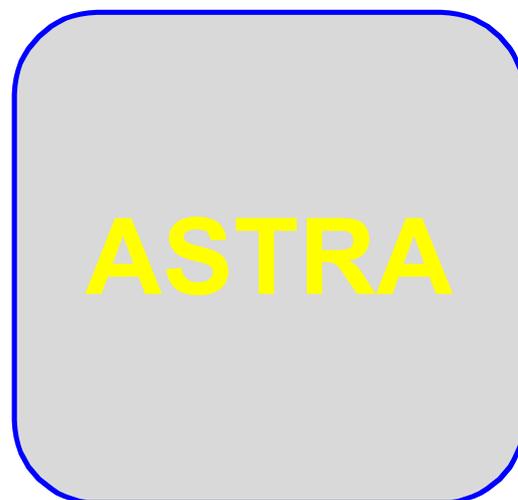


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2 Executive publishable summary

The transport system forms a complex system whose determinants change with different speed or intensity over time. Some of the major driving forces may only be changed in the long run: for instance the construction and planning of transport infrastructure, which takes more than 10 years, while the usage duration is often longer than 40 years. Human habits, like the preference to live in green suburban areas or in city centres, have also developed for a long time before they finally constitute the life-style of a generation of people. To change such habits needs also longer time periods. Other transport determinants have a different pattern, as they vary significantly in the short and the medium term time horizon. This is the case for transport costs which may have a direct impact on modal split (short term effect) as well as on accessibility (short and a medium term effect) or on route choice.

Furthermore, the transport system is strictly connected with other complex systems like the society, the economy and the environment. In history improvement of the transport system was often a major source of growing welfare of societies. In 1995 the EU15 countries transport services generated 4% of the GDP. 6.2 million employees - that is 4.2% of all employees - are working in the transport sector (not including the production of infrastructure and vehicles). By providing the basis for personal mobility transport also forms a part of the social life of society. This is reflected by the growing passenger transport demand that reached a value of 4500 billion pkm in the EU in the year 1995.

On the other hand, transport is a major source of environmental burdens that influence sustainability in the negative direction. In 1995 road transport caused 44.000 deaths by traffic accidents within the EU15 countries. The World Health Organisation (WHO) estimates that additionally 80.000 people in EU15 are killed by hazardous gaseous emissions of transport per year. The contributions of transport to global effects like the greenhouse effect are also considerable. CO₂ emissions of transport contribute with a share of 26% to the man made CO₂ emissions in the EU15 (EUROSTAT 1997).

Therefore transport policy assessment approaches have to be capable of reflecting these highly interrelated systems as well as of measuring long-term changes taking into account the effect of shorter-term cycles. The System Dynamics modelling approach is an appropriate tool for these purposes.

In conventional scientific approaches real systems are split up and allocated to different disciplines. Each discipline such as economics develops "partial" models, which consider many variables to be constants or determined exogenously. This way of scientific division of research - often referred to as the Descartes-type of structuring scientific analysis - abstracts from the interrelationships between the elements of the system and the dynamics, which are induced by feedback mechanisms. System dynamics is one of the few tools, which are able to re-establish these interrelationships and to tie together the elements of reality in one model again.

These ideas form the baseline of the ASTRA project, which was carried out on behalf of the European Commission DGVII. The ASTRA objective was the development of a tool that analyses the long-term effect of the EU Common Transport Policy (CTP) not only for the transport system but also for the most important connected systems.

This final summary report includes a presentation of the model, called the ASTRA system dynamics model platform (ASP), as well as a portrayal of the usage of the model for demonstration examples. The ASP can be categorised as system dynamics model for integrated long-term assessment of the European transport policy with a spatial representation on a functional basis.

The ASP integrates the macroeconomic sub-module (MAC), regional economics and land use sub-module (REM), the transport sub-module (TRA) and the environment sub-module (ENV) into one model. The establishment of interfaces between these originally – Descartes-type – separate models is one of the added values of the ASTRA project. Within the ASP the passenger model and the freight model are implemented in a way that both are formed by parts of REM, TRA and ENV. Each sub-module is subdivided into several model sectors.

The ASTRA model is implemented in two versions: a full Vensim version (ASP) and a core ithink version (iAM).¹ This was necessary to overcome size limits of the ithink software. The full Vensim ASP integrates all four sub-modules and the welfare situation. It is the final outcome of the ASTRA project and the main object described in this report. The core iAM comprises the complete MAC, REM, TRA sub-modules and the car vehicle fleet model from the ENV. Considering policy simulations it is recommended to apply the full Vensim ASP as the capabilities of the core iAM are restricted.

Creating the ASP a very important task of the modelling process is to define the spatial representation within the model. For the MAC a clustering with 4 *Macro Regions* that are based on the geography of 15 NUTS 0 zones is applied. For the passenger model within REM, TRA and ENV a clustering with 6 *Functional Zones* that are based on the settlement patterns of the 201 NUTS II zones is used. The transport system is represented by five *Distance Bands*, which consider different modal choice alternatives and different driving patterns in dependency on the trip length. For the freight model within REM, TRA and ENV a clustering with 4 functional zones is aspired, which corresponds to the macro regions. The freight transport system is represented by four distance bands that consider the different modal choice alternatives for freight transport. The road transport network is divided into an urban-network and a non-urban-network on which passenger and freight transport are competing.

In general, the ASTRA System Dynamics Model Platform (ASP) is working as follows. The macroeconomic sub-module (MAC) estimates the economic framework data of the EU and the member countries respectively. The results of the MAC key indicators (e.g. GDP, employment) are transferred to the regional economics and land use sub-module (REM). Within the REM basic data for transport demand modelling (e.g. population, car-ownership, freight value-to-volume ratios) are calculated. Both data form the input of the first two steps of the classical 4-stage transport model: trip generation and trip distribution on the basis of the previously described spatial representation. The resulting transport demand is transferred to the transport sub-module (TRA), which includes the final two stages of the transport model: modal split and a simplified assignment. The environmental sub-module (ENV) is mainly fed by data from the TRA (e.g. traffic volumes). It includes the vehicle fleet models and models for description of changes in technology. Environmental indicators (e.g. CO₂ emissions) are

¹ The naming conventions are: the full Vensim model is the actual ASTRA System Dynamics model platform called ASP; the core ithink ASTRA model is called iAM.

calculated and the welfare consequences performed by the environmental impacts are estimated in the ENV. Finally the aggregated welfare situation, based on economic, social and employment indicators, is presented. All model variables (e.g. GDP, transport performances, emissions) are calculated as time series from 1986 to 2026, where the first ten years are used for initialisation and calibration of the ASP. The forecasting period lasts from 1996 to 2026.

It has to be emphasised that the data between the sub-modules is not transferred as a complete time series over the whole simulation period. Instead data calculated at a certain point of time - called integration period DT - is transferred among the sub-modules. The data can be used in the other sub-modules for the calculation of variables within the same integration period, of variables in the next integration period or, if there are time lags included in the model, of subsequent integration periods. That means, the MAC does not calculate all GDP values between 1986 and 2026 in one time series before the transfer to the REM. Instead it calculates the GDP, for instance, for the third quarter of 1987. This value is transferred to the REM and the TRA, which calculate the transport demand and the transport cost in the third quarter of 1987. Assuming that there is no longer time lag included in this feedback structure the transport cost of the third quarter are transferred to the MAC. Within the MAC they form an input of the calculation of GDP of the fourth quarter of 1987.

The benefits of the model are explained with the Vensim ASP by undertaking and presenting demonstration examples. The ASTRA demonstration examples cover a reference scenario, five policy packages consisting of sets of policy measures and an integrated policy programme comprising most of the policy packages. The five policy packages can be described as:

- a) Improved emission and safety policy package (ISE), comprising regulatory policies like speed limit, emission legislation and enforced safety-belt usage.
- b) Increased fuel tax policy package (IFT), consisting of taxation policy like fuel tax and labour cost changes.
- c) Balanced fuel tax policy package (BFT), similar to IFT but modified taxation policy.
- d) Rail-TEN policy package (Rail-TEN), comprising taxation policy and infrastructure policy and
- e) All-TEN policy package (All-TEN), similar to Rail-TEN but modified infrastructure policy.

The policy packages are designed in a way that they fit to the general framework of European transport policy. With the chosen packages it is aspired to take advantage of the special capabilities of the system dynamics methodology. The scenarios address policy decisions in the field of taxation, construction of the TEN, mitigation of air pollution and increase of safety of transport. Policies applying increased taxation also consider different ways of spending the increased revenues either for a reduction of the labour costs or for construction of new transport infrastructure. The integrated policy programme integrates the complete ISE, IFT and Rail-TEN as well as the BFT without the introduction of the kerosene tax. Briefly summarising the results the integrated policy programme (IPP) produces the best results considering the whole range of economic, environmental and (un-)employment indicators.

But it seems that also with the IPP environmental sustainability e.g. in terms of CO₂ emissions will not be reached. The most important points might be resumed as follows:

- The policy packages show a plausible range for their effect on economic performance: the change of average yearly GDP growth rate over 25-30 years of policy simulation period was below 0.2%.
- None of the tested packages is able to lead to the fulfillment of Kyoto requirements for greenhouse gases emissions: the best result is a stabilisation at the 1990 level due to the measures included in the emission and safety policy.
- NO_x emissions on ground level will be reduced coming at least very close to a sustainable level in the next decade in the reference scenarios and all policy packages.
- No further significant improvement can be identified for road accidents including fatalities.
- The integrated policy programme provides synergies between the single policy measures and generates the highest growth in GDP, but not in all four macro regions.
- Air transport growth is significant in all policy packages and in some cases it counterbalances most of the policy environmental benefits of the reduction of road transport.
- The investment multipliers for the Rail-TEN and the All-TEN policies indicate that in the long-run both policies are economically positive, even though they do not foresee an “economic bonanza” induced by transport investments.

Summarising, the major output is an operational model for long-term policy assessment on European scale. The results of the ASTRA demonstration examples reveal that the model is able to simulate the implementation of policy packages consisting of policy measures that are taken at different points of time and with varying intensity (incremental policy design). Thus the model is able to unfold synergies between different policies and to design advantageous policy programmes.

The choice of the System Dynamics methodology allows for a long-term assessment of the transport policy packages and provide inherently consistent indicators that are necessary to control the development towards a sustainable transport system. The usage of time-path indicators and the variety of provided indicators encourage a direct assessment by the policy maker without any additional assessment scheme. This is additionally supported by the ASTRA-TIP, a separate tool that can be used to present indicator results interactively. However, the possibilities to feed separate or to integrate conventional assessment schemes like cost-benefit or multi-criteria analysis are excellent.

The exploitation plan for ASTRA is manifold. First of all, it should be used for the assessment of policies that will be actually adopted in the near future or for future policies that currently are a matter of discussion. Second, in the 5th EU research framework programme the TIPMAC project is carried out to get new insights into macroeconomic effects of transport policy. The TIPMAC approach is based on a comparison of two macroeconomic models (E3ME, ASTRA) which first have to be made comparable in their scope. For ASTRA this means a further disaggregation of the macro regions and the economic sectors as well as the

consideration of some additional feedbacks. Third, a national model for Italy, the so-called ASTRA-Italy, will be developed by TRT. Fourth, as energy prices are a major input for energy models it is aspired to link ASTRA with energy models namely with the POLES model. Furthermore, presentations on international conferences have been done (e.g. TRB 2001) or are planned, a dissertation thesis is in preparation and several proposals for the usage and the extension of the ASTRA model are in the pipeline. The major idea is that ASTRA and ASTRA-like approaches respectively are an if not the adequate tool to quantify sustainability issues, which are inherently long-term and have to cover complex interplays between social, technological, economic and environmental systems.

