may be eventually recoverable with improved technology or at higher oil prices. On this basis, the International Energy Agency calculates that remaining oil resources could cover 70 years of average annual consumption between 2003 and 2030.

*Source: International Monetary Fund 2005*

It is crucial to point out that a growing number of experts is claiming that point 7 and 8 made by the IMF are much less relevant than the ratio between demand and actual supply of crude oil, where demand is given by a continuously increasing curve, while supply is depicted by a discontinuous curve depending on oil extraction technologies and geological circumstances. According to these experts, available reserves extraction cannot be increased significantly anymore and will remain on a plateau for some years and then decline: a phenomenon that is named Peak-oil (Campbell 2005, Zittel/Schindler 2004, Hirsch et al. 2005), which would lead to an excess demand strongly driving oil prices to unprecedented high levels, which reflects the situation that we currently observe.

Looking into more detail at the contribution of the transport sector, it can be observed that transport energy consumption in the EU 15 plus Switzerland and Norway has grown by about 2.0 % per year during the period 1990-2000, and equalled 365 Mtoe (million tonnes oil equivalent) in 2000 (some 35 % of all energy use) (Panorama, 2005). As a consequence of the growth in energy consumption, $CO_2$ emissions from transport also continued to increase. The increased transport demand and the continuing shift of transport demand towards road and air, combined with the increasing use of heavier, more powerful cars and trucks, have offset the improvements in fuel economy of improved engine technology. Indeed, road transport totally dominates the energy balance: in the three key OECD regions—the U.S., Japan and the Europe of Fifteen — it represented 85% of the 13 750 billion passenger-km travelled in 2000. Air, rail, tramway/metro and waterway transport account for the rest. It represents 81% of transport-related energy demand and, despite recent advances in energy efficiency, is still the most energy-intensive mode of transport.

The issue of growing energy use and namely energy use for moving passengers and goods deserves special care and is subject of several policy approaches. At the base of the policy approaches there is the expectation that transport energy demand, in absence of specific interventions will growth faster than any other end-use sector. The IEA's World Energy Outlook base case projection, which assumes stable fuel price and no new policy actions, foresees total transport energy demand growing 40% in the OECD and nearly 140% in non-OECD countries in a period that goes from 1997 to 2020. On the other hand, this continued growth is not inevitable, as the decline of fuel consumption in Germany over the past four years has shown, which can be seen as a reaction to long-term eco-taxation, short-term fuel price growth and moderate economic growth.

Currently, two main kinds of approaches to slow down transport energy consumption can be identified. The first approach consists in developing policies which could have an effect on the transport demand, discouraging some travel and promoting the use of the less energy intensive modes (i.e. road transport). In such a category could be grouped policies such as transport charging schemes like, internalisation of external costs, carbon tax, etc. as well as reducing the need of moving goods through an improvement of the logistic chains, revitalizing alternative modes of transport which are less energy intensive and less polluting than road transport. The second approach, which is not alternative to the first, focuses on transport supply: aiming at developing new vehicles technologies, improving fuel efficiency of conventional passenger and freight transport modes, developing alternative fuels and so on.

## The technology trends

The transport market is today almost entirely dependent upon oil-based fuels and is responsible for about 67% of the final oil demand in the EU. The dependency on imported liquid fuels amounts to about 72 % of the European oil consumption and may even increase up to 93 % by 2020, due to the depletion of the EU's own oil resources and an increasing energy demand. Over the last years, several possible alternatives to replace oil based fuels have emerged such as Natural Gas (NG), Conventional Bio-fuels (Biodiesel and Bioethanol), Advanced Bio-fuels (Biomass to Liquids) and Hydrogen. In the short to middle term it is likely that bio-fuels and natural gas will play a major role while in the long term, hydrogen seems to be a promising option for a larger market share. The share of alternative fuels in the total EU fuels market will also depend highly on the development of prospective drive concepts as illustrated in Figure 1.

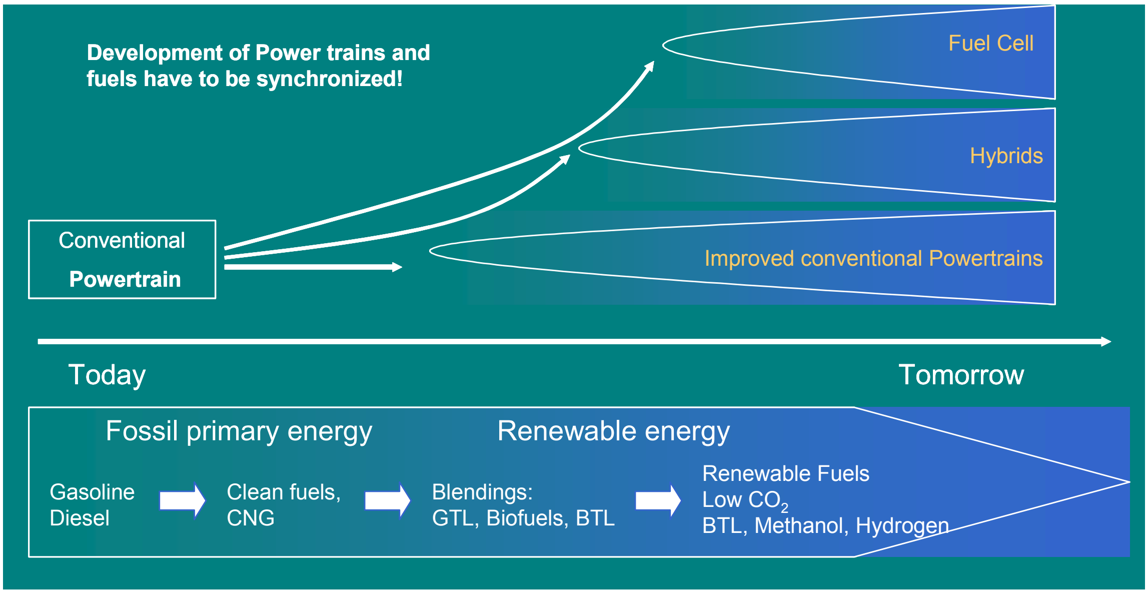

*Figure 1. Vision of Daimler Chrysler and Ford about the development of powertrains and alternative fuels*

Advanced bio-fuels are likely to play a role in the EU alternative fuels market from 2010. Biofuels have a significant potential to overcome traditional barriers to entry into the market due to their compatibility with vehicles without major engine modifications and they can also be blended with current fossil fuels such as gasoline and diesel. In fact, some low-percentage ethanol and biodiesel blends are already being distributed in service stations in Europe and worldwide without significant compatibility problems and avoiding new investments for infrastructure development. These features allow bio-fuels to be introduced rather rapidly in the existing passenger transport market. As bio-fuels are obtained from renewable energy sources they also contribute to meet the 12 percent renewable energy target.

On the other side, the Commission has made the hydrogen economy one of its long-term priorities for its energy system and, to this end, has created a technology platform for hydrogen to devise an action plan aimed at creating a completely integrated hydrogen economy, based on renewable energy sources and nuclear power, towards the middle of this century. Hydrogen:

- can be produced from fossil fuels by conversion, with $CO_2$ separation; this one can be considered the cleanest way to continue using these fuels, that will have also in future an important role in our societies;
- can be produced from other sources (renewable, nuclear) without $CO_2$ emissions;
- can be utilised in different applications (transportation, electricity production, etc.), not producing any pollutant but water steam.

Production of hydrogen from fossil fuel could be considered as a “technological bridge” towards new production processes from renewables and, if the nuclear waste storage problem could be solved, “new” nuclear, expected for the second half of the century. In any case, the development in the next decades of technologies for transport and final use of hydrogen produced from fossil fuel will provide the basis to allow the introduction of the $CO_2$-free hydrogen production technologies in the long term.

## The TRIAS scenarios

The TRIAS scenarios build on the analysis of the current trends, the relevant policies and the technological development. The scenarios are needed to analyse the role of technology to give rise to breaks in the evolution of energy and transport systems like: growing energy demand from the transport sector, oil as the dominating source of energy, alternative fuels and technologies entering in the market at a slow pace. More precisely, TRIAS scenarios are required to assess the effects of technology on the transport and energy systems by means of a modelling exercise. Therefore, the scenarios are designed such that the impacts of alternative key technologies (and of relevant side policies) can be identified and compared to each other and to a reference case.

According to these requirements, the TRIAS modelling scenarios are defined by a two-component approach:

- first, a fixed scenario matrix-based approach and, second,
- a sensitivity scenario analysis to deal with variables where uncertainty is significant or plays a major role in future development, such that high impacts can be expected from variations.

Within the matrix-based approach one can recognise four main elements:

- A Business-as-Usual scenario is defined to simulate the extension of the existing trends to the following 30-50 years (the TRIAS scenarios have a medium to long term horizon, which means that the simulation will start at the base year 2000 and will run until the year 2050). At the same time, a do-nothing scenario is also defined to serve as reference for comparing modelling results. Indeed, in order to assess the impact of policy measures, it is useful to insulate the contribution of such measures, but also a realistic picture of future development is required to identify how the policy measures could actually change the evolution of the system until a different situation in the medium to long term.
- Policy measures that can be used to contrast the current trend are focused on the two main fronts: transport energy demand and supply. Concerning demand, the use of the economic leverage to influence individuals choices is preferred to command-and-control rules as it can play a double role: directly changing the behaviour and at the same time raising funds to finance the infrastructures required to allow the new technologies entering in the market.
- On the supply side, i.e. the technology side, bio-fuels and hydrogen are the two alternatives that are explored as the most promising ways to reduce the dependency on conventional oil-based fuels
- Finally, it is assumed that the success in achieving a trend inversion in energy consumption will be strictly linked, in the future, to the possibility of setting an international agreement on this issue, developing a common policy at least at the European

level. From this point of view, the TRIAS scenario will consider that policies are applied in the whole EU25 (and even beyond, as non EU countries - Norway and Switzerland – as well as candidate countries - Romania and Bulgaria – will be also treated in the same way).

Figure 2 and Table 2 provide a summary of the fixed scenario matrix-based approach based on demand and supply dimensions.

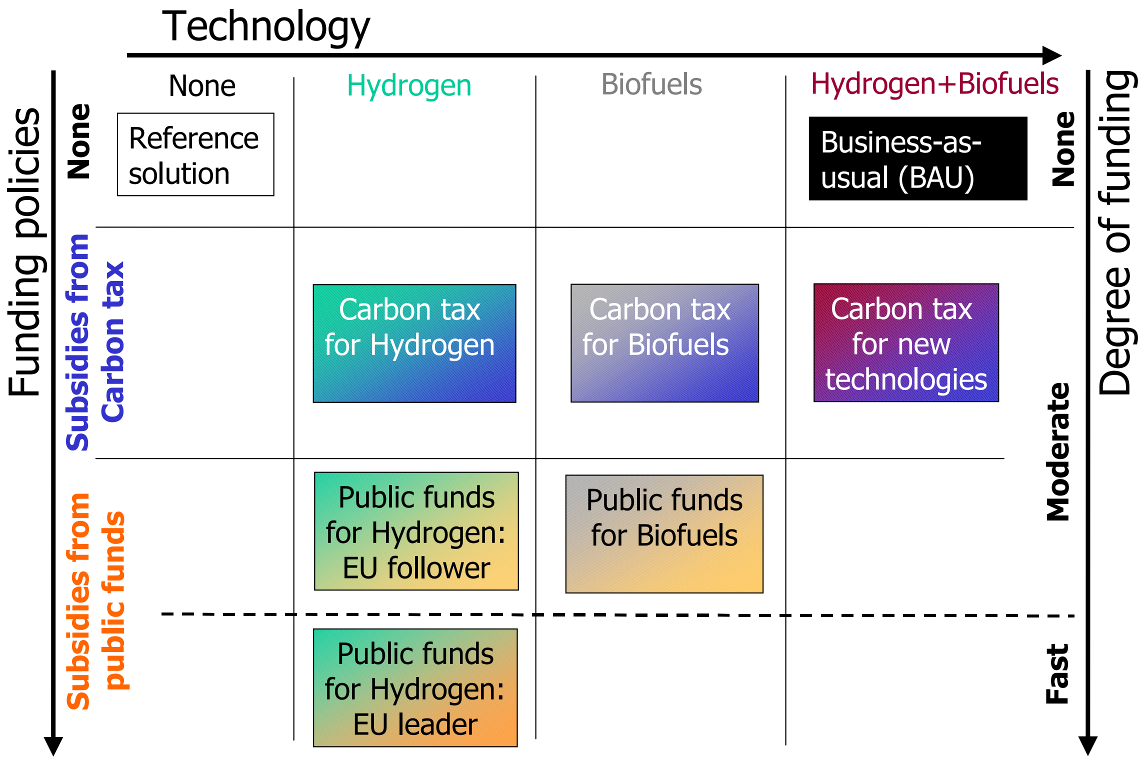

*Figure 2. The TRIAS scenarios framework*

The combination of assumptions concerning such two dimensions allows to define different scenarios. However, a mechanical intersect of alternative assumptions to derive any possible combination would lead to define implausible scenarios[2]. Thus, only eight combinations (scenarios) are considered:

- a *do-nothing scenario*, meaning that no alternative transport fuels would enter the market, which will act as a reference scenario;
- a *business-as-usual (BAU) scenario* extending current trends to generate future market penetration of alternative fuels into the transport markets and without funding strategies implemented;
- two scenarios where *investments in the bio-fuels technology* are associated to two alternative funding strategies: subsidies through public expenditure or subsidies using resources raised by a carbon tax levied on energy usage in the transport sector. The

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[2] As an example, one of the dropped scenarios is where significant additional investments are assumed without any funding strategy.

first alternative means that funds to develop fuelling infrastructures, fuel production plants and so on are to be found within the government budget allowing for an increasing public debt;

- three scenarios where *investments in the hydrogen technology* are associated to the same two alternative funding strategies. Here three scenarios are assumed instead of two because one specific scenario is focused on the analysis of the timing impacts of strategies to foster hydrogen technologies. Namely, one scenario is specifically designed to represent the case of EU leading the introduction of the hydrogen in the market instead of being a follower of other major economies like USA or Japan;
- a scenario where resources are invested in *both bio-fuels and hydrogen technologies* and a carbon tax is levied. This scenario assumes that the two technologies are not alternative but can be somewhat developed at the same time even though with a different timing, as to achieve a larger share of bio-fuels in the market can reasonably be a shorter-term target than to achieve a larger share of hydrogen.

Table 2. Description of the TRIAS scenarios framework

| **Scenario** | **Funding** | **Technology** | |
|---|---|---|---|
| | | **Hydrogen** | **Biofuels** |
| 1- Reference Scenario (REF) | No funding | No Hydrogen as fuel | No Biofuels as fuel |
| 2- Business-as-usual scenario (BAU) | No specific funding, investments as currently observed | Current policy trends, i.e. slow Hydrogen technology development | Current policy trends, i.e. slow Biofuels technology development |
| 3- Subsidising Hydrogen - EU market follower | Subsidies from public expenditure | Moderate Hydrogen technology development (slower than or the same as US, Japan) | As in BAU scenario |
| 4- Subsidising Hydrogen - EU market leader | Subsidies from public expenditure | Fast Hydrogen technology development (faster than US, Japan) | As in BAU scenario |
| 5- Carbon tax for Hydrogen | Revenues of a carbon tax on fossil fuels | Moderate Hydrogen technology development (plus demand driven development) | As in BAU scenario |
| 6- Subsidising Biofuels | Subsidies from public expenditure | As in BAU scenario | Moderate Biofuels technology development |
| 7- Carbon tax for Biofuels | Revenues of a carbon tax on fossil fuels | As in BAU scenario | Moderate Biofuels technology development (plus demand driven development) |
| 8- Carbon tax for Hydrogen and Biofuels | Revenues of a carbon tax on fossil fuels | Moderate Hydrogen technology development (plus demand driven development) | Moderate Biofuels technology development (plus demand driven development) |

*Remark: these scenarios have been slightly refined and extended in the course of WP5, which is reported in Deliverable D4. The version presented here comes from Deliverable D2 and thus reflects an earlier state of decisions.*

At the basis of all these scenarios, common demographic, economic and social trends are assumed. These socio-economic trends for the EU member states will be simulated endogenously, as the TRIAS modelling suite used, namely the ASTRA model, is able to compute endogenously the development of the population, the growth of GDP, the growth of transport demand, etc. ASTRA forecasts will be compared to external references especially as the most recent assumptions of future economic development in EU are generally lower moving closer towards the inherent ASTRA trends.

At this stage the definition of the TRIAS scenarios does not include the quantification of all the variables. Given the features of the scenarios, three main groups of variables used for their description can be identified:

a. exogenous trends common to all scenarios;

b. variables concerning the technological assumptions;

c. variables concerning the economic assumptions.

For variables belonging to the group a), the modelling tools already include assumptions in their structure and these will be updated on the basis of the review of the studies and projections documented in this deliverable.

In particular, a crucial variable for the TRIAS scenarios is the price of conventional sources of energy, especially oil and natural gas. The price of oil and gas in TRIAS will be endogenously calculated by the POLES model. It depends on several factors, both on the supply and the demand side, on which much uncertainty exists. For these reasons, the TRIAS scenarios do not assume any given trend concerning the supply and demand of fossil fuels, but will perform a sensitivity analysis to assess the effects of the policies under a wide range of alternative oil prices resulting from various supply-demand combinations. In more detail, as far as oil demand is concerned, a large part of it comes from outside EU, depending on the economic growth of other world regions, while on the supply side, existing reserves will play a major role in setting oil price. Therefore, economic growth outside EU and existing reserves are the two variables on which a sensitivity analysis will be performed.

With reference to oil supply, the review of studies and projections reveals that most of the estimates agree that proven oil reserves currently amount to about 1.2 – 1.3 trillion barrels. More pessimistic estimates indicate 1.05 trillion barrels while more optimistic views provide an upper estimate of about 1.5 trillion barrels (including also unconventional oil). In brief, for the TRIAS scenarios it seems reasonable to assume that proven oil reserves amount to 1.25 trillion barrels. For the sensitivity analysis a normal distribution on the range 1.05 - 1.45 trillion barrels is assumed. For natural gas, more uncertainty exist and estimates range from 0.83 trillion barrels to 1.35 trillion barrels. For the TRIAS scenarios, the estimates reported by EIA and IEA – 1.1 trillion barrels – will be used as basic assumption while other estimates will be assumed as the lower and the upper limits of a normal distribution.

Concerning the main determinant of oil demand outside EU, that is economic growth, assumptions are not radically different across studies; most of the assumptions lie in the range between 3% and 3.6%. In addition, lowest figures belong to the older study (World Energy Assessment, issued in 2000) while the highest estimate is a high-growth scenario. In brief, it is largely believed in studies concerning the energy sector that the world economy will grow at a pace of 3% per year or slightly more. For the TRIAS scenario it seems reasonable to assume as reference value a growth rate of 3% for the economy outside EU. For the sensitivity analysis, the interval of values between 2% and 4% will be considered applying a Normal distribution with 3% as the mean.

Variables in group b) are somewhat the most significant parameters for the TRIAS scenarios. The assumptions concerning how alternative technologies (bio-fuels and hydrogen) will enter in the market provide the main character of the scenarios. For that reason, in the TRIAS project a specific work package (WP2) is devoted to a detailed analysis of the technological issues; such an analysis will provide major inputs for the quantitative assumptions of the technological variables, including:

- the categorisation of innovative vehicles (i.e. classes of vehicles using bio-fuels and of fuel cells vehicles to be modelled);
- the pollutants for which emissions will be defined;
- the economic sectors where additional investments will be directed.

As far as economic sectors are concerned, a preliminary list includes: agriculture (in relation to bio-fuels development), energy, chemical, vehicle building and construction (for the development of infrastructures for the distribution of hydrogen and bio-fuels). For the categorisation of vehicles and pollutants, the features of the modelling tools (including their development within work packages 3 and 4) will be taken into account.

Finally, variables in group c) concern the size and the distribution through time of the monetary quantities linked to the technological developments assumed. In principles, there are two options that can be followed. One option is to start with a technology objective (e.g. fuel cell costs fall to 250$/kw or 150$/kw) and estimate the investments needed to get there. Another option is to define the investment level, (e.g. x billion Euros per year) and derive the technology improvement that can be achieved with such investments. Both option require the establishment of a link between investment and technology improvement, although in the first case the emphasis is on the technological development, which is assumed first, while in the second case the starting point is the amount of resources available. For the TRIAS scenarios the first option is chosen. Therefore, the quantification of economic variables is dependent on the assumptions concerning variables in group b). Also in this case, results of the analysis performed in work package 2 will provide the necessary input.

The estimate of the amount of investment required to achieve the progress assumed on the technological side will also benefit of the analysis carried out in work package 2. The interventions on taxes will be therefore sized according to the amount of resources to be collected or to be shifted on different uses.

As a general approach, in scenarios when subsidies for investments in new technologies are not associated to an additional tax, the initial assumption will be that the financial resources to fund economic sectors to develop new infrastructures and market will NOT have a correspondent increase of other taxes or cut of other expenditures and hence will increase the public debt. However, sensitivity tests could be carried out to analyse the impact of different assumptions, e.g. an increase of indirect taxes or a cut of social transfers.

Carbon Tax rates will be defined to collect an amount of resources correspondent to the total additional investments. In a basic form, the Carbon Tax will be charged on the transport sector only via an additional fuel tax. A more extensive application of the Tax could be tested.

TRIAS scenarios are modelling ones and four different tools will be used for their simulation. Even if the details of the interaction among models will be defined in WP3 and WP4, Figure 3 provides an outlook of the main linkages.

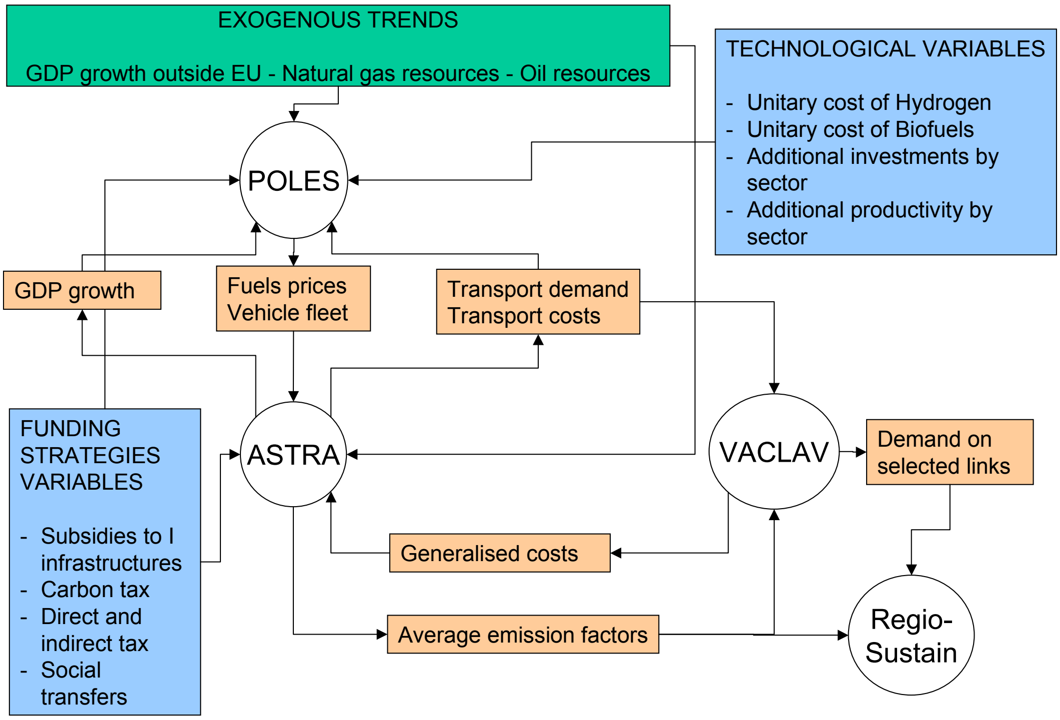

*Figure 3. Variables exchanged between TRIAS models to simulate scenarios*

### 2.3.2 TRIAS D2

**Executive Summary of TRIAS Deliverable D2 "Technology trajectories for transport and its energy supply"**

The target of TRIAS is to provide an integrated Sustainability Impact Assessment of transport technologies and transport energy supply together with economic, environmental and social impacts by using a set of well established models. Work package 2 focuses on providing a fundamental technology base for hydrogen and biofuel technologies, including technical and economic characterisations of each relevant technology. Additionally analyses are made to identify the most promising pathways to supply biofuels and hydrogen.

The most important outcome of WP2 is a comprehensive database for hydrogen and biofuel technologies, which serves as input for the modelling work in the following work packages. The database is organised in excel files that contain all technical and economic data delivering specific costs, carbon emissions and were possible also NOx emissions for all relevant hydrogen and biofuel technologies in the sub-systems production, distribution, conditioning, storage, refuelling and conversion until 2030. An example for the general structure of the biofuel and hydrogen technology datasheets is shown in Table 1 and Table 2.

Table 1: Example technical data sheet: biodiesel rapeseed oil – Large scale

| **Production - Biodiesel Rapeseed Oil - Large Scale** | | | | |
|---|---|---|---|---|
| | **Units** | **2005** | **2020** | **2030** |
| Const. Year | [a] | 2000 | 2020 | 2030 |
| Capacity Fuel | [kW] | 150000 | 150000 | 150000 |
| Annual Oper. hours - Fuel | [h/a] | 8000,00 | 8000,00 | 8000,00 |
| Annual Biofuel Production | [kWh(BF)/a] | 1200000000 | 1200000000 | 1200000000 |
| Economic Lifetime | [a] | 15,00 | 15,00 | 15,00 |
| Efficiency Fuel | [%] | 0,95 | 0,95 | 0,95 |
| Total Investment | [€] | 18600000,000 | 14220915,69 | 12688456,48 |
| Specific Investm. Cost | [€/kWinstall] | 124,000 | 94,806 | 84,590 |
| O&M Costs | [€/a] | 930000,000 | 711045,784 | 634422,824 |
| Annual Invest. Cost | [€/a] | 2173029,536 | 1661423,108 | 1482386,597 |
| Total Annual Cost | [€/a] | 3103029,536 | 2372468,893 | 2116809,421 |
| Cummulative number of plants | Number of plants | 1 | 10000 | 500000 |
| Progress ratio | % | | 0,98 | 0,98 |
| Biomass Input [AP-AR-FP-FR] | [NAME] | RS Oil | RS Oil | RS Oil |
| Main Output | [NAME] | RME-Biodiesel | RME-Biodiesel | RME-Biodiesel |
| Output Biofuel | [kWh(BF)] | 1,00 | 1,00 | 1,00 |
| Specific BF Cost (no inputs costs) | [c/kWh(BF)] | 0,26 | 0,20 | 0,18 |
| Specific BF Cost (with inputs costs) | [c/kWh(BF)] | 6,22 | 8,18 | 9,42 |
| Specific CO2 Emissions | [g/kWh(BF)] | 48,37 | 39,48 | 37,47 |
| Specific NOX Emissions | [g/kWh(BF)] | 0,49 | 0,44 | 0,43 |
| Other Co-products | [Name] | Glycerol | Glycerol | Glycerol |
| Co-prod. Other | [g/kWh(Co-P)] | 0,11 | 0,11 | 0,11 |
| Spec. BF Cost (co-prods. credit) | [c/kWh(BF)] | 5,91 | 7,76 | 8,93 |
| Spec.CO2 Emiss. (co-prod.cred) | [g/kWh(BF)] | 42,58 | 33,69 | 31,68 |
| Spec.NOX Emiss. (co-prod.cred) | [g/kWh(BF)] | 0,49 | 0,44 | 0,43 |
| Specific BF Cost (no inputs costs) | [€/GJ(BF)] | 0,72 | 0,55 | 0,49 |
| Specific BF Cost (with inputs costs) | [€/GJ(BF)] | 17,27 | 22,72 | 26,17 |
| Spec. BF Cost (co-prods. credit) | [€/GJ(BF)] | 16,40 | 21,55 | 24,82 |

Table 2: Example technical data sheet: hydrogen production, natural gas steam reforming, small scale

| | 2005 | 2020 | 2030 | Unit |
|---|---:|---:|---:|---|
| Specific capacity | 333 | 950 | 950 | kW(H2) |
| Specific investment cost | 2.625 | 548 | 401 | €/kW |
| Cummulative number of plants | 1 | 100.000 | 1.000.000 | |
| Progress ratio | | 0,91 | 0,91 | |
| Total investment | 875.000 | 520.649 | 380.613 | € |
| Annual operating hours | 6.000 | 6.000 | 6.000 | h/a |
| Lifetime | 20 | 20 | 20 | a |
| Annual hydrogen production | 2.000.000 | 5.700.000 | 5.700.000 | kWh(H2)/a |
| Operation and Maintenance | 2 | 1,5 | 1,5 | % of investment |
| Annual Operation and maintenance | 17.500 | 7.810 | 5.709 | €/a |
| Annuity | 89.121 | 53.029 | 38.766 | €/a |
| Total annual cost | 106.621 | 60.839 | 44.475 | €/a |
| Efficiency | 46 | 75 | 75 | % |
| Input fuel (natural gas) | 2,17 | 1,33 | 1,33 | kWh(fuel)/kWh(H2) |
| Input fuel cost | 1,79 | 2,00 | 2,21 | c/kWh(fuel) |
| Output hydrogen | 1 | 1 | 1 | kWh |
| Specific CO2 emissions (NG combustion) | 215 | 215 | 215 | g/kWh(NG) |
| Specific NOx emissions (NG combustion) | 0,16 | 0,16 | 0,16 | g/kWh(NG) |
| Specific hydrogen cost (without fuel and electricity cost ) | 5,33 | 1,07 | 0,78 | c/kWh(H2) |
| Specific hydrogen cost (with electricity and fuel cost) | 9,22 | 3,73 | 3,73 | c/kWh(H2) |
| Specific CO2 emissions | 467 | 287 | 287 | g/kWh(H2) |
| Specifc NOx emissions | 0,35 | 0,22 | 0,22 | g/kWh(H2) |

All in all 8 biofuel and 20 hydrogen technologies are contained in the database. The database is attached to this report on CD.