3 Objectives of ASTRA

The major objective of ASTRA was to develop a tool for the analysis of the long-term impacts of the common transport policy (CTP). For this purpose the tool should fulfil the following set of requirements:

- Identify flexible levers to introduce different types of policies with varying scope and time scale;
- Consider feedbacks of transport policies with other related policy fields and other real systems;
- Integrate all relevant systems that can be effected in the long-term by changes of transport policy;
- Provide an interface that enables to modify policies and review results in an easy-to-use manner;
- Build and calibrate the integrated ASTRA model based on a set of reliable and already existing models from different scientific disciplines.

4 Scientific and technical description of the results

4.1 Concepts of ASTRA

4.1.1 Basic ideas and typical features of the ASTRA approach

The aim of ASTRA is to develop a tool for analysing the long term impacts of common transport policy (CTP), putting particular emphasis on the secondary effects which occur through feedback mechanisms between the transport sector, the regional economy, the global economy and the environmental sector. In every of the areas mentioned sophisticated models have been developed to estimate the impacts of exogenous changes on the model variables. Typically every model, which is developed for one impact area, considers the variables describing the situation in the other areas as constants. A transport model, for instance, will start from exogenously determined developments for regional population, employment, economic performance, income levels or location patterns. A macro econometric model, on the other hand usually starts from the assumption that transport activities are fixed exogenously. One idea could be to combine all developed area impact models by constructing a hyper-model, which would include all activities in the different areas in form of endogenous variables. However, this would result in a huge and highly complex model structure, which

would be very difficult to handle, and which needs considerable computer time despite all progress of computer technology.

Hence, a basic principle for the ASTRA approach is to limit the overall complexity in a way that

- the model runs and sensitivity analyses can be performed on-line, and
- the plausibility and the working performance of every single module can be controlled easily by benchmark checking with statistical data or the results of detailed area models.

Starting from these general specifications of the performance of the ASTRA tool three basic components of the ASTRA approach have been defined:

- (1) System Dynamics is chosen as the general philosophy of modelling long term dynamic interaction processes.
- (2) The impact areas are clustered in form of single modules and developed by different specialised research teams on a common software platform.
- (3) Complexity has been reduced by functional modelling (using clusters of regions and network links) instead of detailed spatial modelling of the activities.

Below the ideas behind these basic components elaborated and answer is given why the typical features of ASTRA have been preferred to other possible model approaches. The particular benefits of the model for the user are then pointed out. Using the ASTRA approach several demonstration examples applying different policies have been run and their results will be commented. Finally the lessons learnt and the conclusions drawn from the performance of the model as well as its potential for further extensions are discussed and give the basis for an outlook to future applications.

4.1.2 System Dynamics and dynamic assessment

The assessment of common transport policy measures is based on two components:

- Impact measurement and forecasting, and
- appraisal of impacts.

Usually these two components are treated separately and based on two comparisons:

The state at the end of the time horizon of consideration compared with the initial state, and the state with policy actions compared with the state without policy actions. Instead of this point-to-point approach the ASTRA methodology is based on constructing complete time profiles for all variables beginning with the initial state and ending with the final state of the time horizon. By this way the dynamic parts with and without policy actions taken can be compared. The advantage of this is twofold:

- (1) The information about the time profile of impacts provides an indicator for the acceptability of a policy action. For instance the result of the policy can be positive in the last period but negative in the first periods of time after implementation. The political implementation of such an action would be much more difficult compared with an activity which would yield positive results from the beginning (“win-win”).
- (2) Many policy actions can not be implemented once and for all but have to be spread incrementally over time. Mathematically they would be represented by a function of time, which can be a constant, linear, progressive or degressive. The construction of dynamic impact profiles for the complete time horizon allows for studying the effectiveness of different dynamic policy schedules.

Dynamic time profiles can be modelled by equilibrium or disequilibrium approaches. Equilibrium approaches pre-suppose that the system, after an initial shock through the policy action, converges to a stationary position (static equilibrium) or to a steady state with constant growth rates over time (dynamic equilibrium). The neo-classical economic growth theory is based on this paradigm. In disequilibrium models stationary or steady state solutions only occur by accident or by design. In principle the dynamic development of a system is evolutionary, which means that permanent continuous and discontinuous changes of variables occur over time, which keep the structure of the system changing such that states of the past never repeat. Economic modelling based on evolutionary dynamics dates back to Schumpeter (1939) who has explained business cycles and discontinuous movements of the economy by endogenous market forces such as the innovation behaviour of entrepreneurs. Neoclassical theory always had problems with explaining fluctuations and focused on exogenous shocks.²

System Dynamics Modelling is based on four foundations:

- Cybernetic Feedback Theory,
- Decision Theory,
- Computer Simulation and
- Mental Creativity.

Cybernetic Feedback Theory puts much emphasis on the dynamic relationships between the elements of a system. Feedback loops can be negative, which means, that the dynamic process is dampened over time and converges to a stationary value or a steady state. Positive feedback loops lead to accelerated movements of the variables in upward or downward direction, eventually in form of expanding cycles. To behave sustainable over time it is necessary for a system that all in all the negative feedback loops are the dominating driving forces.

Decision Theory comes in the System Dynamics world insofar as the system might be influenced by policy actions. These policy actions have to be chosen in line with a set of objectives and constraints. System Dynamics can then be used to derive an optimal time-path of variables, which approximates the objectives without violating the constraints.

² A most famous example is the statistical analysis of W.S. JEVONS (1875,1878) on the dependency of business cycles from sunspot cycles. When physical science came out with a new period of the sunspot cycle he manipulated his statistics to save the empirical validity of his hypothesis.

The mathematical structure of a System Dynamics Model is described by a usually large number of difference equations. There is no limitation for the degree of the difference equations, or in economic terms, with respect to the time lag for the reaction between variables. There are also no limits with respect to the non-linearity. Therefore, from the mathematical point of view, the equation system can develop very complex, even with the consequence that an exact mathematical solution is impossible. Solution technique is based on computer simulation in form of a sequential (step-by-step) solution of the equations over time. Using methods of numerical approximation even very complex equation structures can be handled comparatively easy and fast on a computer.

It is a premier principle of System Dynamics to model all basic dynamic features and inter-relationships of a system. If for parts of a system a mathematical representation, which is tested econometrically, is not possible, expert judgements and expert rankings are included. The philosophy behind says that neglecting interrelationships in a system is worse than using expert judgements to fill the gaps of numerical models. According to the main developer of System Dynamics, J. Forrester, and the most famous protagonist Dennis Meadows, for long-term analysis it is not so much important to model empirical objects in much detail rather than to get the most significant interrelationships right and to describe the "Gestalt" of a system and the forces which drive this system over time.³

4.1.3 Impact analysis and assessment

Conventional cost-benefit or multi-criteria analysis starts from a fixed impact matrix, which exhibits the impacts of exogenous stimuli on defined decision criteria. This presupposes that a measurement with and without the exogenous stimulus can be performed, assumed that the stimuli are introduced at an initial state of the system and generate a change which is measured at the end of the time horizon considered. This methodology presupposes that the criteria of evaluation are independent of each other and also the exogenous stimuli as for instance the policy activities, can be separated clearly. Furthermore this approach presupposes that the impact mechanism is one-directional. That means, it starts from an exogenous shock on the transport sector, for instance by introducing investment activities or pricing policies, and ends with a change of social product, employment, environmental indicators or overall social benefit.

In System Dynamics the criteria used for evaluation directly can be variables of the system, which are parts of interacting feedback mechanisms between variables of the transport sector and variables of other sectors of the economy. For instance motorisation is influenced by disposable income of the households, but there is also an inverse relationship stating that car-purchases of the households increase overall consumption, lead to an increase to final demand, thus increasing sectoral and overall production, which finally leads to an increase of the disposable income. In this example transport and macroeconomic variables are inter-linked by a positive feedback loop.

As in the System Dynamics approach all variables are computed for every period of time, two important consequences arise, which make this approach fundamentally different from conventional assessment methods:

³ The basics of system dynamics have been formulated by FORRESTER (1962, 1972) and MEADOWS et al. (1972). Broadened applications are presented in HANNON/RUTH (1994) and BOSSEL (1994).

- Policies can be defined as a sequence of stimuli over time. This is very important for a realistic modelling of policy activities, which are rarely introduced by sudden big shocks rather than smooth changes over time (For instance: environmental policy, pricing policy).
- The impact variables, i.e. the indicators of the assessment scheme, can be modelled in form of time-profiles. This is crucial for the analysis of the acceptability of a policy action. For instance it can happen, that the considered indicator changes towards a positive direction in the final phase of the time horizon while in the first phase it shows a negative sign. Then the policy considered might not be acceptable without a packaging with other compensating measures.

Conventional cost-benefit criteria or multi-criteria analysis can easily be integrated into the System Dynamics approach, which then would generate a much richer set of results, because the complete time profiles can be evaluated. Furthermore the so-called meta-appraisal techniques can partly be included as soon as they are based on ordinal or cardinal scales. With respect to the meta-appraisal techniques, which have been investigated in the SAMI project of the fourth framework program, e.g. the spider or the regime analysis, can be included without major difficulties.

4.2 ASTRA System Dynamics model platform (ASP)

4.2.1 Modular structure of System Dynamics modelling

The basic issue of System Dynamics is to model all important interrelationships between the impacted areas. Naturally this challenge leads to a complex modelling task. It can be structured by defining separate modules, which can partly be developed independent. For the ASTRA System Dynamics model four sub-modules have been defined: Macroeconomics sub-module (MAC), Regional Economics and Land-use sub-module (REM), Transport sub-module (TRA) and Environment sub-module (ENV). In addition a small sub-module has been integrated for computing the indicators describing the social welfare situation. This means that variables from the four basic sub-modules are extracted and combined in a way that the welfare situation measured by typical approaches of cost-benefit analysis or multi-criteria analysis, can be looked at.

The definition of sub-modules in ASTRA has been chosen in a way that

- one research team can work de-centrally on one-sub-module, and that
- the development and testing of a sub-module can be done by means of an existing well-tested model, which describes the impact area concerned in enough detail.

The following figure 1 gives an overview on the ASTRA System Dynamics Platform (ASP), the defined sub-modules and the area models chosen to derive the key-functions for ASTRA and to calibrate the ASTRA computation process.