The technology database is accompanied by

- Report 2.1: Report on biofuels and hydrogen technologies for mobile applications (task 2.1) and
- Report 2.2: Report on pre-selected technologies and pathways (task 2.2)

The two reports basically serve as background and complementing information for the technology database (attached on CD).

In **Report 2.1** each relevant technology is qualitatively described. Detailed technical descriptions, the state of the art and the plant size range are provided and advantages and disadvantages are discussed.

With respect to biofuels, the database also includes historical production values since 1995 for all 25 European Member states for existing biodiesel and bioethanol in the market until 2004. Such historical data is not provided for hydrogen because hydrogen is currently not being produced as a transport fuel.

Figure 1 and Figure 2 illustrate the last 3 years production for biodiesel and biofuels in selected European Member States. Among the EU Member States, Germany is currently the worldwide top producer for biodiesel mostly from rapeseed followed by France and Italy. Among the new Member States, Czech Republic is the only producer currently with 80.000 tons in 2004.

Other member states have plans to increase their capacity for biodiesel production in the coming years. Bioethanol is currently mostly produced in Brazil and USA worldwide and in Europe is starting to play a role with growing capacities in France, Spain and Germany, which soon will add production capacity to the market. Various new member states are also active in bioethanol production such as Czech Republic, Latvia, Poland and Slovakia.

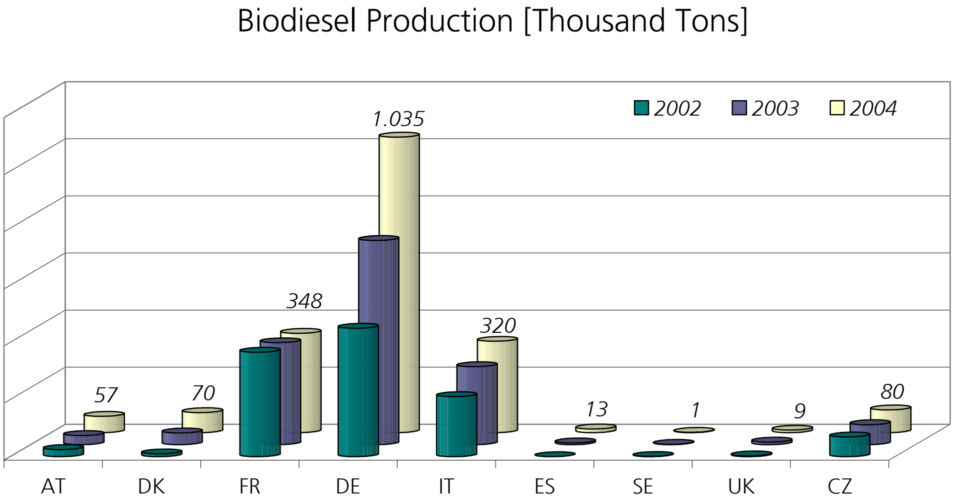

*Figure 1: Biodiesel Production 2002 – 2004 – EU*

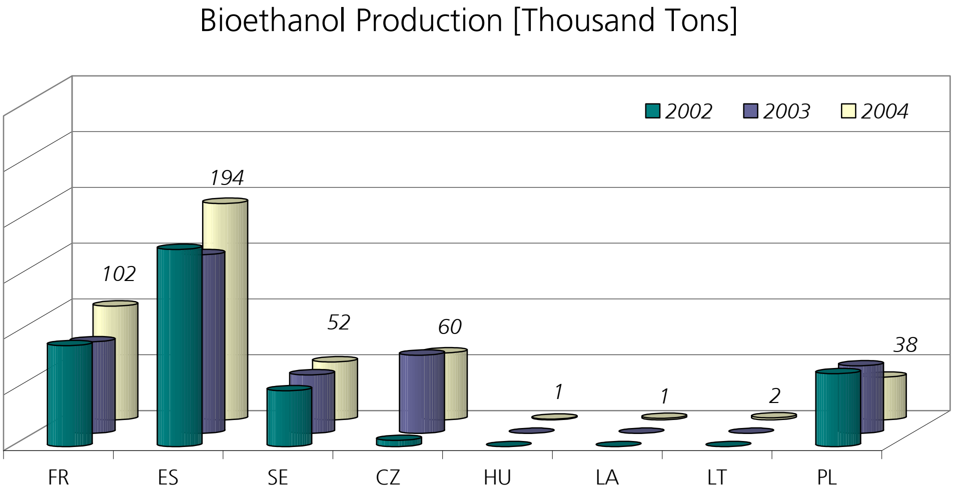

*Figure 2: Bioethanol Production 2002 – 2004 – EU*

The European Commission has set inidicative substitution targets for renewables fuel for transportation in the Directive 2003/30 which correspond to 2% of the total fuel demand in 2005 which approximately amounts to 6 Mtoe. This target was not fulfilled at the end of 2005 as the total EU25 production amounted approximately to 2.8 Mtoe in 2005. For 2010 the 5.75% target in EU25 amounts to 18.6 Mtoe.

One of the arguments in the biofuels impact assessment and biofuels strategy from the European Comission is that the future development of the emerging biofuels industry in Europe is widely constrained by the availability of dedicated biomass feedstock for biofuels production as well as the competition between the different bioenergy technologies for electricity and heat production. In this respect, the database also intends to assess the potential of the most important energy crops that are likely to be dedicated for biofuel production at EU25 Member State level for the time frame 2010-2030.

Figure 3 illustrates the total biofuel share of total EU25 fuel (gasoline and diesel) demand that is possible to be covered by biofuels produced mostly from dedicated energy crops grown in Europe. Furthermore, a second case is illustrated corresponding to a share of residues fractions of biomass available for advanced biofuel technologies in particular bioethanol from lignocellulosic materials and biomass-to-liquids (BTL). It is visible that almost 24% of the total EU25 fuels demand in 2030 could be maximally covered by biofuels without taking into account biomass residues fractions. Considering approximately one third (1/3) of the total biomass residual fractions being available for bioenergy in EU25 for the production of biofuels, this results in almost a 30% biofuel share of the total EU25 gasoline and diesel demand. Note that these values indicate resource availability possibilities and other socio-economic barriers, difficult to quantify, which could have an impact to reduce this share.

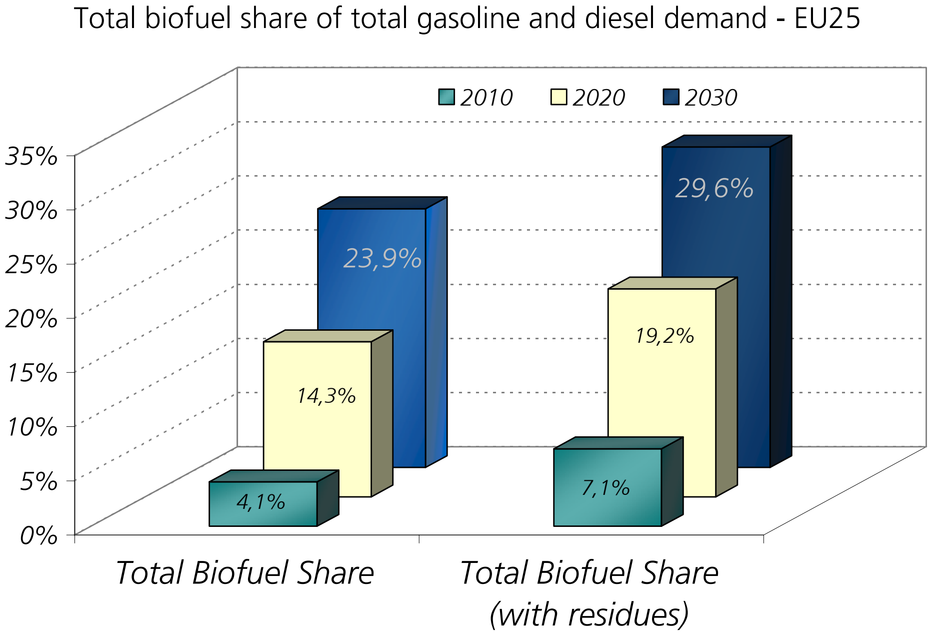

*Figure 3: Total biofuel share of total gasoline and diesel demand - EU25 - 2010 – 2030*

Complementing the last diagram, Figure 4 shows the shares of the total gasoline and diesel demand in EU25 for each specific biofuel technology for the years 2010, 2020 and 2030.

Observe that the conventional biofuels shares, especially biodiesel and bioethanol are very low in the long run explained by the fact that dedicated oilseeds and starch crops remain limited in each Member State (assumption for calculations based on experts discussions) due to constraints of the agricultural areas as well as climatic differences across Member States.

Furthermore, it is assumed that the import of these feedstocks for biofuel production purposes will allow more area for growing other types of energy crops. This therefore, corresponds to an agreed vision of forthcoming technology trends leading towards advanced biofuels such as bioethanol from lignocellulosic biomass and biomass-to-liquids technologies, which are able to make use of the whole energy crop including residual fractions and thus resulting in higher potential figures. As observed in the graph, these options have increased substitution shares in 2020 and in 2030 amounting up to 15.2% for BTL including residues fractions and 14.4% for bioethanol from lignocellulosic materials.

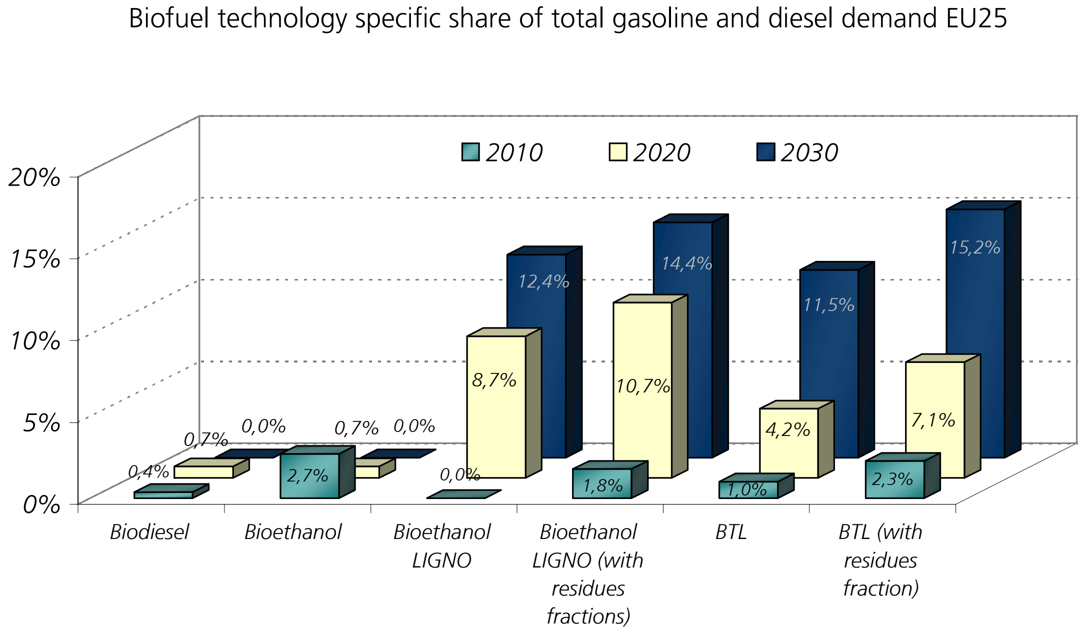

*Figure 4: Biofuel technology specific share of total gasoline and diesel demand - EU25*

**Report 2.2** aims at selecting sound technology pathways for the supply of biofuel and hydrogen from feedstock preparation over production, distribution, conditioning, storage till refuelling. In a first step the available technologies are critically characterized for their eligibility to contribute to supply biofuels or hydrogen for the transport sector (pre-selection of technologies). In a second step, a number of possible pathways are analysed with respect to their specific carbon emissions and costs and compared to each other in a so called well to tank analysis (from feedstock preparation till provision of fuel at the filling station). Besides the pure emission – cost evaluation also criteria focussing on other sustainability aspects of the pathways are taken into account, such as feedstock availability and competing utilisation possibilities, unsolved questions concerning waste treatment (nuclear waste, carbon capture and storage) or stakeholders views.

On this basis a number of promising pathways are pre-selected (pre-selection of pathways). In this context we have to bear in mind, that the final selection of fuel pathways will be done by the models itself, in particular the POLES model. This first analysis should only provide an initial idea to better understand the coherences.

With respect to ***biofuels*** pathways there are various available routes including existing biodiesel and bioethanol from commercially available processes as well as progressive emerging technologies such as biomass to liquids (BTL) and bioethanol from lignocellulosic materials.

The cost performance of the initially selected pathways based on general cost and emissions criteria is illustrated in Figure 5 and compared with their reference substitution fuel either gasoline or diesel (excluding taxes). In general, biofuels costs result to be higher (circa 2 to 3 times) when compared to their fossil fuels counterparts. Middle to large scale BTL and bioethanol technologies are expected to perform better when technologies are introduced in the market while conventional biofuels are not likely to improve their economic performance considerably. Sugarbeet has been selected among the possibilities but is likely to be phased out by lignocellulosic ethanol due to feedstock constraints and possibilities for cost reduction in the future.

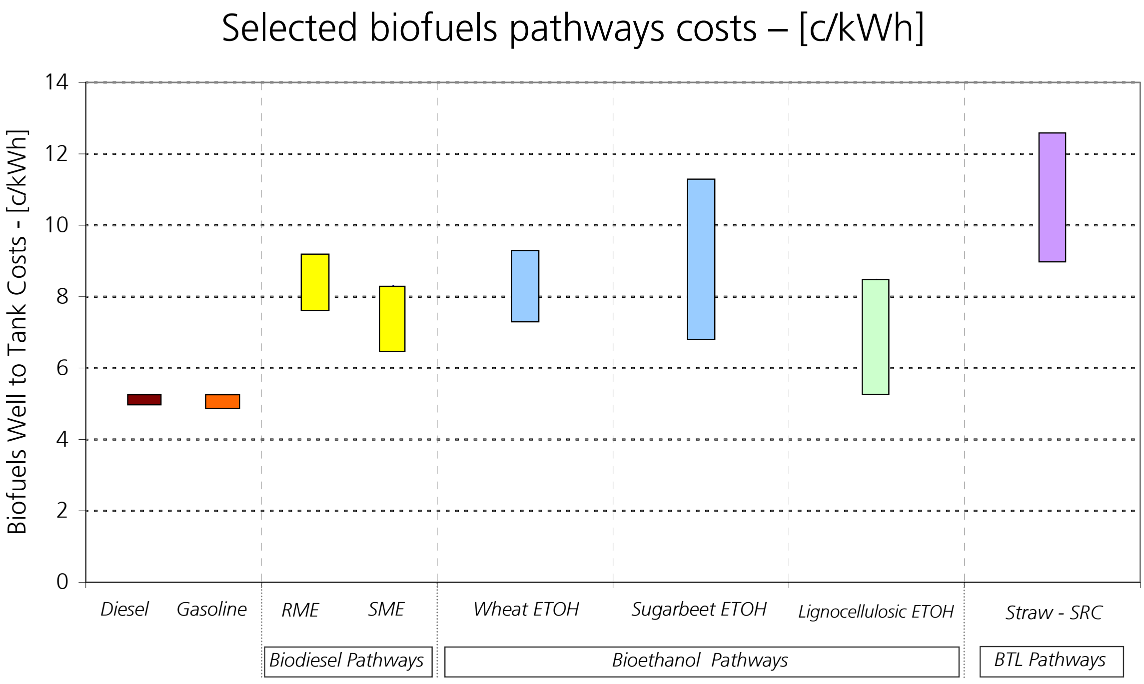

*Figure 5: Selected biofuels pathways costs – [c/kWh]*

The range of costs for the selected pathways is explained by different factors such as the scale of production of the technologies considered differentiated between small and large scale systems for all technologies, except for Biomass-to-Liquids, where small, middle and large scale systems were also assessed.

For all pre-selected pathways, *by-products* were considered in all cases as they result to have a positive influence in costs and emissions performance. However, the use of by-products and the way they are characterized in analysing biofuels production from well to tank is not always comparable with other studies, as assumptions regarding use and replacement are not always the same leading in some cases to ambiguous results that could speak in favour or against biofuels.

In this respect and following technology trends in Europe, emerging systems known as ***bio-refineries,*** which go a step forward with the objective to maximize the whole biomass-for -energy chain beyond the scope of electricity, heat and biofuels polygeneration to the production of bio-plastics and bio-chemicals, will have an important effect not only in future biofuels pathways but also in other productive sectors of the economy. Future research focusing on assessing the potential and techno-economic feasibility of these systems taking into account the interacting effects with existing/emerging biomass energy concepts is therefore necessary.

With respect to ***hydrogen*** pathways the well to tank analysis with a focus on $CO_2$ emissions and costs reveals, that all pathways are more or less a trade off between costs and carbon emissions.

Good trade-offs offer pathways based on by-product hydrogen, nuclear power, cheap renewable electricity, or cheap biomass feedstocks, followed by pathways based on natural gas reforming with and without carbon capture and sequestration, coal and lignite gasification with carbon capture and sequestration (compare Figure 6). However most of those pathways are subject to certain limitations or disadvantages: By-product hydrogen and also cheap sources of biomass (e.g. from residues) are limited and for biomass various competing utilisation possibilities exist (like generation of electricity and/ or heat). Nuclear power and also carbon capture and sequestration are technologies that are seen critically, due to unsolved problems concerning the treatment of nuclear waste, the risk of nuclear accidents or the stability of long-term $CO_2$ storage.

Less attractive trade-offs with a look on costs and $CO_2$ emissions have pathways based on coal or lignite gasification without carbon capture and sequestration, due to very high emissions. The same is true for pathways based on expensive renewable feedstocks (like miscanthus plantation) or electricity sources (like solarthermal power), due to very high costs. In the latter case however there is still the advantage of emission free hydrogen production and large potentials in Europe. The trade-off between emissions and costs is shown in Figure 6.

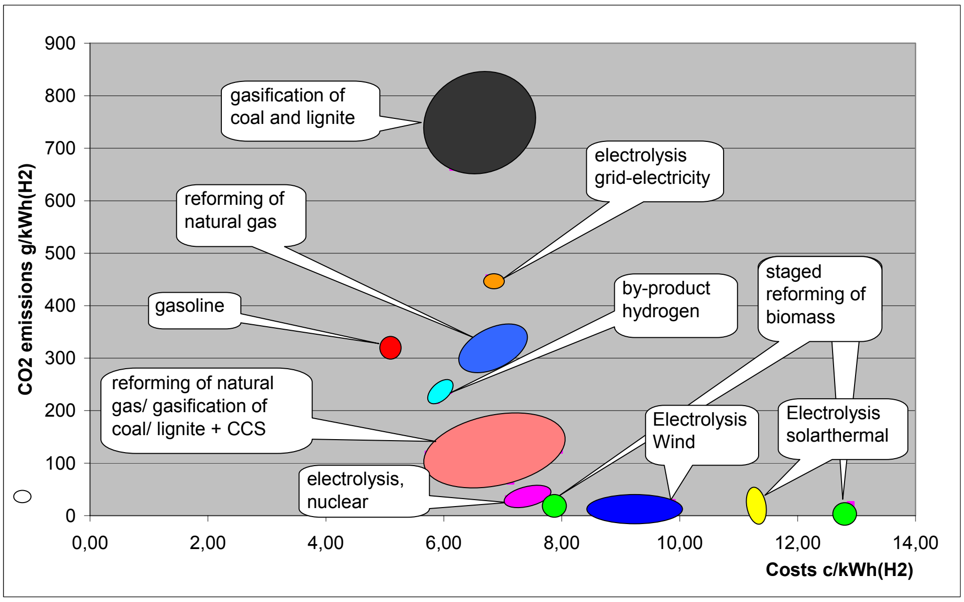

*Figure 6: Trade-off between $CO_2$ emissions and costs of different hydrogen pathways in comparison to gasoline*

In order to involve stakeholders views a hydrogen stakeholder workshop, organised by the Fraunhofer Institute Systems and Innovation Research (FhG-ISI) took place on February 21st 2006, in Frankfurt. In the afternoon session general topics concerning the sustainability of a hydrogen economy were discussed in five break-out discussion groups and self-completion questionnaires were distributed. The aims of the break-out groups and questionnaires were to elicit stakeholders' visions of sustainability in relation to hydrogen transport technology and their views on viable pathways and any barriers to sustainable hydrogen-based transport. Among the participants were researchers and consultants, NGO representatives, policy-makers, and members of the automotive and energy industries from across Europe with interests in hydrogen and transport technologies (compare Figures 67 in main text of Deliverable D2).

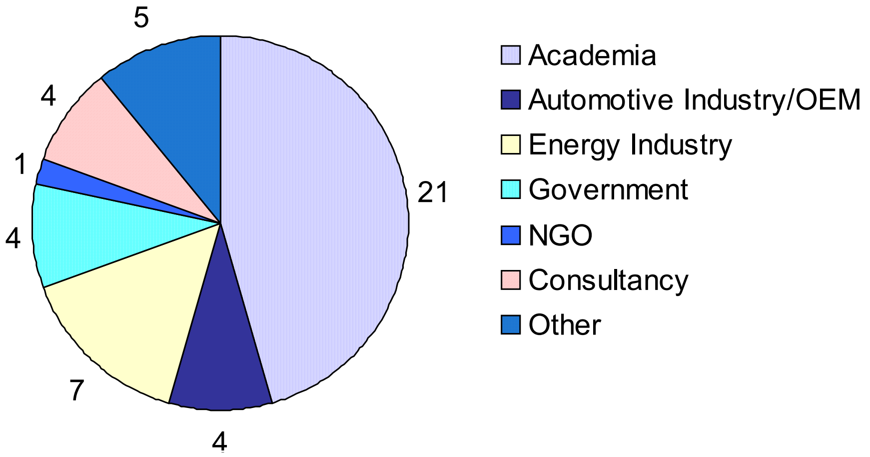

*Figure 7: Background of participants present at the first stakeholder workshop*

The main outcome of the group discussions is summarised below:

- There was widespread support amongst all groups for the ultimate goal of having renewable sources for hydrogen production. As several participants noted, renewable sources are needed to address air pollution, climate change and dwindling oil and gas supplies. However renewables are seen as challenging. Several groups talked about the practical difficulties in moving towards a renewables-based transport system and referred to trade-offs (e.g., demand from other sectors like electricity or heat or industry/ other land use needs like food production).
- Diversification of supply was also seen as an important feature of future energy systems. This was raised by participants in nearly all groups. Furthermore, participants pointed to the risks associated with focussing on, and becoming locked in to, one technological solution to the exclusion of possible alternatives. Participants proposed that future energy supply security will depend upon diversification of both energy sources (different primary energies and different geographic sources of supply) and modes of delivery of final energy services.
- There was disagreement between the stakeholders over whether nuclear or coal with carbon capture and storage (CCS) are "sustainable". For a number of participants, sustainability was equated with zero emissions or "CO2 free". These feedstocks fulfil this criteria and, additionally, many stakeholders felt these are necessary to achieve energy security and diversified, flexible supply. However other participants pointed out the problems with these technologies. For hydrogen on the basis of nuclear power the problem of nuclear waste and concern about the vulnerability of nuclear power to terrorism and misuse of the technology were addressed. For CCS the storage problem was mentioned.
- In three groups the economic opportunities associated with a hydrogen transition were discussed. Participants pointed to the need for a timely response to international competition in developing hydrogen technologies, and to provide good value alternatives to attract consumers. A number of participants argued that consumers' transport choices are motivated above all by cost.

- Overall, stakeholders pointed to the attractiveness of hydrogen in offering environmental and economic benefits. In particular, they highlighted the potential for hydrogen technologies to offer emissions reduction, energy supply security and economic growth.

On the basis of the well to tank analysis (cost and $CO_2$ emissions), the evaluation of further sustainability criteria as well as stakeholders' views on the topic, a first pre-selection of pathways is performed. The pre-selection of hydrogen technology pathways is shown in Figure 1.

Table 3: Pre-selection of hydrogen technology pathways

| **ES** | **Production** | **1st cond.** | **Transport** | **2nd cond.** | **FS** |
|---|---|---|---|---|---|
| NG | on-site SMR | - | - | compression | gaseous |
|  | SMR |  | pipeline | compression | gaseous |
|  |  | liquefaction | truck |  | liquid |
|  | SMR + CCS | - | pipeline | compression | gaseous |
|  |  | liquefaction | truck - | - | liquid |
| Coal/ lignite | gasif. + CCS | - | pipeline | compression | gaseous |
|  |  | liquefaction | - | - | liquid |
| El.* | on-site Ell. | - | - | compression | gaseous |
| El.** | Ell. | - | pipeline | compression | gaseous |
| El**. | Ell. | liquefaction | - | - | liquid |
| BM*** | staged Ref. | - | pipeline | compression | gaseous |
| By-pr. H2 | - | - | pipeline | compression | gaseous |

*grid-electricity, ** wind power, solar power, nuclear power *** forestry residues or other cheap sources

ES = energy source, Cond. = conditioning, FS = filling station, NG = natural gas, El = Electricity, BM = biomass, By-pr.H2 = by-product hydrogen, SMR = steam reforming, gasif. = gasification, CCS = carbon capture and sequestration, Ell. = electrolysis, Ref. = reforming.

A comparison of the TRIAS pre-selection of technologies and pathways to the findings of other current hydrogen projects like HyWays and WETO revealed that TRIAS is quite in line with the other studies.

A third outcome of task 2.2 is a rough **quantification of the necessary infrastructure investment** for the supply of hydrogen, on the basis of existing studies. Here again it is important to note, that the final quantification of the infrastructure investment in the context of the TRIAS scenarios is an outcome of the modelling work. Up to now, a preliminary infrastructure investment analysis can only aim at giving a first notion of the dimensions we have to expect.

According to the findings of the International Energy Agency (IEA 2005)

- a hydrogen supply infrastructure for road transport costs in the order of several hundred billion USD.
- If centralised production is adopted, the costs of a worldwide hydrogen pipeline system for the transport sector ranges from 0.1 to 1 trillion USD.
- The incremental investment for hydrogen refuelling stations would be somewhere between 0.2 and 0.7 trillion USD.
- A full hydrogen economy for transport and stationary applications would require a global pipeline investment of around 2.5 trillion USD.

In the HyWays project the **total cumulative infrastructure investment** for the ten-years-time-period from 2025 to 2035 **for 6 EU member states** is calculated at less than **100 bn €**

In the HySociety project the hydrogen investment impact for EU25 is calculated for two scenarios. One with a high hydrogen penetration rate of 20% at the total energy demand and one with a low hydrogen penetration of 5 % until 2030. The results for the infrastructure calculations are as follows:

- the total cumulative infrastructure investment till 2030 for Scenario A was calculated at 583bn €
- The total cumulative infrastructure investment till 2030 for Scenario B was calculated at 123bn €
- The annual infrastructure investment for Scenario A was calculated at 57bn €
- The annual infrastructure investment for Scenario B was calculated at 13bn €

### 2.3.3 *TRIAS D3*

**Executive Summary of TRIAS Deliverable D3 "Outlook for Global Transport and Energy Demand"**

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.

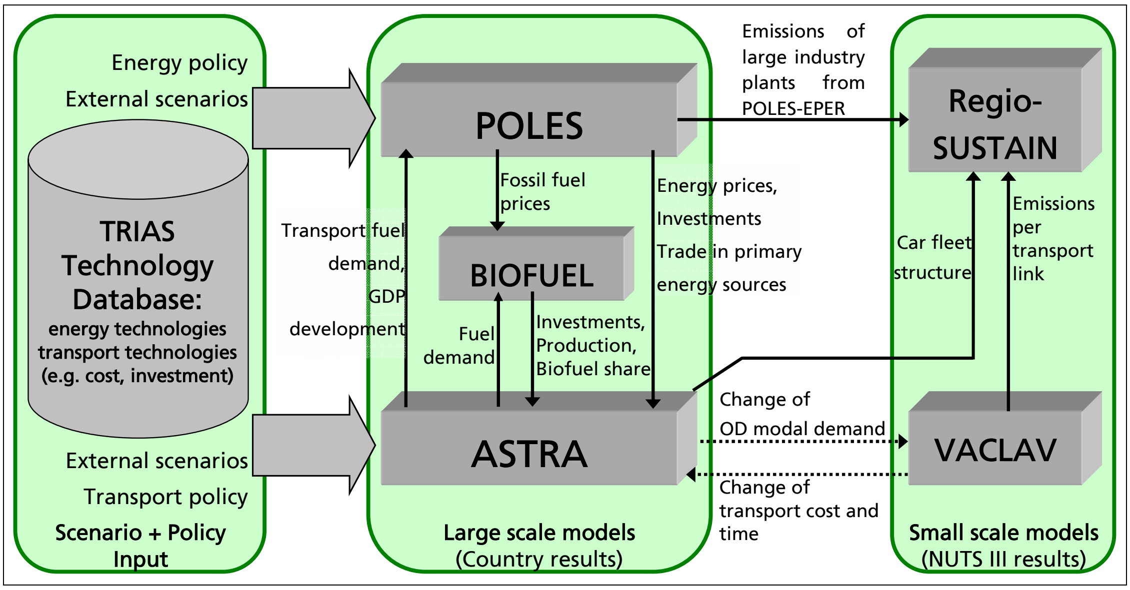

*Figure 1: **Linkage and interaction of models in TRIAS.***

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.