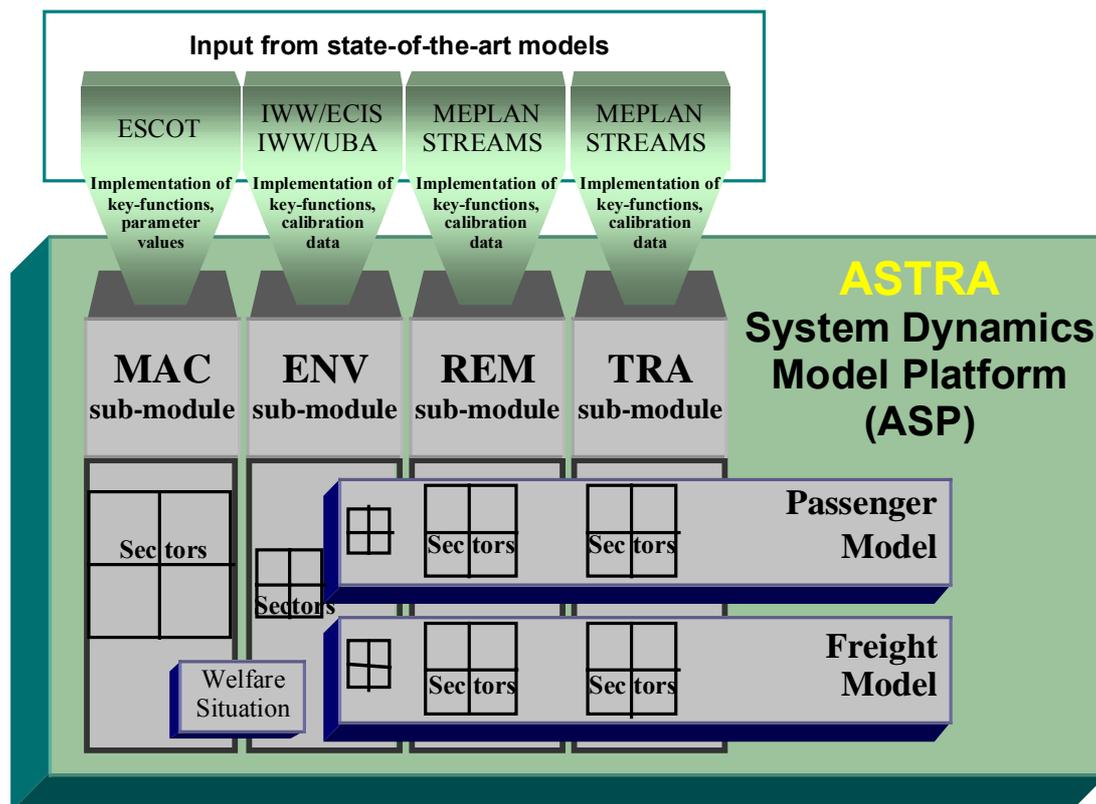


Figure 1: Structure of the ASTRA System Dynamics model platform (ASP)

By this type of work organisation the feedback process, which is proposed for the overall model, could also be applied for the development of the single modules. While the work of the four research teams could be organised widely in a de-central manner, the results were linked together by the project leader and checked for overall consistency. But also the single developers could test the results of their partial modelling on the whole model context because a release of the complete ASTRA System Dynamics Platform was distributed periodically to the partners. Thus the efficiency of the inter-links between the sub-modules could be tested by the project leader as well as by the responsible sub-modules developers. The following diagram gives an example for the aggregate relationships, which have been constructed for the passenger transport model.

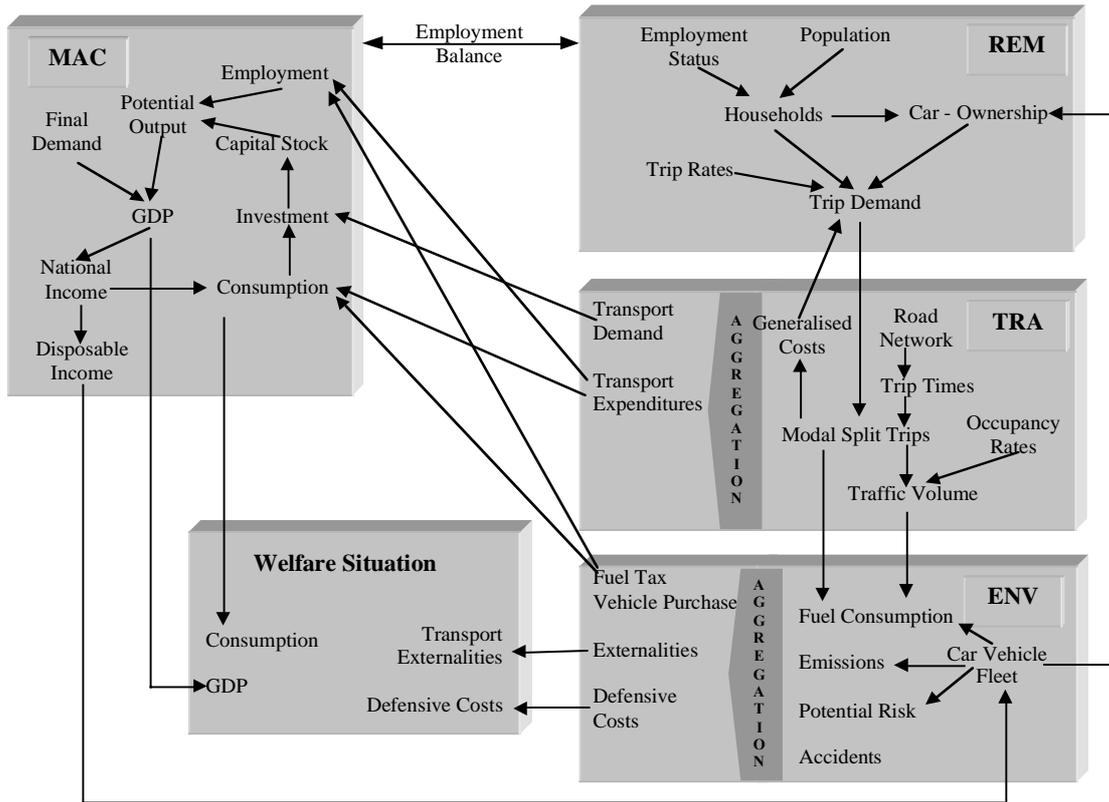


Figure 2: Aggregated relationships of the passenger model

Based on potential output and final demand the GDP is calculated considering also taxes and transfers. GDP determines the national income, which is used to calculate the level of disposable income. Mainly the development of disposable income influences the car vehicle fleet. Population density and fuel prices are considered to be further influences on the fleet. The actual stock of the cars is used as input for the car-ownership calculation. Together with the population development (distinguished into age classes) and the trip rates (dependent on household types that e.g. consider different employment situations) the car-ownership drives the trip demand. The demand is transferred to the TRA where the modal-split (dependent on times and costs) and assignment is determined. The TRA calculates the number of trips and the traffic volume for the different passenger modes. Based on this output transport expenditures are calculated and transferred to the MAC. Within the MAC the transport expenditures, which cover for road mode only perceived costs, are part of consumption and drive employment in the transport service sectors. Trips and traffic volume are transferred to the ENV where indicators for fuel consumption, emissions and accidents are calculated. Based on the fuel consumption the fuel tax is calculated and transferred to the MAC where it forms a part of private consumption. Based on vehicle purchase the fixed costs for car purchase are calculated and added to transport expenditures such that they also influence private consumption. Additionally they affect employment in the transport vehicle manufacturing sectors. Externalities and defensive costs of emissions and accidents are estimated and define a part of the welfare situation. Within the MAC the remaining indicators that describe the welfare situation are calculated.

The organisation of the sub-module development and the construction of the overall ASTRA model platform has proven to be efficient. Naturally every sub-module developer is interested in constructing as many dynamic key functions as possible in the System Dynamics Model (SDM) to make the model as accurate as the detailed Area Model. However, putting in too many dynamic key functions from every sub-module makes the overall system explode. Therefore compromises are necessary. The ASTRA model, which evolved from these interactions between the developer teams can be characterised as follows:

- The key functions are widely based on econometrically tested area models. Therefore ASTRA goes far beyond the high aggregation level of the applications which have been tried so far (for instance: the world model of the Club of Rome). So, ASTRA – after a careful initial calibration through the area models – is able to simulate and forecast the development of impact variables precisely enough to construct a sound base for a dynamic assessment scheme.
- On the other hand ASTRA is not a substitute for detailed area modelling. For instance detailed transport modelling or macro-econometric modelling will produce much more accurate results in the medium run. But there is also a value added for the area modelling generated by ASTRA: First ASTRA can construct time profiles for all the variables while area models usually apply a point to point analysis only. Secondly the interrelationships considered in ASTRA can produce dynamic shifts of area variables already in the medium run, which are not discovered by a partial area model. Thirdly the longer the time horizon, the lower is the value added of detailed area modelling. Dominant feedback structures will govern the system in the long run, which only can be modelled by the systems approach and not by partial area modelling.

4.2.2 Functional modelling and calibration

The most important step for reducing the complexity of the area models is to apply a functional way of modelling instead of modelling geographical regions and networks by virtual computer representations of reality. This means that in the ASTRA model the geographical regions are substituted by a regional or functional cluster and the transport networks for road, rail, inland waterways or air traffic are modelled by link types assigned to certain distance bands. The objective of the clustering approach is to derive relatively homogenous geographical areas in terms of their transport patterns on which to generate and distribute the demand for travel and the modal split.

While the principle of functional modelling looks easy some complexity can arise through the insight that different types of aggregation might be useful for the single sub-modules. In ASTRA the representation of space is treated in two distinct ways by the sub-modules within the ASP:

- Macro-regions;
- Functional zones.

4.2.2.1 Macro regions

The macro-economic sub-module (MAC) works with a concept of “Macro Regions” which are defined in geographical space as aggregates of EU15 member countries. This same representation is used in the modelling of freight demand in the REM and TRA sub-modules and for all aggregated variables in the ENV. The macro-regions are classified by the following conventional aggregation of 15 EU-countries to 4 regions (see also figure 3):

- Macro Region 1 Germany and Austria;
- Macro Region 2 France, Belgium, Luxembourg and the Netherlands;
- Macro Region 3 Italy, Spain, Portugal and Greece;
- Macro Region 4 United Kingdom, Ireland, Sweden, Denmark and Finland.

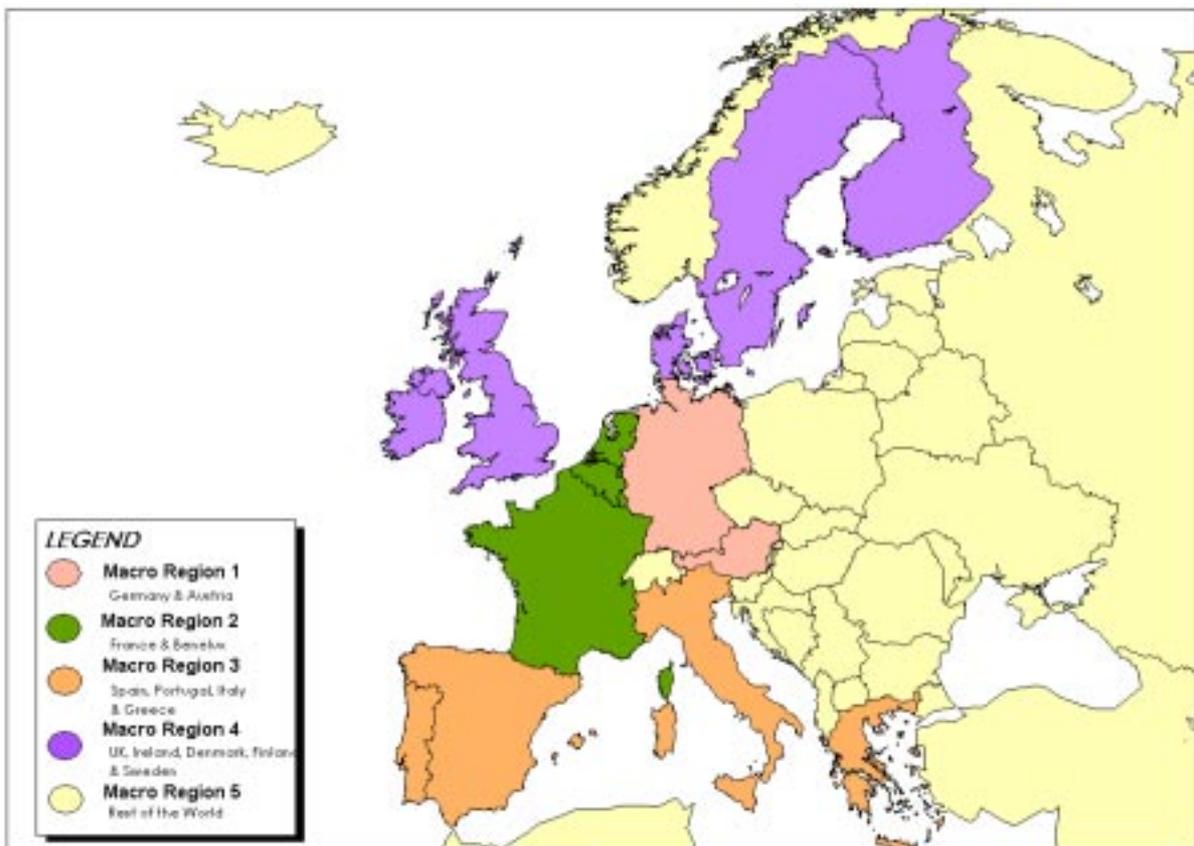


Figure 3: Basic zoning scheme of ASTRA System Dynamics model platform (ASP)

4.2.2.2 Functional zones

The passenger model in REM and TRA uses a more abstract representation of the spatial dimension thought to be more suited for modelling passenger demand in this particular application. This representation uses the concept of “Functional Zones” based on a functional definition of the settlement characteristics of all NUTS II zones depending on population density and centrality of the major settlement where each component part of the “functional zone” has a similar settlement pattern.