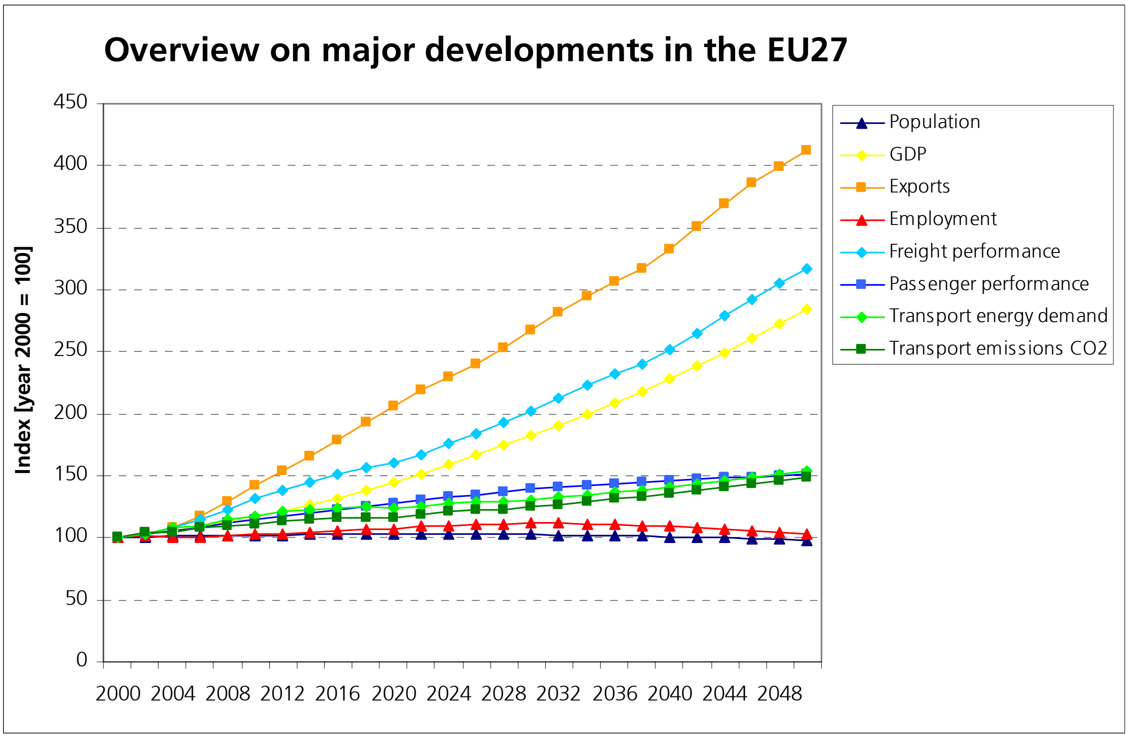

*Figure 2: Major developments in the transport-energy-economic system of the EU27*

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.

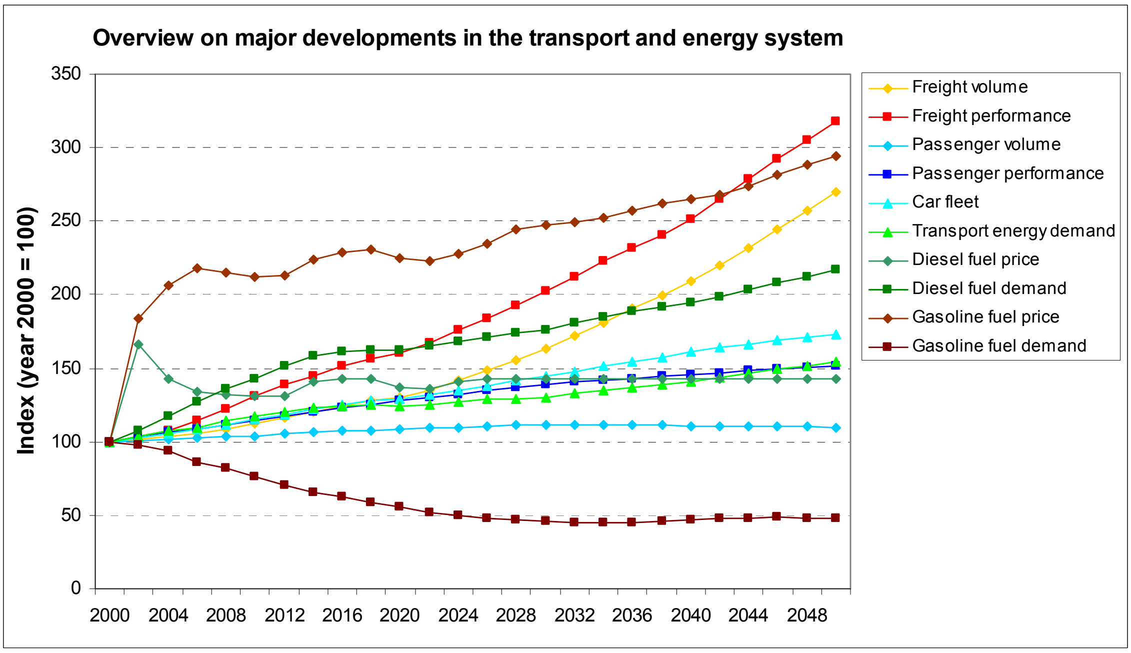

*Figure 3: Major developments in the transport and energy system of the EU27*

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.

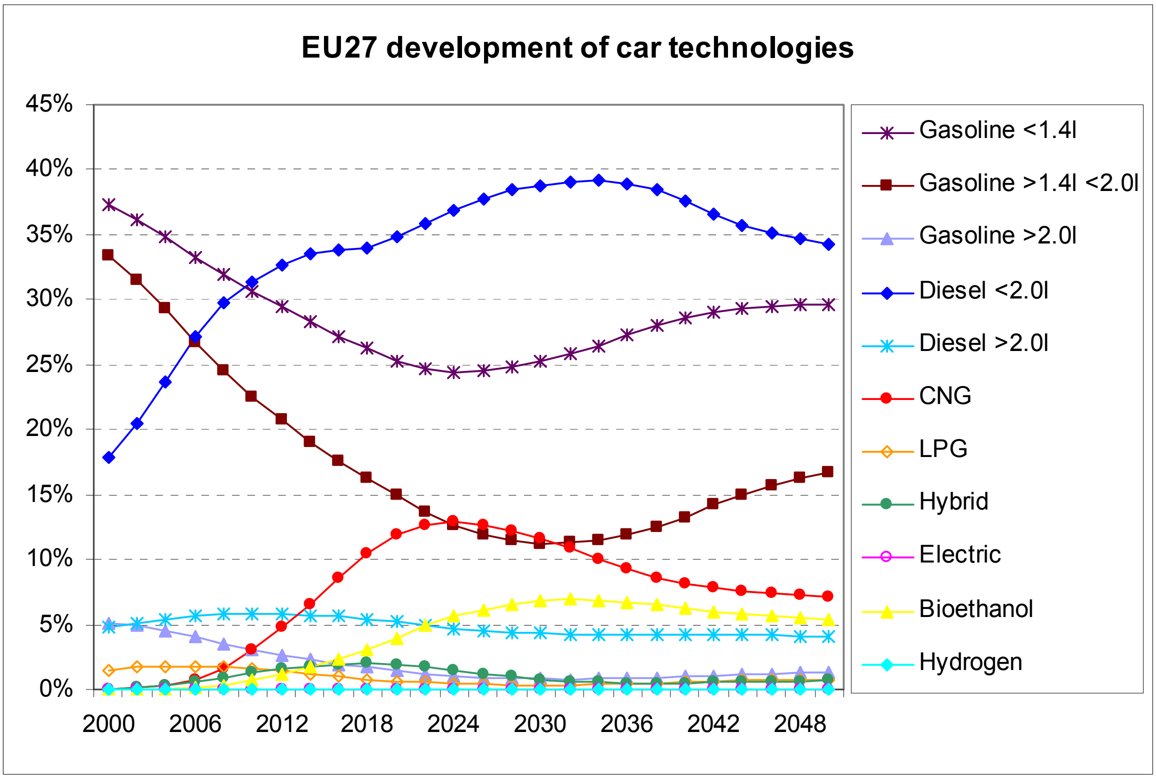

*Figure 4: Share of passenger car technology in EU27*

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.

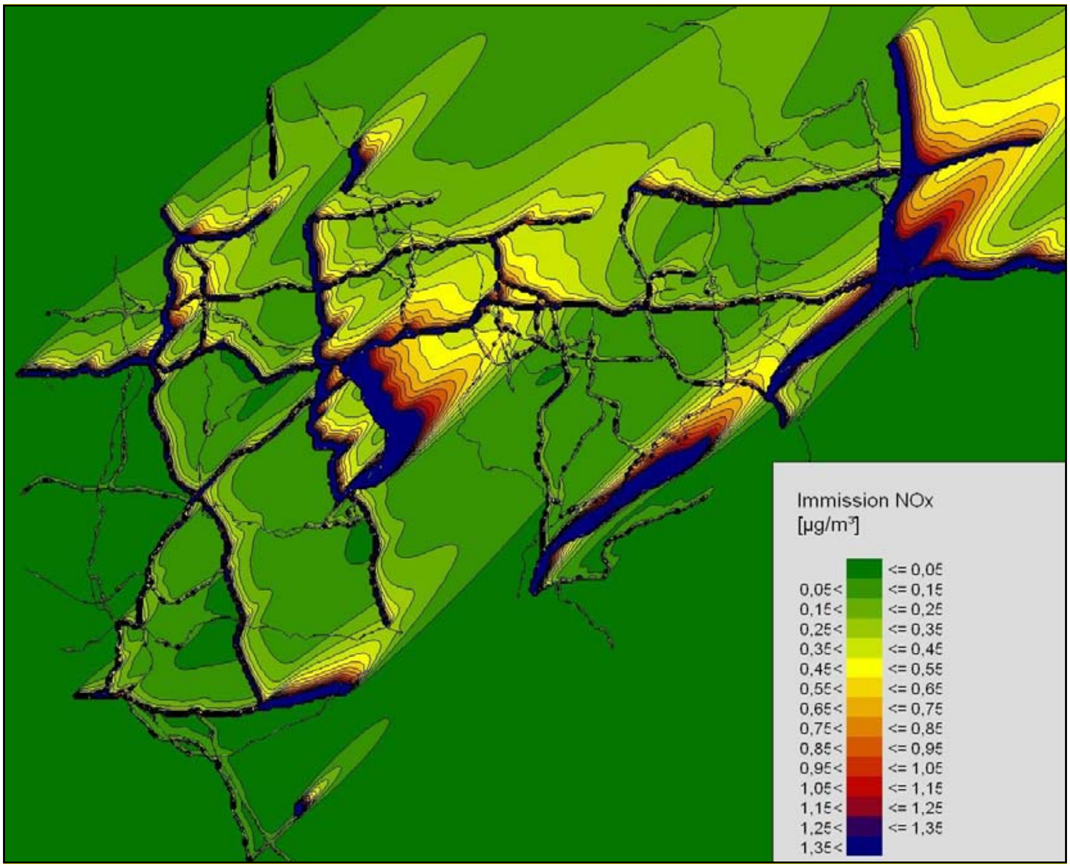

*Figure 5: NOx immissions in the Ruhr area (Baseline scenario for 2000)*

### 2.3.4 TRIAS D4

**Executive Summary of TRIAS Deliverable D4 "Alternative Pathways for Transport, Technology and Energy to promote sustainability in the EU"**

The TRIAS project has performed a "*Sustainability Impact Assessment (SIA) of Strategies Integrating Transport, Technology and Energy Scenarios*". The attempt was made to develop further the concept of SIA, which so far focused on assessments at a sectoral level and as a linear sequence of four steps: screening potential measure, scoping of assessment, preliminary sustainability assessment and mitigation of negative impacts of measures. The improvements of SIA in TRIAS were oriented at the concepts suggested for the approach of an Integrated Sustainability Assessment (ISA). ISA is defined as a cyclical, participatory process consisting of four stages i.e. scoping, envisioning, experimenting and learning through which a shared interpretation of sustainability for a specific context like the linked energy and transport systems is developed and applied in an integrated manner in order to explore solutions to persistent problems of these systems.

The approach chosen for the TRIAS project is placed somewhere between SIA and ISA. Our assessment is more comprehensive than the original concept of sustainability impact assessment as developed for the WTO negotiations, implementing some elements of integrated sustainability assessment, but not the complete methodology.

TRIAS extends the sustainability impact assessment (SIA) methodology through implemention of some of the features of an integrated sustainability assessment (ISA):

- TRIAS is a macroeconomic analysis.
- TRIAS is also a sectoral analysis, but combines multiple sector analyses to a holistic macroeconomic analysis. We analysed transport, energy, production and trade sectors.
- TRIAS integrates multiple spatial aggregation levels. Quantitative results are available on world-, national and regional levels.
- TRIAS incorporated stakeholder participation of the assessment process in a number of workshops and fed back inputs from stakeholders into the assessment and experimenting phases of the analysis.

In previous stages of TRIAS the applied models POLES, BIOFUEL, ASTRA, VACLAV and Regio-SUSTAIN were improved and linked such that the TRIAS Baseline Scenario could be established (see TRIAS Deliverable D3). In this deliverable the TRIAS policy scenarios are specified and tested with the models. At an initial phase of TRIAS six policy scenarios were suggested for analysis (see TRIAS Deliverable D1). Following the discussions at the TRIAS workshops and in the energy and transport field in general, two further policy scenarios on mandatory biofuel quotas and on introducing $CO_2$ emission limits for cars have been added such that the list of policy scenarios to be analysed in TRIAS comprised the following eight policy scenarios:

Technology focussed scenarios:

1. Subsidies scenario to foster biofuels, which pays subsidies on biofuels from the government budget increasing the debt.
2. Subsidies scenario to foster hydrogen, which pays subsidies on hydrogen from the government budget increasing the debt.

Combined technology and transport/climate policy scenarios:

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. 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:

6. First mover scenario for hydrogen use for transport presupposing that the EU be-comes the first world region to produce and use hydrogen cars affecting especially trade of vehicles.
7. Mandatory biofuels quotas resulting in higher penetration rates of biofuels then in the Combi scenario.
8. $CO_2$ emission limits for cars defining maximum emission standards of the average fleet of new registered cars in Europe, which is to a large extent equal to establish a regulation of fuel consumption.

The policies were introduced starting in 2008. Some measures such as 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. Policies focused on passenger transport. Freight transport was mainly affected by indirect effects of changes in passenger transport as well as in the economic system. The level of intervention by the policies was chosen to be moderate.

In general, the picture of all the policies is positive, due to a number of synergistic effects. Looking at the GDP of EU27 compared with the baseline development (see Figure 1) the impacts in 2050 lies in the range between close to +0.2% and +2.8% increase of EU27 GDP compared with the TRIAS baseline scenario. Positive impacts occur for a number of reasons:

1. All policies stimulate innovation and 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 cars) or improvements of existing technologies (e.g. efficiency of gasoline vehicles to cope with $CO_2$ emission limits), and

  - and also due to shifts of demand towards sectors with higher investment intensity in relation to demand.

2. The budget neutral financing of the additional investments by carbon taxes on fuel 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.
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 1 reveals that setting a $CO_2$ emission limit for cars 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 for Europe.

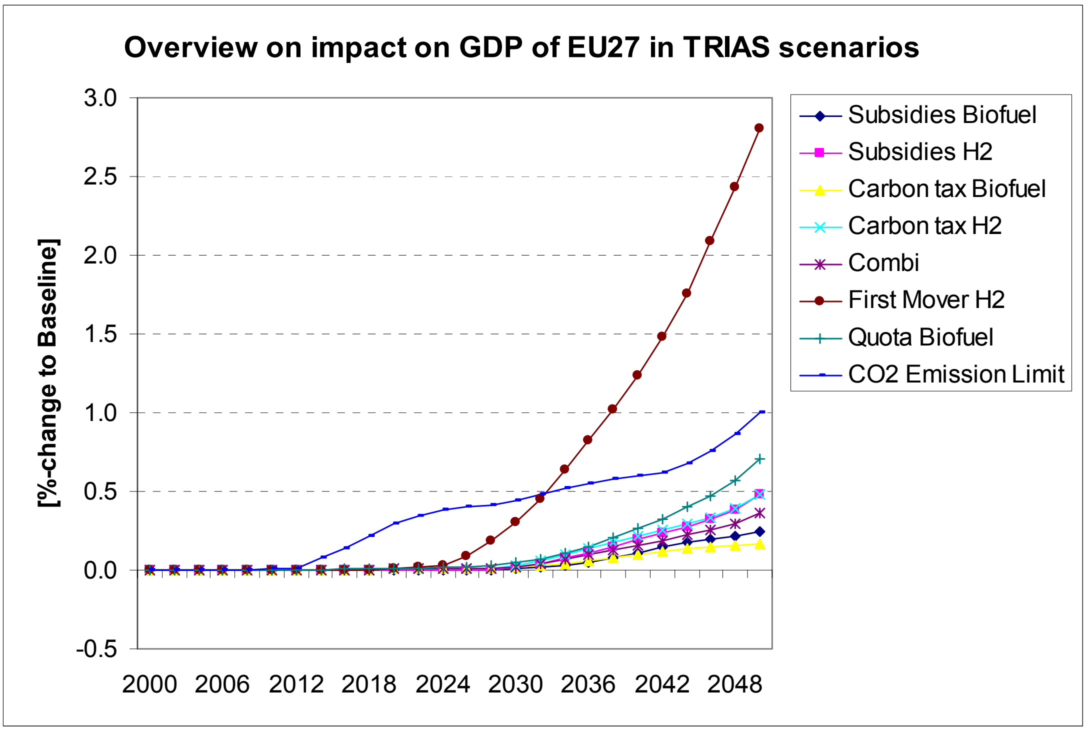

*Figure 1: Impact on GDP of EU27 as percentage change to baseline*

An interesting aspect to notice for the $CO_2$-emission limits is that these constitute the only policy in which the average cost of car transport significantly decreases (see Figure 2). The reason is the improvement of fuel efficiency that over-compensates the cost increase induced by the carbon taxes as well as the higher prices of vehicles. The remarkable side effect is that modal share of car transport in this policy would increase (which is called a rebound effect of such a policy).

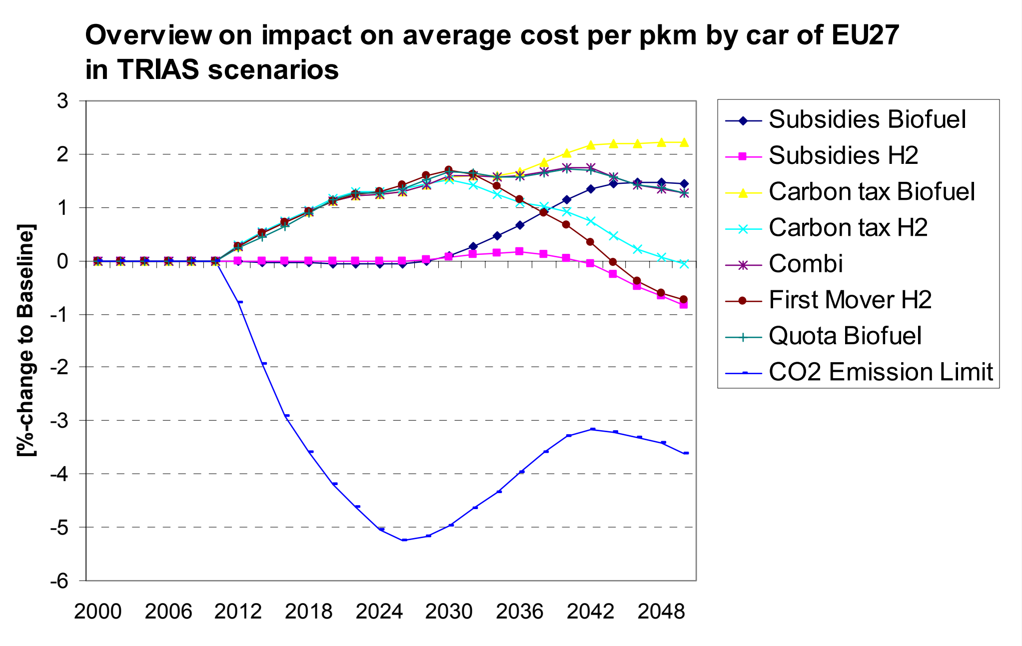

*Figure 2: Impact on average cost per pkm by car for EU27*

Transport energy consumption is affected by the policies (see Figure 3). But, in most scenarios the effect is minor and can partially be explained by the different demand development of passenger and freight transport, where the reduction of passenger demand coupled with a shift towards more efficient cars (in particular diesel and bioethanol cars) and more energy efficient modes leads to energy savings, while the growth of freight transport after 2030 increases energy demand. Larger energy savings can be gained with the biofuel quotas, which foster the stronger shift towards bioethanol cars, though this effect is temporary; due to the relative price increase of bioethanol after 2030 this trend is reversed by gains in competitiveness of efficient gasoline cars. The most significant reduction of transport energy demand by about -6% can be achieved with the mandatory $CO_2$ emission limits for cars as this policy is equivalent to regulating energy demand of fossil fuel based cars.

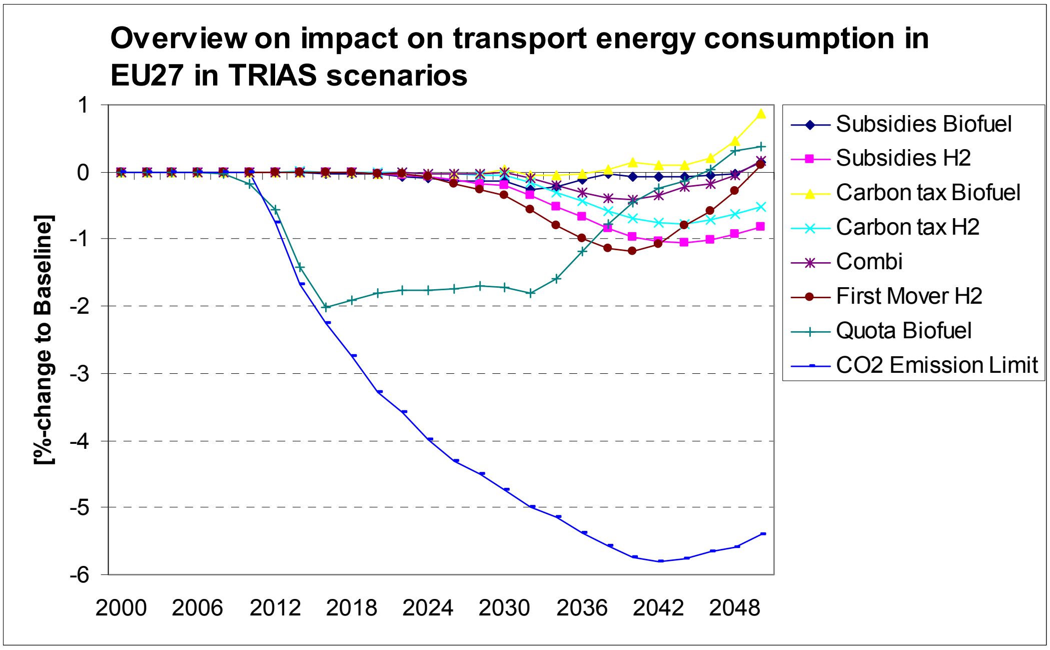

*Figure 3: Impact on transport energy consumption of EU27*

In terms of $CO_2$ emissions of transport all policies lead to a decrease (see Figure 4) though the decreases remain in the range of -1% to -5%. Comparing the subsidies and carbon tax policies for biofuels and hydrogen the potentials to save $CO_2$ emissions are larger for the hydrogen option. Policies with stronger regulation (in particular the $CO_2$ emission limits for cars) are more effective then those based only on technology shift and the moderate price signals implemented in the TRIAS policy scenarios.

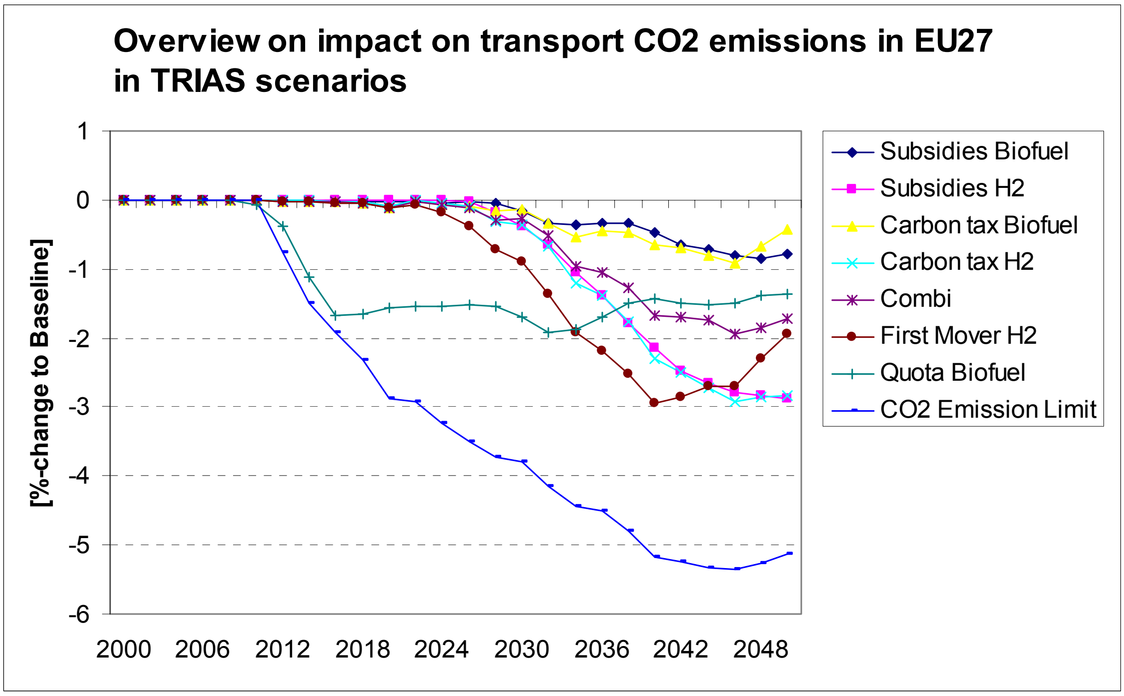

*Figure 4: Impact on transport CO2 emissions of EU27*

The energy imports in monetary terms are also affected in the TRIAS policy scenarios. The subsidy scenarios lead to smaller reductions as their influence on transport demand is negligible such that the reduction only comes from fuel switch to biofuels and hydrogen, respectively (see Figure 5). Policies complementing the subsidies by carbon taxes lead to stronger reductions of imports. The most ambitious regulations (i.e. biofuel quotas and $CO_2$ emission limits) cause the strongest decrease of imports. In those policy scenarios where GDP in the long run is stimulated more this dampens the reductions of energy imports at the end of the period.

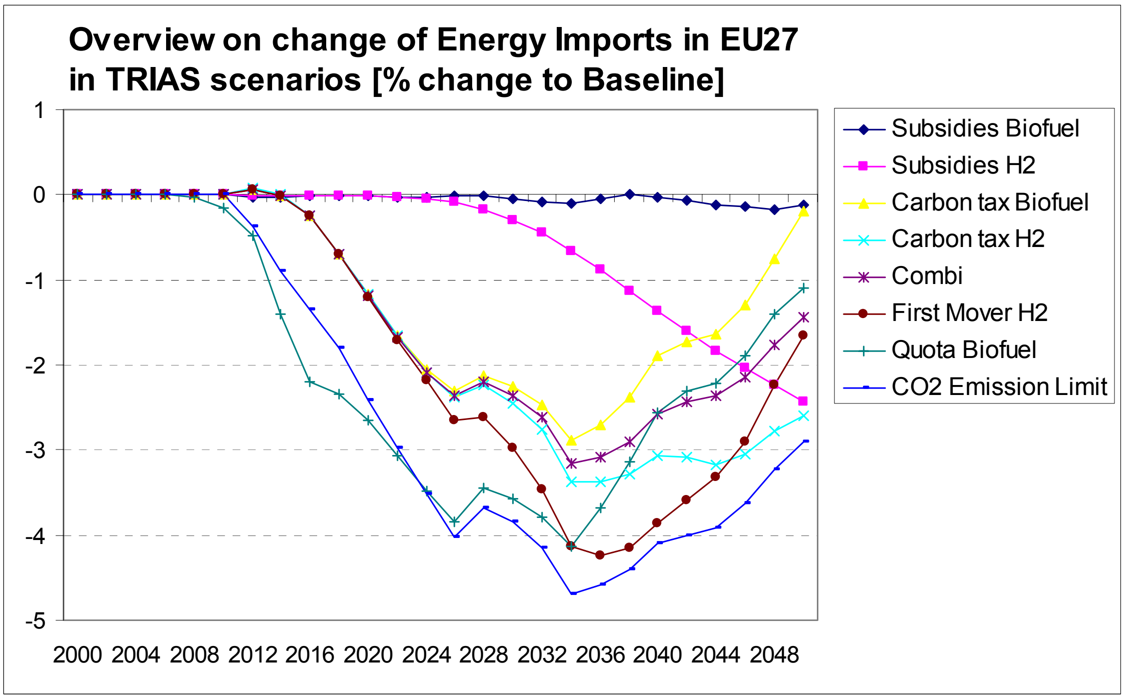

*Figure 5: Impact on energy imports of EU27*

The policy scenarios significantly affect the purchase decisions of new cars. In general gasoline cars loose market share, diesel cars in the first three decades increase their share and loose some share afterwards, with a very similar result for bioethanol cars. Bioethanol cars benefit with an increase of about +4% in all policies that subsidize biofuels due to the lower fuel cost in the first three decades. In the later decades they loose share to hydrogen cars. Stronger reactions happen with the $CO_2$ emission limits, which increase the price of gasoline cars in the first two decades and hence make bioethanol cars even more competitive. However, in the later decades the increased fuel efficiency makes larger gasoline cars again more competitive then bioethanol cars such that their share is reduced below the level of the other scenarios.