Six functional zones were defined based on settlement type. Due to the importance of the zones in generating the demand for travel the categorisation of zones has to be done carefully, bearing in mind the need to distinguish origin/destination pairs that have specific transport relevance. The functional zones defined in the ASTRA modelling framework are:

- Large Stand Alone Metropolitan Centres (**LSA**).
- Metropolitan Areas plus Hinterlands (**MAPH**).
- High Density Urbanised Areas (**HUA**).
- High Density Dispersed Areas (**HDDA**).
- Medium Density Regions (**MDR**).
- Low Density Regions (**LDR**).

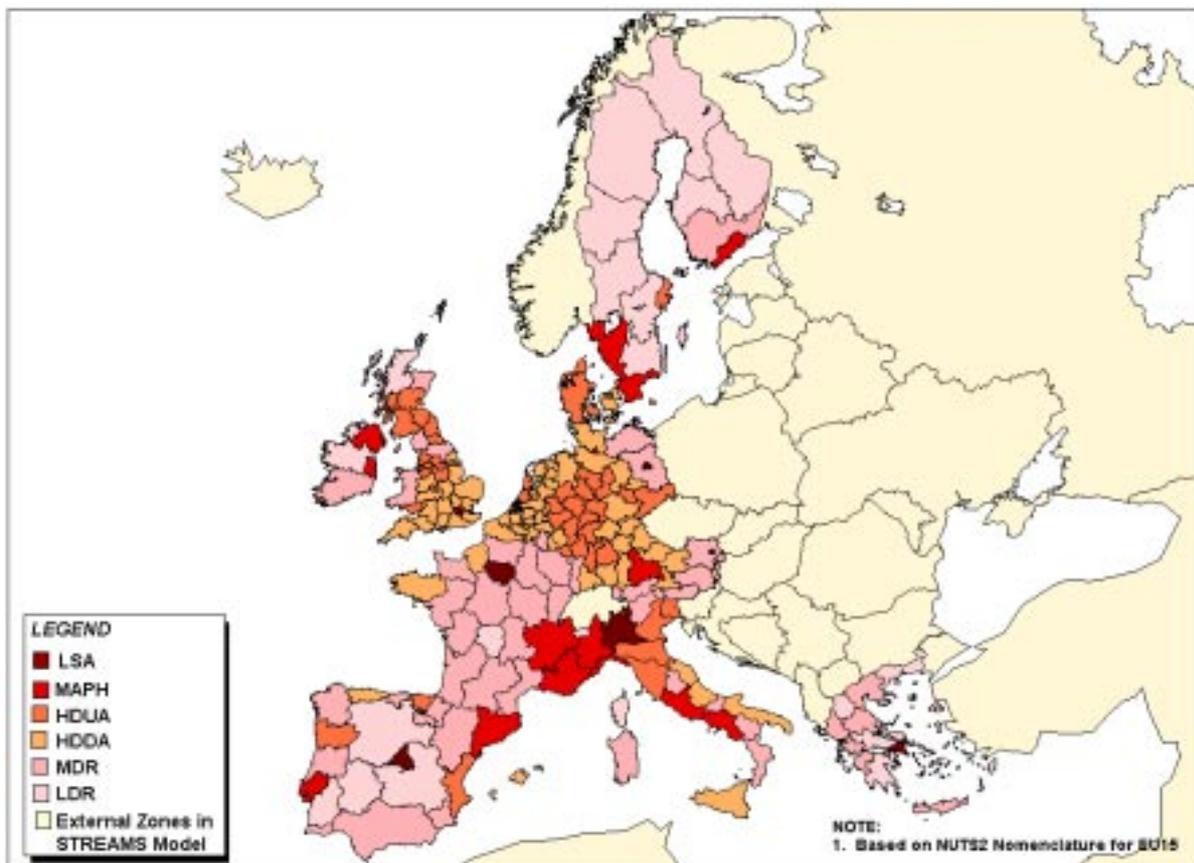


Figure 4: Zoning scheme for passenger model in ASTRA System Dynamics model platform (ASP)

4.2.2.3 Application of the different zoning types

Table 1 summarises the spatial units used in the different parts of the four sub-modules. In addition, for the potential health risk caused by soot particles modelled as part of the ENV a differentiation into different potential local situations is listed.

Table 1: Spatial units used by sub-modules in ASTRA System Dynamics model platform (ASP)

Sub-module	Spatial unit
Macro-economic (MAC)	Macro regions
Regional economic and land use (REM)	<i>Passenger generation & distribution</i> - Functional zones <i>Freight generation & distribution</i> - Macro regions
Transport (TRA)	<i>Passenger modal split</i> – Functional zones <i>Freight modal split</i> - Macro regions <i>Passenger and freight assignment</i> - Macro regions
Environment (ENV)	<i>All aggregated variables</i> - Macro regions <i>Disaggregated road emissions</i> – Functional Zones and Macro regions <i>Potential risk of soot particles</i> – Local Situations

4.2.2.4 Distance bands for passenger and freight transport

In a functional zone matrix (consisting either of macro regions or functional zones), each cell represents all relations existing in the transport networks for a pair of geographic zones, which belong to the origin and destination district types. The different relations that build up a given cell, make reference to different distances and thus to different modal choices. The segmentation of the distance bands for passenger and freight transport and the available transport means in each distance band are shown in figure 5.

Segmentation aspires to create homogenous distance bands in terms of demand and supply characteristics .

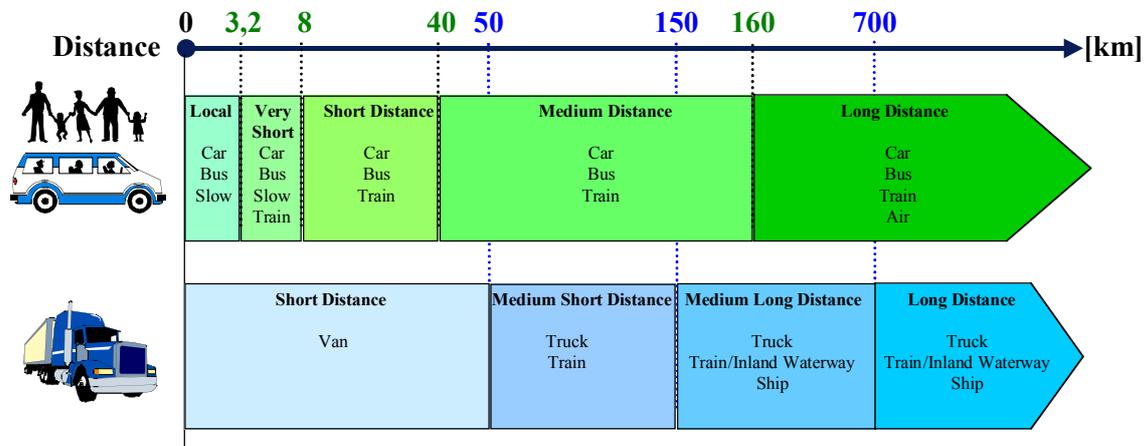


Figure 5: Structure of distance bands for passenger and freight transport

The functional zone matrix approach combined with the distance band approach makes it also possible to separate *intra-zonal* (=shorter distance bands) and *inter-zonal* (=longer distance bands) flows by mode within the ASTRA SDM.

4.2.2.5 Calibration of clustered variables

It is important that all aggregation steps and functional modelling approaches have been performed on the base of an existing well-tested and detailed area model. This concerns

- The CEBR version of the QUEST model for the macro-economy of the 15 EU member-states; this model later was exchanged by the ESCOT model, which IWW had developed for the OECD. Since ESCOT covers Germany only, its model structure and the key functions have been used for ASTRA, while the calibration was performed with statistical data from various sources on the European level;
- The STREAMS model (developed in the fourth framework programme) for modelling transport and the regional economy/land use inversions elaborated by ME&P and TRT;
- An environmental impact model incorporating the vehicle fleets and their relevant changes over time (Euro II, Euro III, Euro IV, etc.) developed by IWW, and
- A welfare model based on the UIC studies on external effects of transport, developed by INFRAS and IWW.

This close connection to existing area modelling helps to define almost all key functions and the inter links between the models based on a tested relationship. Therefore, contrasting other system dynamics approaches, the role of qualitative value judgements is low and the introduction of expert rankings and results from questionnaires were not necessary. This does not mean, that the model is free of value judgements of the developers. But it means that these

value judgements are transparent, lie in the interfaces between the sub-modules and are not hidden in the key functions.

The calibration of the sub-modules has been performed in a two-step-procedure. First the sub-modules have been adjusted to statistical indicators and the outcomes of the area models by a tuning of parameter values. This means that an ASTRA sub-module generates time profiles for a time interval of the past (1985 to 1995), which can be controlled by existing statistics. Furthermore, it can be controlled by area modelling for a medium term time interval of the future. Parameter values of the ASTRA SDM sub-modules have been set in a way that the sub-module approximates as well an ex-post development as an ex-ante development for a medium term future. Secondly the overall ASTRA model, consisting of all sub-modules, has been calibrated by adjusting parameters of the inter-link key-functions, which link the single sub-modules together. This guarantees that the long-term ASTRA simulations start on a model base, which produces reasonable results for the past and for a foreseeable future. For the long term simulations comprising a time horizon between 20 and 40 years of the future, the only control is the plausibility check of experts.

Main idea of modelling long term and secondary impacts through dynamic feedback mechanism is to generate new insights in possible developments. Hence experts should be careful with rejecting model results, which appear implausible when comparing them with past experience. The idea of system dynamics modelling is to start a learning process between modeller and the dynamic model, which helps the expert to think in new ways and conceive new development paths of transport in the long-term future.

4.2.3 System Dynamics software platform

With respect to the software some performance specifications have been set:

- Software should be available to all partners of the consortium and after the accomplishment of the model also to the Commission.
- Computation time for the assessment model on the SDM platform should not exceed some minutes such that the assessment model can be applied as an on-line decision support instrument.
- Putting in the variables for studying particular CTP policies should be easy and supported by a user-friendly interface.

In line with these requirements the ASTRA-team has decided to develop the model on a commercial SDM software. The first choice was the itthink-software, distributed by High Performance Systems (HPS), but it became evident later that a second software package had to be used in form of the Vensim-package distributed by Ventana Systems.

Itthink⁴ provides three levels for model development. On the top level it is possible to create a user-interface with a user-friendly handling to test different policies. Such interfaces can comprise switches or sliders for policy implementation, animations and tools to display results. Additionally, aggregated maps of the model structure can be designed, which display the itthink model sectors. On the middle level the internal structure of the model (e.g. stocks,

⁴ Details about the itthink software can be obtained from the itthink documentation distributed by High Performance Systems (HPS 1997a, 1997b)

flows) is designed and the interrelationships given by the equations can be implemented. The bottom level contains the whole list of equations. It can be used to insert equations, too. Time profiles of all model variables resulting from (policy) simulations can be displayed with built-in graphical tools and tables on the top and the middle level.

ASTRA model development commenced with the itthink-software developing the passenger transport side first. When the modelling process of the ASP arrived at a stage when the freight transport model was added to the transport sub-module and an updated environmental sub-module was integrated in the joint model the size limit of the itthink-software was reached. An adjustment of the single sub-modules to the overall space constraint was not possible. Therefore it was decided to split the ASP into a cut-down version, which can be handled by itthink (later on called the itthink ASTRA model iAM), and a full version, which is computed on the Vensim platform. The cut-down version includes MAC, REM, TRA together with the car vehicle fleet model from the ENV. The full version, the actual ASP, incorporates all four sub-modules. All descriptions in this final report refer to this full Vensim ASP.

Practically, the interface between itthink and Vensim is provided in a way that the calibrated cut-down version of the ASTRA model is translated from itthink to Vensim syntax and subsequently is linked with the ENV, which from this very moment has been developed on the Vensim platform. For the transfer from itthink to Vensim a translation tool has been developed, which provides a semi-automatic translation from itthink syntax to Vensim syntax. However, simulations with the iAM revealed some weaknesses of the MAC extracted from the QUEST model, which could not be moved. Therefore the MAC in the ASP of the full Vensim version is replaced by a MAC based on the structure of the ESCOT model. ESCOT means **Economic assessment of Sustainability poliCies Of Transport**. The macroeconomics module of ESCOT includes the demand and supply sides with technical progress dependent on transport innovations. Structural changes are considered through built-in input-output analysis. ESCOT is a System Dynamics model developed in Vensim for the project on Environmentally Sustainable Transport (EST) of the OECD (UBA/IWW 2000).

The Vensim⁵ software provides only two levels for model development and usage: the sketch level and the equations level. These are comparable to the middle level of itthink (used for view on model structure) and the bottom level of itthink (used for display and modifications of equations). However the middle level is not providing a complete picture of the model structure, but it is divided into separate views. Each view is representing a model sector. Results of (policy) simulation runs can be presented with similar types of built-in graphs or tables as in itthink. Both can display time series data for either different variables in the same policy or the same variable in different policies.

Policies in Vensim models can be implemented in four distinct ways. Simple policies can be introduced by the change of values of variables (constants or graphs) on the sketch level. Second, Vensim provides a simulation control dialogue on which the list of constants or graph variables is offered for changing their values. Third, complex policies can be defined in specific policy data files, which can be loaded from the hard-disk and then can be tested or modified. Finally, simple switches and sliders can be implemented within the complete ASP or within a separate Vensim tool, called Venapp. The latter tool has been applied in the

⁵ Details about the Vensim software can be obtained from the Vensim documentation distributed by Ventana Systems (VS 1997a, 1997b)

ASTRA project to develop the ASTRA-TIP, an additional tool to present results of the tested policies (see section 4.5.4).

So, while the itthink-software provides more comfortable user-interfaces for policy testing, the Vensim-software provides more powerful mathematical tools for solving larger systems. All input/output procedures and the computation process are running much faster in Vensim compared with itthink. Furthermore Vensim includes powerful optimisation techniques to select optimal timepaths with respect to objectives defined such that, from the scientific point of view Vensim is clearly superior. The provider has announced that the next update of Vensim will include improved easy to use user-interfaces for a better control of input and output procedures. Thus this software is more appropriate for the overall ASTRA assessment.

4.3 Advantages of policy testing with ASTRA

The use of the system dynamics methodology provides several important advantages compared with traditional forecasting and assessment approaches. These can be summarised as:

- consistency,
- verifiability,
- stepwise or incremental policy implementation,
- multiple policy implementation,
- time-path indicators,
- intensity indicators and
- combination with back-casting approaches

4.3.1 Consistency of policy results

Traditional forecasting and assessment approaches abstract from the interactions between transport and impacted areas. This is inconsistent and can lead to wrong decision making. One example is induced traffic. In fixed-demand models induced traffic is neglected, in flexible-demand approaches increased traffic activities are considered that are induced by a reduced time budget for travel after a transport network has been improved. But also the flexible-demand model tells only a part of the story. The secondary impacts of better transport networks work through the change of settlement structure and can only be captured by introducing a land use/regional economy sub-module in the assessment methodology. Another example for consistency problems is that a key variable is influencing various variables in different impact areas or is influenced by these (multiple active or passive influences). In this case traditional methods tend either to an underestimation of impacts by neglecting multiple influences or to an uncontrollable double counting. A proper modelling of the dynamic feedbacks avoids these caveats and helps to generate well-balanced decision supports.

4.3.2 Verifiability of SD models

As most standard SD software packages provide similar easy-to-use graphical user interfaces (GUI) the possibility for users (e.g. decision-makers, other expert users) exists to review the structure of the complete model and to verify implemented functional relationships or the underlying assumptions consisting of the exogenous variables. The scope of this verification opportunities depends on the users equipment and the technical possibilities of the software to create executable or interpretable files. The broadest position for verification is given, if users dispose about the same standard software. However, this might imply an additional investment in the purchase of the software package. The most practicable solution is to provide users with runtime versions, which should provide the necessary capabilities for comprehensive verification but limits the ability to make changes at the model. In the case of executable files the users can only run the model and receive the results.

4.3.3 Stepwise or incremental policy implementation

SD models provide data for all included model variables over the full simulation period. Policy variables can be introduced at any point of time during the simulation. They can be changed for any time-step during the simulation. The changes at policy variables can be implemented in three ways. If only at one or two points of time a certain variable is changed, this can be done within the equation with the use of an if-then-else statement. For a policy with several changes of intensity at different points of time this can be realised with graphs (ithink) or lookups (Vensim). Furthermore policies can be fed from exogenous data files like spreadsheets (e.g. EXCEL) or software specific files. An example for stepwise policy implementation with a graph/lookup is given in figure 6:

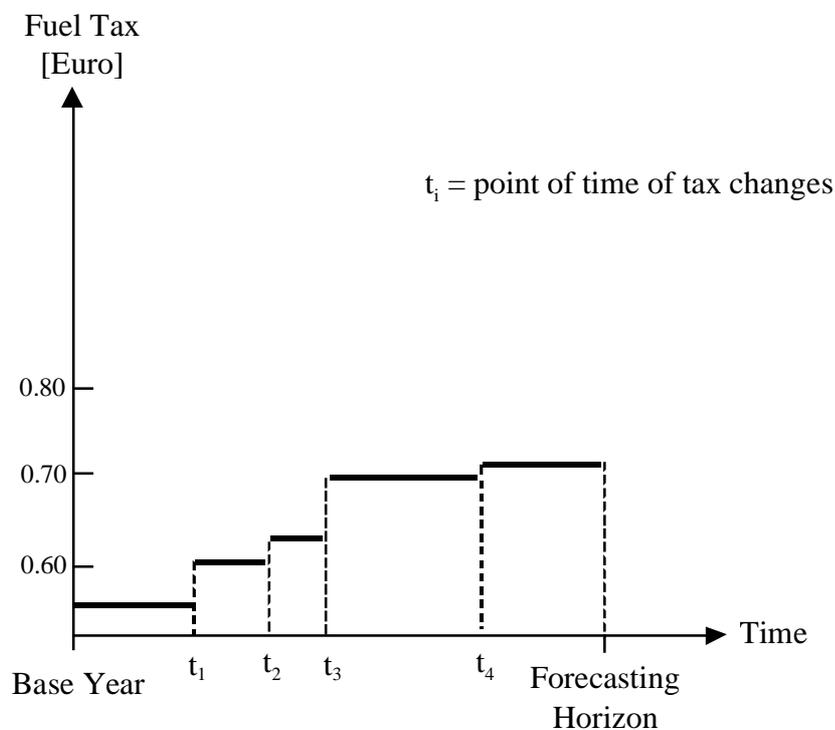


Figure 6: Example of stepwise policy implementation

However, for the demonstration examples it should not be necessary to vary the policies within the model variables or graphs itself, as these are implemented with control tools on the ASTRA Steering Panel.

4.3.4 Multiple policy implementation

The ability for multiple policy implementation means to apply more than one policy measure during one simulation run. Each policy might be implemented stepwise. This enables to check if synergies or counter-effects between the policies exist. With the knowledge on synergies different policy measures can be grouped to more effective and reasonable policy packages. By use of the control panels of the SDM software optimal policy packages can be constructed. In particular it is possible to control whether the impacts of these policies lie in reasonable range of acceptability.

4.3.5 Time-path indicators

The values of each variable are calculated for every point of time during the simulation period. Thus it is possible to present the development of indicator variables during the complete time path of the simulation, which is a big step ahead compared to point-to-point analysis where the results consist of a base year value and a forecast year value. Also for some variables a policy can cause important different effects even when the values at the forecasting horizon are the same. This happens when the aggregate values would be different. Considering for instance CO₂-emissions it makes a big difference if the aggregated CO₂-emissions of two policies differ significantly. This is shown in Figure 7, where the left diagram shows the yearly values of CO₂ emissions for a point-to-point forecast (endpoints of dotted black line) and a time-path forecast (solid grey line). Looking only at the values within the circles for the point-to-point and the time-path forecast it seems that the forecasted results are the same. However, the aggregation over time of CO₂ emissions for both approaches assuming a linear development for the point-to-point forecast leads to the black curve (point-to-point forecast) and grey curve (time-path forecast) in the right diagram. Obviously a major difference between both approaches occur, which e.g. in the case of CO₂ emissions is of high importance. The difference between the curves in the right diagram of Figure 7 can only be explained by using time-path indicators.

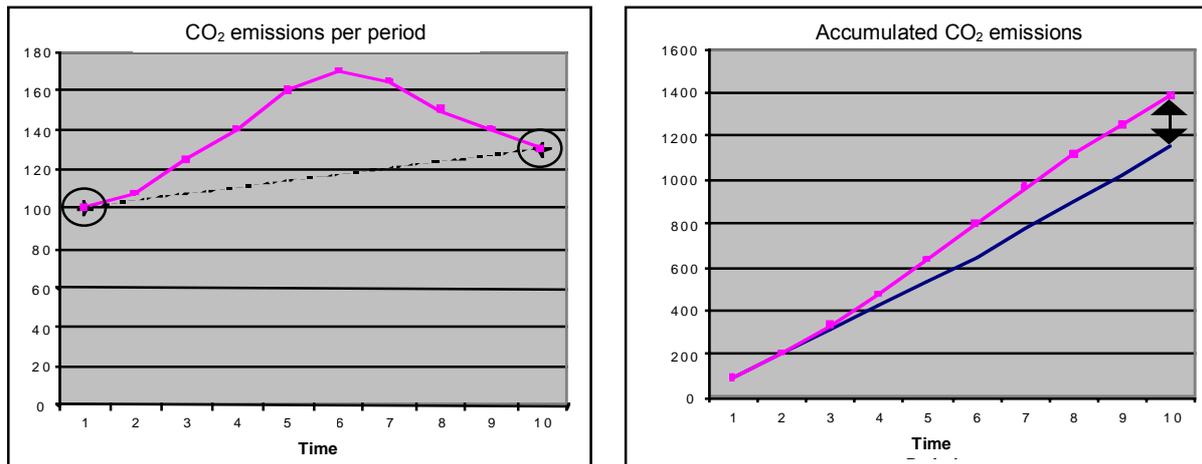


Figure 7: Different results with point-to-point-indicators and time-path-indicators

4.3.6 Intensity indicators

SD models require the quantification of all included variables. Therefore new indicators can be constructed by connecting two or more variables. In principle, this can be done with every combination of variables and any mathematical function. A reasonable approach would be to calculate intensity indicators by dividing one variable through another one. For instance CO₂-emissions from transport divided by GDP provides an important information about the CO₂-emission intensity per GDP of different policies.