The analysis of the local environmental impacts of the TRIAS policy scenarios for the two case study regions Ruhr-area in Germany and Andalusia in Spain concluded that the technological improvements between the base year 2000 and the time horizon 2050 would reduce air pollution much more than the influences of the policy scenarios. The changes of the car fleet with about 10 to 15% higher shares of non-conventional cars compared with the TRIAS baseline scenario are too limited to exert a significant impact on local air pollution.

The TRIAS project also involved a sophisticated sensitivity analysis applying variations of uncertain parameters to the three models POLES, BIOFUEL and ASTRA. Variations concerned the range of available fossil fuel reserves affecting fossil fuel prices, the range of biofuel prices that are triggered by the changes in the fossil fuel prices, that range of imports of fossil fuel to EU27 in monetary terms and the range of GDP growth in China and India, which affects fossil fuel prices and the exports from EU27 to these countries.

It turns out that some of the results could be changing significantly with other settings of the parameters than in the TRIAS baseline scenario. Oil prices could vary between -50% lower prices than in the baseline and +100% higher prices. For biofuels the ranges are narrower with -20% and +40%. One of the major consequences thus observed in the sensitivity analysis concerns the market introduction of biomass-to-liquid (BTL) fuel, which does not enter the market in the TRIAS baseline scenario as it becomes not cost competitive with fossil fuels. However, with higher fossil fuel prices it would enter the market after 2030 and together with 2nd generation bioethanol based on lingo-cellulose would provide about 70% of the car fuel consumption in the EU27 in 2050 involving also significant quantities of imported biofuels.

Also the second observation of strong changes in the sensitivity analysis is caused by the fuel price changes of fossil fuels, which actually is by far the most influential parameter in the sensitivity analysis. The changes of fossil fuel prices may also significantly change the composition of the car vehicle fleet. In particular, the share of gasoline and bioethanol vehicles reacts strongly, with gasoline cars loosing up to -60% of their stock in the fleet with high fossil fuel prices and gaining also about +60% with low fossil fuel prices. With favourable conditions for bioethanol cars i.e. high fossil fuel prices and lower biofuel prices bioethanol cars may even reach stocks in the fleet that are +170% higher than in the TRIAS baseline scenario.

The sensitivity analysis with ASTRA included a test of the sensitivity of the penetration rates of hydrogen vehicles due to different strategies of subsidisation. In TRIAS policy scenarios the main subsidies were on hydrogen fuel. For the sensitivity test subsidies of hydrogen car prices were also considered, as suggested by projects such as HyWays (2006). Both the -70% reduction of H2 fuel price and the -50% reduction of H2 car prices enable significantly stronger penetration of H2 fuel cell vehicles into the fleet. In case of the reduction of the H2 car prices the H2 car fleet of EU27 would be more than fourfold higher in 2050 than in the Combi scenario, which was used as a reference here, since in the TRIAS baseline scenario the policies completely lack the measures that would be needed to kick-off the market penetration of hydrogen vehicles.

Evaluating the results for GDP and $CO_2$ emissions from transport against European policy targets to foster economic growth and competitiveness and at the same time reducing $CO_2$ emissions it seems that European transport policy making is going in the right direction. In the shorter term setting $CO_2$ emission limits for cars will provide economic stimulus as well as it will reduce $CO_2$ emission. This can be enforced by fostering biofuels, though limits to the use of biofuels should be taken into account, because (1) overambitious use of biofuels could lead to conflicts between the use of biomass for food and the use for energy, which seems not to be reasonable considering (2) that the impacts on economy and $CO_2$ emissions of the biofuels policies remain limited. In the longer term, hydrogen seems to be a suitable option to foster economic growth and to significantly reduce $CO_2$ emissions and other environmental impacts of transport. However, this presupposes that this hydrogen is mainly produced from renewable sources and that the introduction of hydrogen vehicles into the car fleet is strongly supported by policy-making.

### 2.3.5 TRIAS D5

**Executive Summary of TRIAS Deliverable D5 "Final Report of the TRIAS Project"**

The TRIAS project has performed a quantitative "*Sustainability Impact Assessment (SIA) of Strategies Integrating Transport, Technology and Energy Scenarios*" for the European Union. The project objectives to fulfil this task 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.
- Base the assessment on an integrated model-based approach looking at environmental, economic and social impacts (sustainability impact assessment).
- Provide an assessment capability for both external scenarios and scenarios developed in TRIAS.
- Consider the life-cycle implications of all strategies investigated.

The challenge of the project is to describe and model the symbiotic development of both the energy and transport system. Such a development has to overcome a number of "chicken-and-egg" problems where one action only appears to happen, after another action has happened, which in turn required the first action to have happened. In particular, this is valid for the introduction of new transport technologies that require adapted energy supply technologies like the introduction of hydrogen as a fuel for transport.

This systemic and interdependent problematique requires an improvement of the current sector oriented and linear sequence of four steps to carry out a Sustainability Impact Assessment (SIA): screening potential measures, scoping of assessment, preliminary sustainability assessment and mitigation of negative impacts of measures. The improvements of SIA in TRIAS were following the concepts suggested for the approach of an Integrated Sustainability Assessment (ISA). ISA is defined as a cyclical, participatory process consisting of four stages i.e. scoping, envisioning, experimenting and learning through which a shared interpretation of sustainability for a specific context like the linked energy and transport systems is developed and applied in an integrated manner in order to explore solutions to persistent problems of these systems (Weaver/Rotmans 2006).

The approach chosen for the TRIAS project is placed somewhere between SIA and ISA. Our assessment is more comprehensive than the original concept of sustainability impact assessment as developed for the WTO negotiations, implementing some elements of integrated sustainability assessment. Thus the main features of the TRIAS SIA are:

- TRIAS is a macroeconomic analysis.
- TRIAS is also a sectoral analysis, but combines multiple sector analyses to a holistic macroeconomic analysis. We analysed transport, energy, production and trade sectors.
- TRIAS integrates multiple spatial aggregation levels. Quantitative results are available on world-, national and regional levels.

- TRIAS incorporated stakeholder participation of the assessment process in a number of workshops and fed back inputs from stakeholders into the assessment and experimenting phases of the analysis.

## Scenario framework and TRIAS policy scenarios

TRIAS is not the sole project working on scenarios for the development and transformation of the energy and transport systems in the medium- to long-term. Hence, the project started with a thorough analysis of existing scenarios and assumptions for such transformations. Eleven of these studies prepared by major Institutions active in the energy and transport field (like the IEA, EIA, EC, UN-WEC) have been selected for in-depth analysis. Their findings concerning world energy supply, energy demand, economic development, transport demand of passenger and freight and potential technological development are taken into account to develop a scenario framework for TRIAS. Basically, the scenario framework is constituted by:

- a growing world economy driven by high growth rates in China and India, lower growth rates in the US and Japan and modest rates in Europe.
- a stabilizing or in some parts even declining population in Europe, which is part of the reasons for slowed down growth in Europe.
- a constrained supply of fossil fuels due to geological limitations of extraction and resources.
- an accelerated development of new fuels e.g. fuels that can be based on biomass (e.g. biofuels or hydrogen) or on the production from electricity (e.g. hydrogen).
- an accelerated development of new technologies for both production of new fuels and propulsion of transport vehicles.

Given the previously described framework TRIAS developed a reference scenario freezing the current technological level of using conventional fossil fuel for transport and a business-as-usual (BAU or Baseline) scenario with slow penetration of new technologies into the transport market. The BAU-scenario in particular considered biofuels, but not hydrogen since no specific policies were taken to introduce H2 for transport. The reference developments of the BAU-scenario are compared with eight contrasting policy scenarios, which would either foster accelerated market penetration of biofuels, of hydrogen or of both biofuels and hydrogen for transport.

Four scenarios foster *either biofuels or hydrogen* by implementing *either subsidies funded by general government budget or subsidies financed by a selective carbon tax*. Subsidies are given to fund investments into production and distribution facilities of such new fuels decreasing their fuel prices as well as a direct subsidy that reduces end user fuel price of biofuels and hydrogen. One scenario combines all these subsidy and carbon tax measures to promote both biofuels and hydrogen for transport. On top of this combined scenario three scenario variants were developed to cover a number of currently debated policy issues. (1) One particular scenario investigates the outcome if Europe would choose the first-mover strategy in terms of hydrogen introduction for transport. (2) Another variant assumed mandatory quotas for blending biofuels into fossil fuels (gasoline and diesel). The quotas are oriented at European policy objectives. (3) The final variant focussed on another topical policy debate, which is on setting $CO_2$ emission limits for cars.

### Technology assessment

In parallel to the definition of scenarios analyses of promising technologies for energy supply and propulsion of the future transport system have been undertaken. The analyses concluded that the most promising new technologies for in-depth technology assessment and application in scenarios for sustainable transport would be biofuels and hydrogen-using technologies. This was already reflected in the definition of the TRIAS scenarios as suggested by the description of work. However, in mid 2007 by the time when the TRIAS analyses were completed significant progress of battery technologies could be observed e.g. in terms of safety, recharging processes and lifetime of Lithium-Ion batteries. This technological breakthrough seems to improve the competitive position of electric battery vehicles (or hybrids with small combustion engines but batteries and electric engines) significantly, which could not be considered in the TRIAS policy scenarios. Thus the potential of these technologies seems to be underestimated and should be considered in follow-up projects to TRIAS.

In-depth technology assessment thus covered the biofuels and hydrogen related technologies for the supply-chain of transport fuels, which include the sub-systems production of raw materials, distribution, conditioning, storage and refuelling, as well as for conversion, which could occur in conventional propulsion systems (i.e. internal combustion engines), in fuel cells and electric engines or in hybrids thereof. This results in a so-called well-to-wheel analysis for the different fuels and technologies. In such a well-to-wheel analysis each combination of different technologies at each stage of the fuel supply-chain for a specific fuel represents a possible pathway that could be chosen for future development depending on the techno-economic characteristics that are identified for the pathway as a whole.

The analysis for biofuels identified eight major pathways starting from different types of crops producing the input of biomass into the fuel production i.e. sugarbeet, rapeseed, sunflower, wheat, miscanthus, woody biomass and straw. Other crops like sugar cane or maize seem to be inferior for use as energy crops compared with the ones linked to the eight major pathways such that these pathways provide the pre-selection of technologies for biofuels. However, even for these pre-selected pathways the price of such biofuels would be about 50%-100% higher compared with fossil fuels in 2005.

The analysis for hydrogen as transport fuel revealed that the number of technically feasible pathways is much larger than for pure biofuels since the "raw material" to produce hydrogen could on the one hand be biomass, similar as described for the biofuels, but on the other hand it could be produced from fossil fuels or from electricity, which could in turn be generated from renewables, fossils or nuclear. Furthermore, hydrogen can be used in vehicle engines in two different physical conditions: liquid or gaseous with compression.

In general, the possible hydrogen pathways show an obvious trade-off between cost of H2 fuel and $CO_2$ emissions per unit of fuel. Pathways that generate cheap hydrogen generate high amounts of $CO_2$ emissions and vice versa. This also holds for the 12 most promising and hence pre-selected pathways for TRIAS, of which four lead to liquid hydrogen and eight to gaseous hydrogen. Two of the pathways generate hydrogen on-site at the fuelling station either by electrolysis or by steam reforming of natural gas, while the other 10 pathways require the built-up of large scale production and distribution systems producing hydrogen by large scale coal and lignite gasifiers, steam-reformers or electrolysers, which then require input of either coal, lignite, natural gas or electricity and, in the case of fossil inputs, facilities for carbon capture and sequestration (CCS). Compared to gasoline the most obvious pathway for hydrogen as transport fuel would be hydrogen as a by-product of chemical processes, which e.g. in Germany would be sufficient to fuel about 500,000 cars annually. This pathway would be slightly more costly than gasoline but would also slightly reduce the $CO_2$ emissions. In terms of cost also those pathways based on natural gas would be close to gasoline, while in terms of $CO_2$ emissions especially the pathways based on electrolysis from renewables or nuclear would strongly reduce $CO_2$ emissions.

Of course, the different pathways cannot be seen as independent. Investing into one pathway and neglecting another one would bring cost down of the selected pathway and its related technologies due to economies of scale and technological progress from learning-by-doing as well as what concerns biomass there is competition of the different sources of biomass for a limited amount of land and between the different ways to use biomass e.g. heating or electricity instead of as transport fuel.

The interdependency of the different pathways is taken into account by further steps in TRIAS. These steps included the implementation of the different pathways in terms of their techno-economic characteristics within a set of models, which then optimize the selection of pathways under the given constraints and estimate the impact for the energy system and subsequently the transport system. The models applied were POLES for the world energy system and BIOFUEL, a newly developed model estimating production cost and production of biofuels in Europe. With these models it was feasible to estimate the impacts for the energy system e.g. the changes of prices for the different fuels and to provide these to the other TRIAS models calculating the impacts for the transport system e.g. changes of modal-split, the impact on the environment e.g. changed $CO_2$ emissions and the economic impact e.g. changes of GDP growth.

The TRIAS work on the scenarios and technology assessment was complemented by the organisation of a cluster workshop on the *Sustainability of a hydrogen economy* (Feb. 21st 2006 in Frankfurt) at which the planned TRIAS policy scenarios and the technology assessment were presented and discussed by stakeholders. In the course of the workshop a group discussion concluded that the sustainability of hydrogen depends to large extent on characteristics of the feedstock to produce hydrogen, where the unambiguous sustainable option would be to use renewables while for nuclear and fossils with CCS doubts were raised about their sustainability.

## Modelling work

A very significant part of TRIAS concerned the update of the four applied models ASTRA, POLES, VACLAV and Regio-SUSTAIN to incorporate new elements that are required to model market entry and diffusion of the new technologies in the energy and transport sector as well as to assess their economic and environmental impacts. For POLES a new module was developed to model biofuels prices and production, the so-called BIOFUEL model. This is implemented as a separate module with connections and overlap to both POLES and ASTRA. For ASTRA, the vehicle fleet module was updated to include besides gasoline and diesel vehicles also hybrids (gasoline and diesel), battery electric vehicles, CNG, LPG, bioethanol and hydrogen fuel cell vehicles. Also all fuel consumption and emission factors for the different vehicle types are updated. Further the cost model of the transport model was significantly extended both to consider separately the different fixed and variable cost elements of the different modes, in particular road, and to reflect the cost of the new technologies. For the economic model the linkages from the new technologies to consumption and investment are established, the fuel prices and taxes on the new fuels are considered and the GDP trends for the European countries and the nine rest-of-the-world regions distinguished in ASTRA have been adapted to GDP trends used also in the MATISSE and ADAM projects both funded by the EC 6th Research Framework Programme. For Regio-SUSTAIN the linkage with POLES and the EPER database (European Pollutant Emission Register) is established and the new CEMOS2 model (chemical exposure module for spot-sources) was developed as part of Regio-SUSTAIN.