4.3.7 Combination with backcasting approaches

Back-casting approaches are extremely useful tools for generating images for future states of the world. In particular the construction of a sustainable scenario for the transport sector is a challenge in itself and has led to several remarkable research activities in the fourth framework programme. One example is the POSSUM project, another example are the EST (environmentally sustainable transport) scenario constructions of the environmental directorate of the OECD. The back-casting scenarios work in a way that the sustainability scenarios are constructed on the base of safe minimum standards for the environment and the social cohesion. Then political activities are defined by backward chaining starting from the future sustainability position and ending at the present time period. This is a very useful approach, but it is clear that the series of policy measures derived by the backward chaining process is not unique and has to be tested with respect to feasibility and optimality. This can be performed by the forward chaining procedure of the system dynamics model, which constructs the future states of the world step by step and is able to control consistency, feasibility and - with some limits - optimality of the policy mix over time.

4.4 Combining ASTRA with appraisal methods

Traditionally, the assessment of policy strategies is performed by constructing an impact matrix and transforming this matrix by normalisation procedures and preference ordering into a utility scale. The impact matrix is constructed by measuring the differences between the "with" and "without" outcomes for the tested policy strategies and every decision criterion. The transformation and preference mapping procedures can be organised in form of cost-

benefit, cost-effectiveness or multi-criteria analyses. Many variants of these methods have been developed and tested in the EU research framework programmes. One of the last research activities on this field is the SAMI-project, which results in suggesting a variety of "meta-appraisal" methodologies (SAMI, 2000).

All these traditional methods have in common that the alternative policy strategies are assumed to be fixed or at least discrete. This is not necessarily realistic. It might be more challenging to assume that the policy variables are continuous and can be combined/designed flexibly. In the mathematical sense this would result in a so-called vector maximum optimisation problem.⁶ Problems of this type are closer to reality but very hard to solve optimally. Therefore simplified decision support technologies have been developed, which guide the decision-maker by means of an interactive process through the decision space. In many approaches of this type the information process is designed in a way that the influence of subjective value judgements necessary to achieve an acceptable solution is minimised. This can be done by propagating articulated preferences progressively.

The ASTRA system dynamics model is able to support both of these appraisal methodologies. If the policy alternatives are fixed then it is possible to use ASTRA for calculating the impact matrix, because many of the decision criteria are defined as variables in the ASTRA system dynamics model. For instance, the cost-benefit analysis can be based on criteria of macroeconomic sub-module, e.g. the values of national and regional income or consumption. If a meso-economic platform for benefit evaluation is preferred the ASTRA model would produce the relevant supply and demand figures for the transport sector as well as the externalities. ASTRA can also produce combined indicators from taking variables out of different modules such as for instance CO₂ per unit of GDP. Furthermore ASTRA can generate data for meta-appraisal analyses, for instance for preparing a spider-picture for depicting goal achievements in different areas. Last but not least the Analytical Hierarchy Process (AHP) of T.L.Saaty (1980) can be supported by generating the initial values for the decision matrices.

If policy variables are continuous and can be combined most flexibly it is necessary to produce a series of results in an interactive communication process between the policy tester and the model. The policy tester can construct a cross-walk through the decision space according to his own logic or can (partly) rely on the optimisation option of the model. As a model run takes only 1-2 minutes an interactive working with the model is possible as long as the user does not expect to receive a proof for an optimal solution. The latter might imply some thousands of model runs and is not the real strength of the ASTRA model. As soon as the user expects satisfying or acceptable solutions (the conditions for acceptability can be defined as thresholds) there can be powerful support generated by the model. As a result ASTRA can not only be used for constructing policy packages continuously but also to design appropriately the single policy actions over time.

Looking at the present state of the ASTRA development it is obvious that not much emphasis has been paid to the appraisal part. Therefore only a few of the options mentioned above have been implemented until now. The major work input has been invested to prepare a platform for a dynamic impact analysis, based on the detailed modelling existing in different areas. The

⁶ See for instance HWANG/MASUD (1979)

philosophy behind is – to put it a bit provocative - that a careful impact analyses often makes a sophisticated appraisal methodology unnecessary. This means that the policy maker can already by inspecting the results of the impact analyses draw the conclusion whether the depicted developments are according to his preferences or not. He can easily discover whether benchmarks or standards set for variables are met. For instance he could set up a short-list of benchmark indicators for describing sustainability and check the success of different policies tested against the benchmarks. In case that this is not sufficient ASTRA offers an open architecture to extend the appraisal part by own developments according to the preferences of the decision-maker. This option, however, is only feasible if the user owns the developer version of the VENSIM software.

4.5 ASTRA demonstration examples

The premier objective of the ASTRA project is to develop a model for strategic policy assessment, capable of identifying and analysing the long term impacts of European policy decisions, notably those related to the Common Transport Policy (CTP) and the Trans-European Networks (TENs).

In order to use the ASTRA model to predict the impact of a given set of policy scenarios, a reference scenario is designed. Each scenario, either the reference scenario or the policy scenarios, is described by a corresponding simulation run with specific changes of exogenous variables and model parameters.

4.5.1 The ASTRA reference scenario

The construction of the ASTRA reference scenario follows the approach of the SCENARIOS project and was constructed with a projection of past and current trends of key variables to the desired time horizon, assuming that during the simulation period until 2026 no break in trends occurs. *“In this way the reference scenario can provide a standard against which other contrasting hypotheses can be compared. However this does not imply that the reference scenario is the most probable future position.”* (SCENARIOS, 1998)

The sources for the definition of the ASTRA reference scenario were the SCENARIOS project, the STREAMS model reference run, which defines reference developments for several variables in REM and TRA, EUROSTAT statistics and results of research projects like MEET (HICKMAN et al., 1997) and EUFRANET (EUFRANET, 1999), the Swiss/German handbook on emission factors (HB-EFAC) (BUWAL et al., 1999), and OECD projections.

The curves in Figure 8 (development of GDP for all regions) show that, the model is focussed on long-term economic trends and does not reflect oscillations caused by short-term business cycles. The resulting development of real GDP is in line with the forecasts of long-term yearly average growth rates until 2020 in the SCENES project. Such high growth rates can be justified beyond others by the accelerated technical progress that fosters productivity caused by the new information technologies and growing market entanglement. However, as forecasted population will start to decline between the years 2004 to 2010 in the different European regions the risk of shortages of employees, at least shortages of qualified employees, arises. In this case a reduction in growth of productivity will hamper the economic growth because of a lack of labour force, that would imply that the optimistic forecasts can not be realised (In fact the ASTRA model considers immigration only as one aggregated

number for each of the functional zones. But there is e.g. no differentiation into immigrants with different skills).

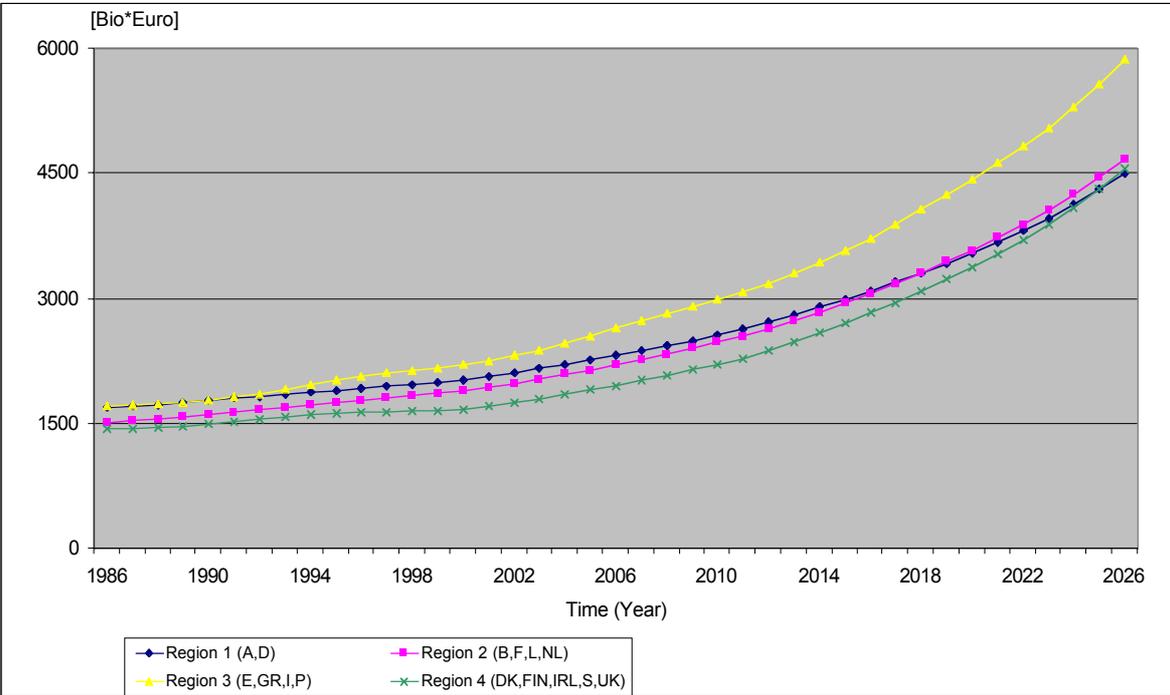


Figure 8: GDP in base scenario for all regions

Figure 9 presents the development of European population based on the structure of the functional zones. In total the decline described above leads to a slight decrease of European population after 2006.

The depicted development of population is the major influencing variable for the demand of passenger trips shown in Figure 10. Until 1998, the total trip demand increases by 0.7% per year. After this period the demand is nearly stable, which is explained by the declining population. About 75% of all trips are private trips, which is almost constant over time. The share of business trips is around 20%. Tourism trips count for about 2.5% of all trips and are slightly increasing over time.