During the course of the project it was felt that the ASTRA model would grow too much to maintain it as one single file as in the past. Hence, in agreement with the EC an approach was conceived to split ASTRA into a number of separate stand-alone models that on request could be merged together using either all or only selected models. Since the first attempt to use an available tool for this split-and-merge process failed, TRIAS developed its own tool, the so-called ASTRA-Merger, with which it was then possible to merge the ASTRA model and obtain again a fully operational integrated transport-economy-environment model.

Further work in TRIAS concerned the linkage of the different models such that they could exchange results between each other. The link between ASTRA and POLES where a large number of variables is exchanged in both directions was implemented successfully both in terms of logic (i.e. meaning and usability of variables) and technology (i.e. file system and protocol for data transfer, which involved the setup of a repository system). The same holds for the linkages from POLES, ASTRA and VACLAV to Regio-SUSTAIN. These were designed as soft-linkages with manual exchange of data, since the number of points of times at which data was to be exchanged is limited and no feedback from Regio-SUSTAIN to the other models is required. The most difficult to handle was the link between VACLAV and ASTRA, which could not be completely developed as a hard link during the project duration of TRIAS due to technical difficulties. Instead, most of the simulations used the internal transport model of ASTRA making reference to basic VACLAV results.

### Scenario and sensitivity analysis

By applying the newly calibrated and interlinked models the baseline scenario of TRIAS was successfully developed. In terms of broad economic development, the ASTRA and POLES model followed the GDP trends of the ADAM and MATISSE projects with average annual GDP growth of EU27 until 2030 slightly above 2%, and significantly below 2% after 2030. For transportation, the trends foresee a strong continuous growth of freight transport, while for passenger transport only moderate growth until about 2030 is expected and afterwards nearly a stabilisation. In terms of energy consumption growth is slower than the total growth of transport, which implies moderate improvements of efficiency of transport. New technologies will enter the transport vehicle market with different time horizons. In the medium term, in particular bioethanol and CNG vehicles will achieve significant market shares, while hydrogen will not enter the market without policy support, which is in line with results of the European HyWays project.

After the baseline scenario was completed, it could be used as the basis from which the policy scenarios could be derived. Hence, the scenario levers were implemented into those models which were appropriate to handle a specific policy. On this basis the scenario runs could be undertaken and provided the results for the indicators for the sustainability impact assessment. For this purpose, the quantitative indicators from the models were combined with qualitative analysis on specific aspects e.g. the biomass potentials to produce biofuels and the related question on food versus energy and meat versus energy, respectively. A summary table is developed to provide an overview on the scenario results for policy-makers.

A further development was the linked sensitivity runs of the ASTRA and POLES model. For these runs the POLES model assumed reasonable ranges for reserves of fossil fuels (crude oil and gas) and ranges for the GDP growth in China and India. The result were reasonable ranges for fossil fuel prices that could feed into a sensitivity analysis of ASTRA together with the same GDP growth ranges for China and India and ranges for the imports of fossil fuels of the European countries in monetary terms. ASTRA then produced ranges for results of economic variables (e.g. GDP, employment), of transport variables (e.g. transport performance, energy demand) and of environmental variables (e.g. $CO_2$ emissions, $NO_x$ emissions).

## Results of the TRIAS project

The project results achieved were an update of the POLES, ASTRA, VACLAV and Regio-SUSTAIN models with new model elements required for the specific scenario analysis in TRIAS e.g. extending to the time horizon 2050, adding new technologies to the vehicle fleets, modelling of biofuels for the energy and transport markets as well as the new development of the BIOFUEL model. In particular, the ASTRA model made a large step ahead as during the course of the project it was agreed to actually modularize the software and to develop a tool that would merge it back to the integrated System Dynamics model that incorporates the most important feedbacks between transport, energy, technology and the economy. A further achievement was the improved linkage between ASTRA and POLES that enabled fast running of scenarios in an iterative manner and achieving convergence between the two models.

Applying the improved models and using the newly established linkages between the models the eight policy scenarios could be tested and compared with the baseline scenario. The main conclusion is that all scenarios showed both a positive impact on the economy, though in most of the scenarios the improvement remained quite limited, and a reduction of emissions and resource use. The two most effective scenarios were the first mover scenario for hydrogen and the introduction of $CO_2$ emission limits, because the main driver for making scenarios positive were the additional investments induced by the policy and these two were the scenarios with the highest investments. A further stimulus was the reduction of fossil fuel imports. It has clearly to be noticed that all scenarios were comprehensively specified such that e.g. to increase investments always either increased cost, increased taxes or government expenditures are specified that would keep the economic system closed.

Table 1 summarizes the TRIAS findings in a qualitative manner, relative to the best performing scenarios. Assuming neutrality for the transport indicators (because of the conflicting targets of providing mobility to goods and persons but also decoupling transport from economic growth which could mean reducing transport performance), an increase is positive for the economic indicator of GDP and a reduction is positive for the economic indicator of fossil fuel imports as well as for the resource indicators (energy use) and environmental indicator (transport $CO_2$). It can be concluded that the $CO_2$ emission limit policy for cars provides the best outcome closely followed by the first mover strategy for hydrogen fuel cell vehicles. Further positive scenarios in particular to reduce $CO_2$ emissions would be those fostering the penetration of hydrogen fuel cell cars (subsidies and carbon taxes for H2-FCV cars). In terms of reduction of imports of fossil fuels the quota for biofuels also proves to be successful, but with less strong impact on $CO_2$ and GDP. The least effective policies with respect to nearly all policies would be the policies focussing on biofuels only either by subsidies or by carbon taxes.

Table 1: Overview on results of the eight TRIAS policy scenarios

| | **pkm** | **tkm** | **energy** | **transport $CO_2$** | **GDP** | **Fossil fuel imports** |
|---|---|---|---|---|---|---|
| Subsidies Biofuel | ≈ | ≈ | ≈ | ≈ | ≈ | ↓ |
| Subsidies H2 | ≈ | ≈ | ↓ | ↓↓ | ↑ | ↓ |
| Carbon Tax Biofuel | ↓ | ≈ | ≈ | ≈ | ≈ | ↓ |
| Carbon Tax H2 | ↓ | ≈ | ↓ | ↓↓ | ↑ | ↓↓ |
| Combi | ↓ | ≈ | ≈ | ↓ | ↑ | ↓↓ |
| First Mover | ↓ | ↑ | ↓ | ↓↓ | ↑↑ | ↓↓ |
| Quota Biofuel | ≈ | ↑ | ↓ | ↓ | ↑ | ↓↓ |
| CO2 Emission Limit | ↓ | ≈ | ↓↓ | ↓↓ | ↑↑ | ↓↓ |

*Source: TRIAS*

Looking closer at the results for GDP and $CO_2$ emissions from transport over the time period 2010 until 2050 (Figure 1 and Figure 2) it seems that European policy making is moving in the right direction. In the shorter term, setting $CO_2$ emission limits will provide economic stimulus as well as reducing $CO_2$ emissions. This can be reinforced by fostering biofuels. The type of biofuels must be carefully selected according to sustainability criteria and to limit the use of biofuels, because (1) overemphasized use of biofuels could lead to strong conflicts between the use of biomass for food and the use for energy, which seems not to be reasonable considering (2) that the impacts on economy and $CO_2$ emissions of the biofuels policies remain limited. In the longer term, hydrogen seems to be a suitable option to foster economic growth and to significantly reduce $CO_2$ emissions and other environmental impacts of transport. However, this presupposes that other countries follow the same but delayed trend towards transport infrastructure based on hydrogen and, therefore, hydrogen cars would become a more successful export good than todays European cars. Furthermore, it assumes that this hydrogen is mainly produced from renewable sources.

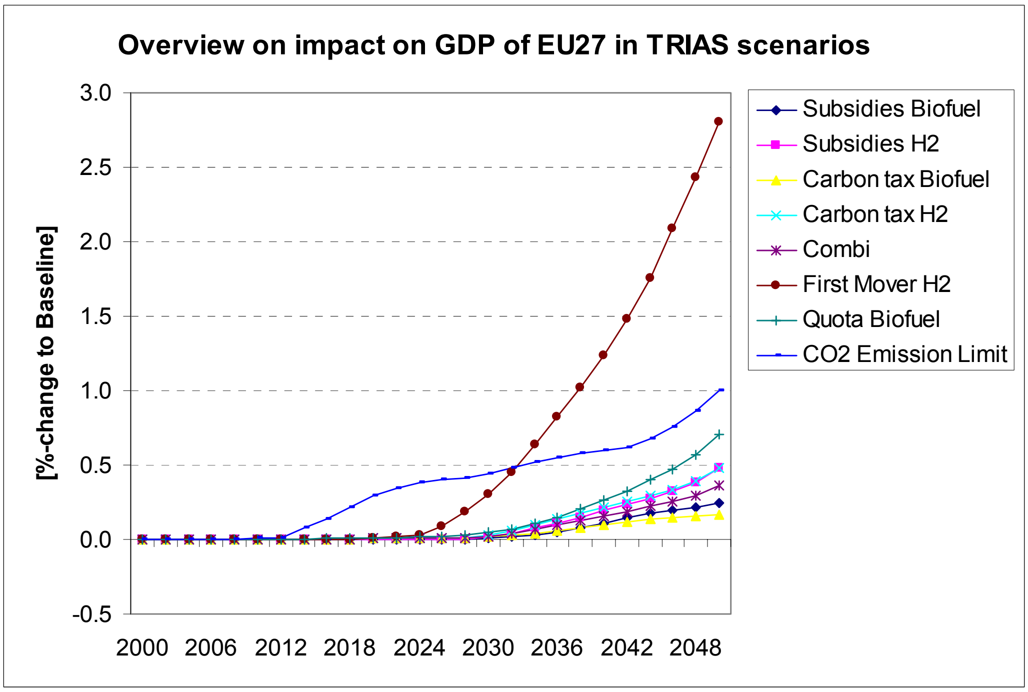

*Figure 1: Impact on GDP in the eight TRIAS scenarios*

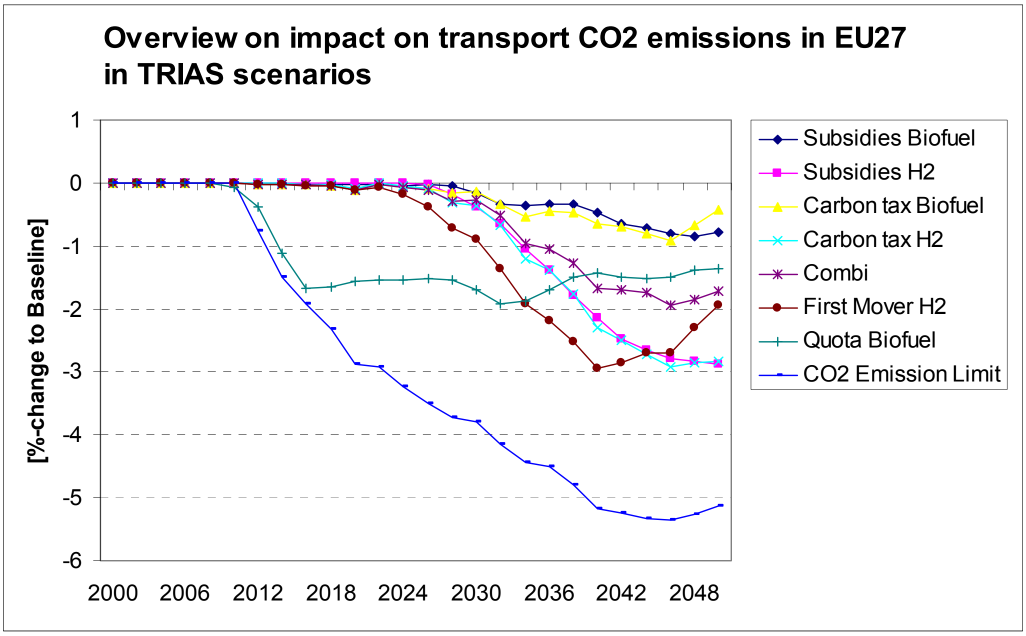

*Figure 2: Impact on transport $CO_2$ emissions in the eight TRIAS scenarios in EU27*

While the model outcomes are consistent among each other, some important constraints should be taken into account:

(1) The policies analysed in TRIAS are conservative. In particular, meeting ambitious $CO_2$ emissions reduction targets until 2050 require policies to be designed more ambitiously than those considered here.

(2) In TRIAS, only changes of policy instruments designed for affecting the transport sector are reflected. This allows estimation of the impacts of transport policies but might be considered as incomplete as e.g. setting $CO_2$ emission limits in the transport sector is likely to be only one element of an overall $CO_2$ emission reduction strategy, and pushing biofuels shall be

seen in the context of increasing the share of renewable energy sources in overall energy demand.

(3) The technology screening of TRIAS does not account for the fast development of batteries, in the recent two years. This was not considered in the TRIAS scenarios. Thus battery-electric vehicles may play a more important role than in the TRIAS scenarios.

(4) Finally, some systemic effects could not be modelled with the available toolset. For example, no competition was assumed to happen between biofuel and hydrogen fuel production from biomass, even though this may occur through e.g. gasification of biomass. Other model-inherent parameters of the BIOFUEL model, such as the feedstock price elasticities describing the feedback of an increased biofuel demand on feedstock prices are calibrated on historic data with limited biofuel volumes. With biofuels gaining importance and the demand of crops for energy purposes attaining a high share of overall crop production, those elasticities might need to be modified. Similarly, the model does not allow for a comprehensive assessment of the origins and quantities of imported biofuels, resulting in uncertainties about the overall related GHG emissions.

Besides the technical work and the resulting findings, the TRIAS project was also the main organizer of two cluster workshops, of which the latter was also the projects final conference. First, the cluster workshop on the *Sustainability of a hydrogen economy* was hold in February 2006 in Frankfurt, and, second the cluster workshop and TRIAS final conference titled *Running transport on hydrogen and biofuels* was hold in Frankfurt in June 2007. Both workshops were co-organized with the European research projects HyWays and MATISSE and for the first workshop the ENCOURAGED project was the fourth co-organiser.

The TRIAS conclusions can be summarized as: the policies applied change EU development in the desired direction. However, implementing them in a moderate way as in TRIAS would not be sufficient to achieve European policy targets such as achieving a significant reduction of transport $CO_2$ emissions or increasing security of energy supply. This requires more ambitious and stringent policies e.g. in terms of higher carbon taxes than in TRIAS, comprehensive carbon taxation of all fuels or more focused subsidy of new vehicle technologies at market entry. The TRIAS sensitivity analysis reveals that such policies would pay-off for Europe, in particular when oil prices are sustained at current high levels.