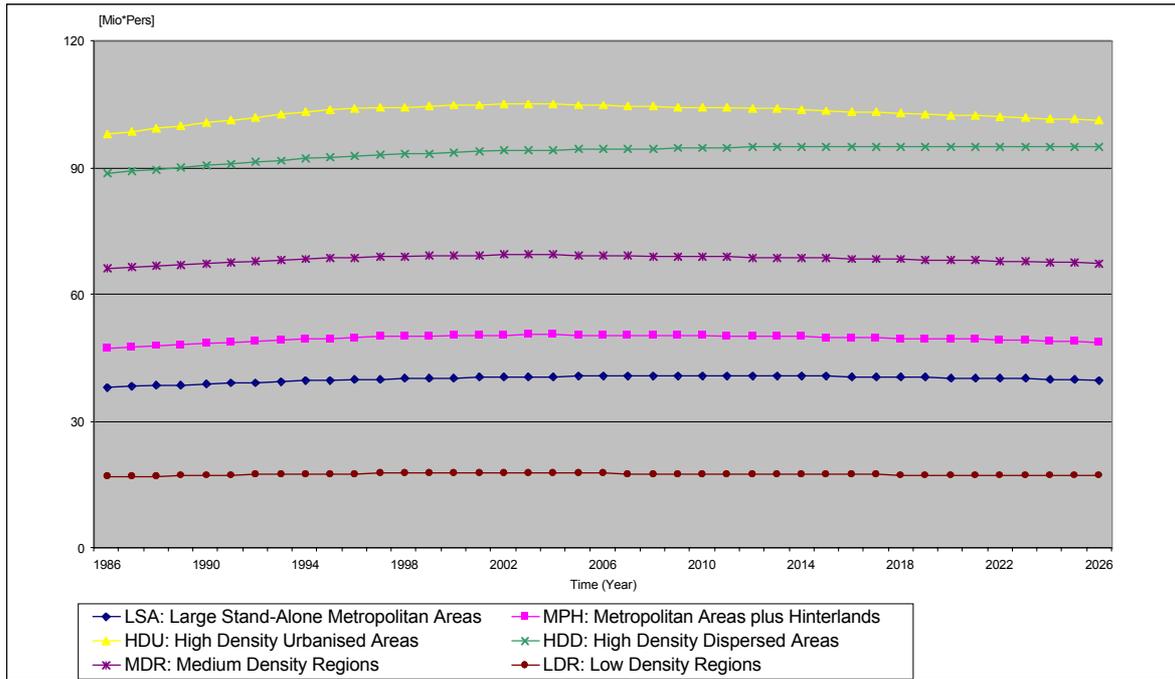


Figure 9: Total population per functional zone

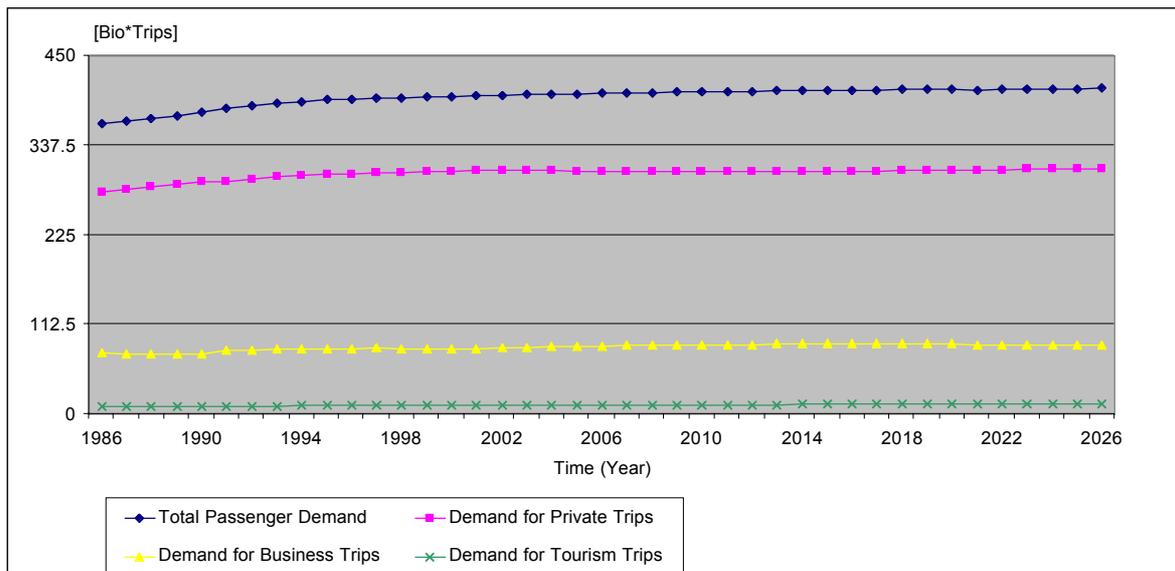


Figure 10: European demand for passenger trips

In Figure 11 the passenger modal-split related to transport performance (pkm) is depicted. It can be observed that the split of car transport is relatively stable with a plateau of 74% in the years before 2000. For bus transport the share is decreasing strongly and the share of rail transport is declining slightly. A very strong increase can be observed for the share of air transport, which is nearly doubling between 1986 and 2026. Slow mode is stable with a share of around 1%.

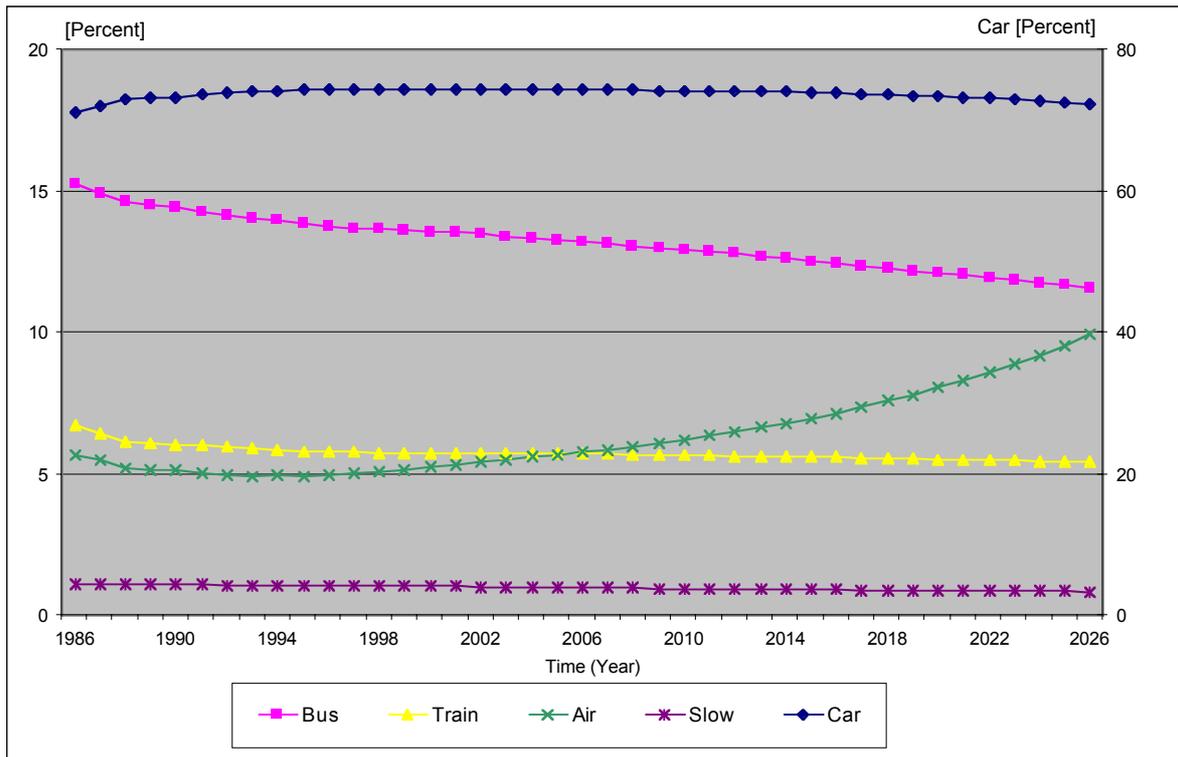


Figure 11: Passenger modal split related to transport performance in EU15 countries

Figure 12 shows the *origin* passenger transport performance (pkm) in the long distance band over 160 km for the functional zone covering the metropolitan areas plus hinterland (MPH). The notion *origin* stands for all trips starting in the MPH zone e.g. a trip from MPH zone to HDD zone would count for MPH zone.

The most interesting curve is obviously curve 4 representing air transport, which in the initial years is at the same level as bus and train mode. But around 2024, air mode has more than doubled and has even overtaken car transport. Rail mode is nearly stable, while bus mode is strongly decreasing. Car mode is increasing but it seems that the maximum level is reached around 2015.

It should be noted that the ASTRA reference scenario assumes a growth rate for the passenger value of time. Coherently with the assumptions for the STREAMS and SCENARIOS projects, this value is linked to the expected GDP growth and therefore a yearly rate of 2.6% is applied. This means that the value of time nearly doubles in the time span between 1995 and 2026, leading to a strong preference towards faster modes of transport.

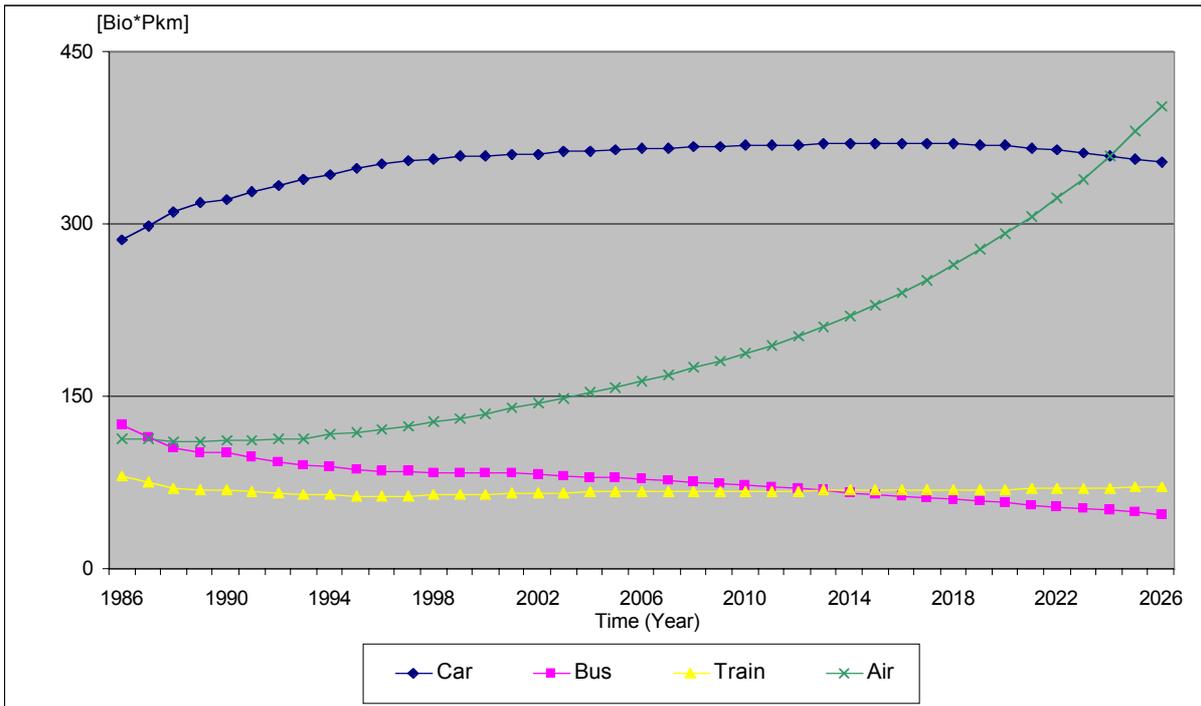


Figure 12: Yearly origin passenger kilometres per mode for metropolitan areas plus hinterland (MPH zone) in the long distance band (>160km)

Based on the previously described indicators, especially the vehicle kilometres travelled, the yearly hot NO_x-emissions per mode are illustrated in Figure 13. For all regions a strong decline of NO_x-emissions between 1992 and 2004 can be observed, which is due to the introduction of the EURO emission legislation. After 2004 minor decreases occur, which after around 2016 are followed by minor growth. It can be seen that mainly car transport contributes to the strong reduction of NO_x-emissions, while the final increase is caused by an increase of air transport and a remaining high level of truck transport.

The development for CO₂ emissions derives from factors like transport performance, occupancy factors and technical characteristics of the vehicles (emission factors). The ASTRA model predicts for all regions a slow but steady increase of the hot CO₂ emissions of all modes from driving activities.

Additionally to the hot CO₂-emissions, other quantities of CO₂ emissions are related to transport. For two of them the emissions caused during road vehicle production and during fuel production are shown in Figure 14. These production related emissions amount to about one third of the hot CO₂-emissions. The oscillations in the curves are mainly due to the purchases made for the fleets that are modelled in dependency of demand and age structure (LDV, HDV, bus). Especially the age structure that shows similar oscillating patterns too is triggering such oscillations.

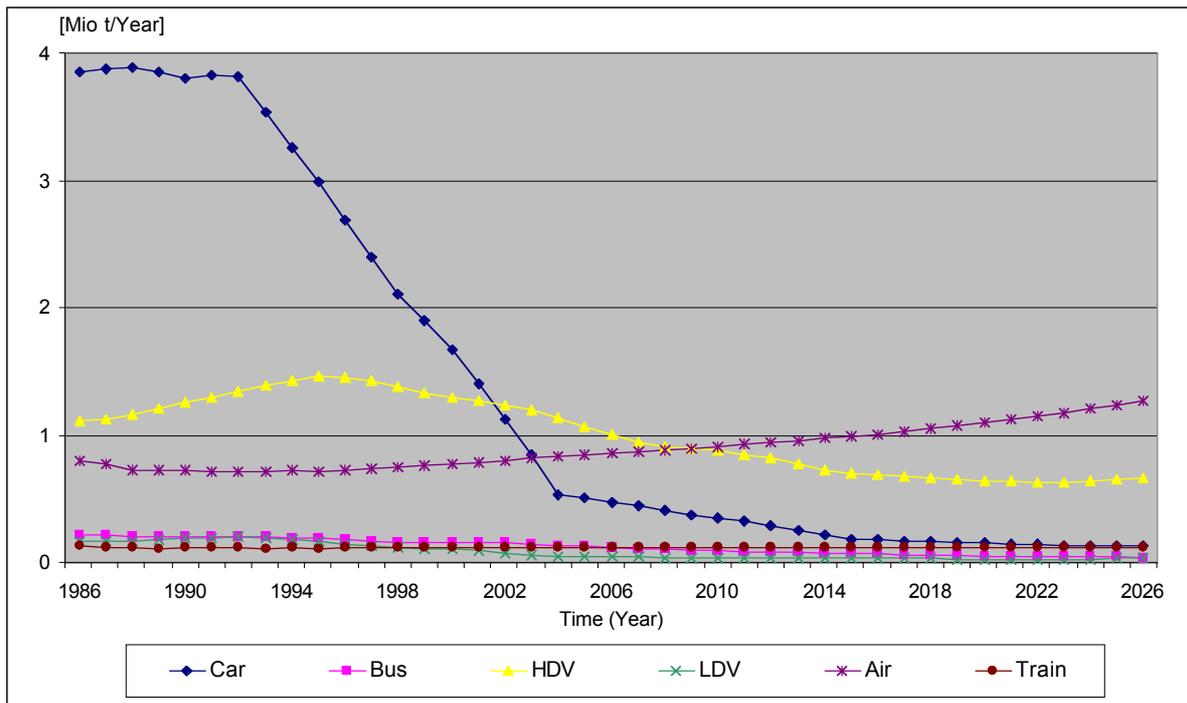


Figure 13: Hot NO_x-emission for EU15 countries per mode

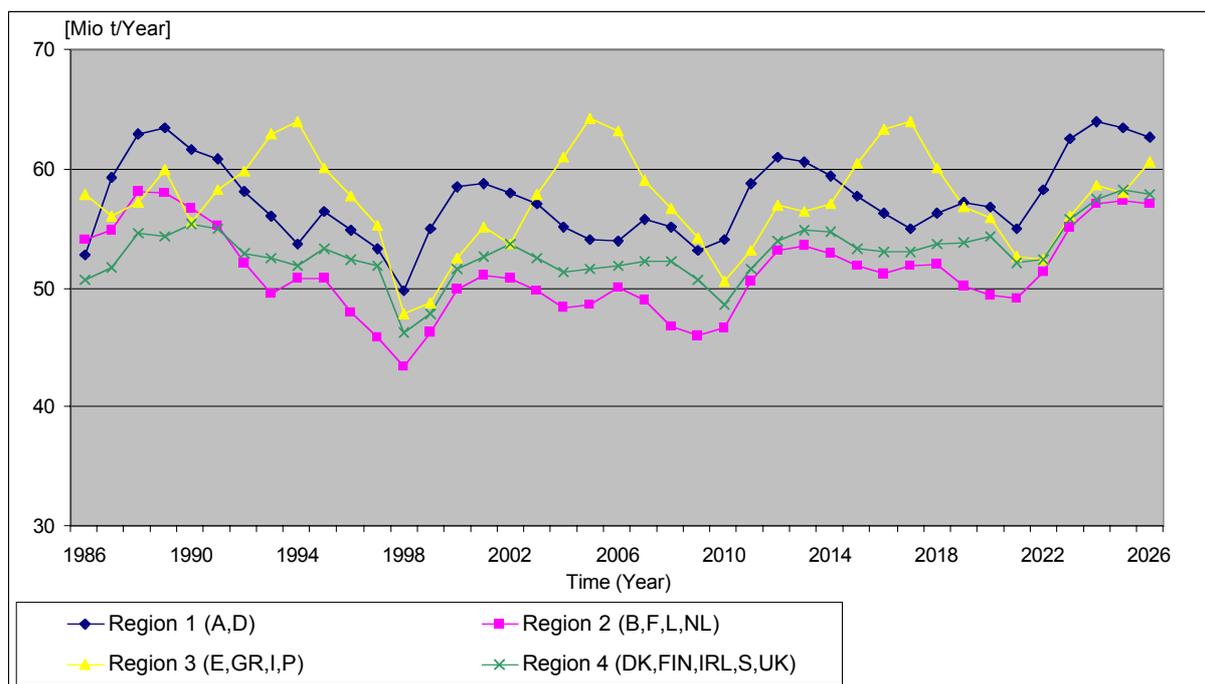


Figure 14: CO₂ emissions from road vehicle production and fuel production

4.5.2 ASTRA simulation runs for policy packages and policy programmes

By means of the ASTRA model a reference scenario, four policy action scenarios including policy packages and one scenario for an integrated policy programme have been tested. Policy packages consist of a set of single policy measures. The developed policy programme consists of the slightly adjusted policy packages. The hierarchy of policy actions and the defined policy scenarios are shown in the following figure:

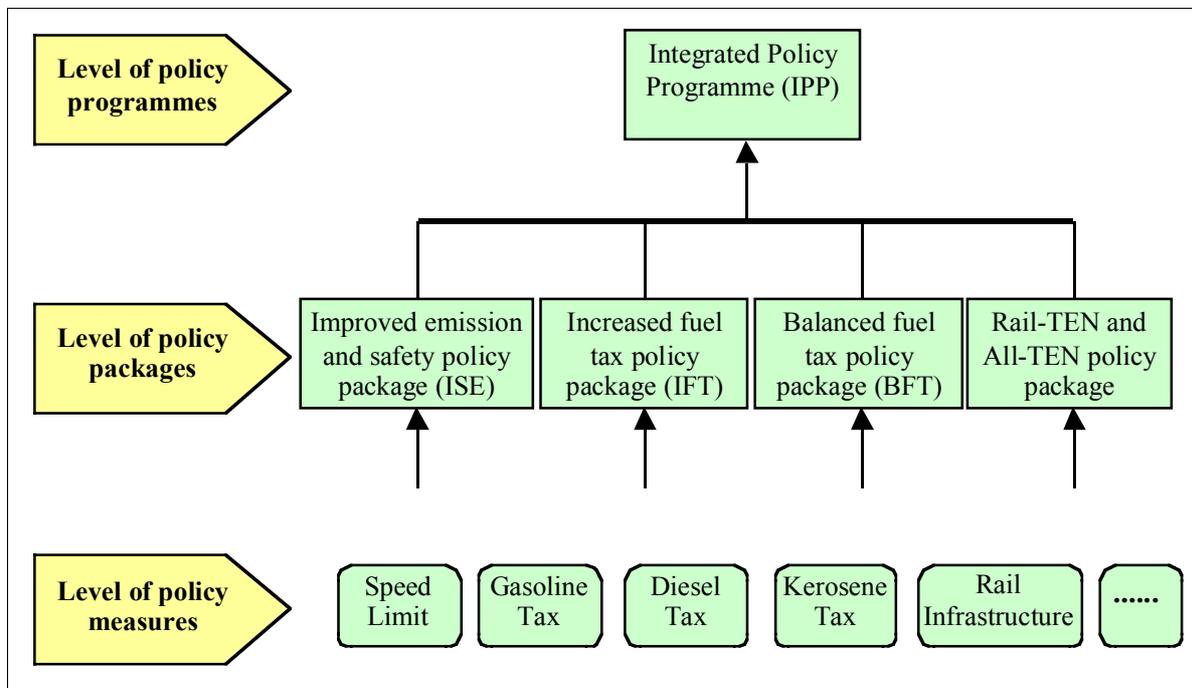


Figure 15: Structure and notion of the ASTRA demonstration examples

4.5.2.1 Policy package 1: improving safety and emissions situation (ISE)

This policy package combines three measures affecting safety and air pollution. The baseline for the safety measures comprises an enforced speed limit for the long distance road network, an increased usage of safety-belts and an enforced emission legislation by means of an anticipation (three years earlier) of the point of time when new emission standards for passenger cars come into force (EURO I-IV emission legislation, starting with the EURO II).

For the reference scenario speed limits are kept constant at the 1995 levels, while for the policies it is assumed that a maximum level of 110 km/h on motorways (90 km/h on other rural roads) for cars and 80 km/h for trucks is introduced. The safety-belt usage in the reference scenario increases only by 1% from 1996 to 2026, while it is increased from 1996 by 1% per year to reach a maximum of 98% in all four macro regions (front passengers).

This policy provides a broad range of direct and secondary effects. Direct effects in the transport system are performed by the strengthened speed limit that changes travel times, leading to changed trip distribution and modal-split in the passenger and freight model. Secondary effects then occur, e.g. because the overall demand per mode is altered with the consequence that expenditures and investments per mode are different compared to the base

scenario. The reduced speed decreases the specific emission factors in the interurban distance bands, which decreases overall emissions. This reduction of emissions is increased by the enforced emission legislation, which reduces the specific emission factors in all distance bands. Strengthened speed limit and increased safety-belt usage reduce the number of fatalities and the other adverse impacts of road accidents⁷. The reduction effects for fatalities are also influenced by trade-offs between the modes: road speed limits induce less car transport and more transport with competing modes.

4.5.2.2 Policy package 2: increased fuel tax plus reduction of labour costs (IFT)

This package is designed to generate revenues from the transport sector while the amount of additional revenues is compensated by a reduction in the direct taxation and the social protection payments of labour, such that the overall balance is neutral. The fuel taxation is imposed to diesel and gasoline fuel and thus to all road modes (gasoline and diesel cars, vans, trucks). In particular the balanced fuel tax policy adds additional tax increases from 2000 to 2010: every two years the tax rate is increased by 5% for diesel and gasoline.

The increased taxes cause additional fuel tax revenues for the government, which are used to reduce the labour costs, such that employment is fostered. In this sense the policy is similar to the green tax approaches requesting for increased energy prices and reduced labour costs to improve both employment and environment situation.

Analysing the sequence of effects caused by the tax increase, the first effect is performed on the road transport costs and is different among distance bands and purposes, according to the relative weight of fuel on perceived transport costs for passengers. The changes in transport costs affect the passenger modal split, such that especially air and rail mode become more attractive, and the trip distribution across distance bands (due to the growth in average transport costs). Therefore trips decrease in the short and medium distance bands, whereas they increase in the local and very short distance bands.

Effects on the macro side are assumed for employment and, via the links with total transport expenditures, for other macro variables like consumption. The structure of the passenger car fleet is changed as the higher fuel efficiency of diesel cars becomes more important, when fuel prices for diesel and gasoline are increasing. In total the passenger car fleet is reduced by about 2% up to the year 2020 and this has a negligible influence on employment in transport production⁸.

4.5.2.3 Policy package 3: balanced fuel tax plus reduction of labour costs (BFT)

This policy package is also designed to create a neutral taxation by increasing transport taxes and reducing labour costs. In contrast to the previous policy package (IFT), it is aimed to compensate the differences existing between gasoline and diesel taxation in many European countries. It introduces taxes for air mode of transport to compensate the taxation level between air and other competing modes of transport. Thus diesel and kerosene cost are increasing stronger than in the base scenario, while gasoline cost are kept to the development

⁷ The accident rate for all road modes is reduced by the strengthened speed limit while additionally the injury risk for passenger cars is reduced by the increased safety-belt usage

⁸ Employment in the car industry is substituted by employment in industries producing vehicles for transport services (e.g. rail waggons and planes) and that car industry employment is also depending on export, which is nearly not changing.

of the base scenario. The difference between fuel tax revenues in the base scenario and in the balanced tax policy is treated as additional revenues that are used to reduce the labour costs in the same way as explained for the increased fuel tax policy (IFT).

The increase of fuel price for diesel and kerosene in dependency of the tax increase leads to changes of modal-split and trip distribution for both freight and passenger. The strongest reaction is the slowed down increase of air transport, which changes the modal-split in the passenger long distance band. Due to the fact that only owners of diesel cars are affected by the tax increase changes for car transport are minor. This can be made clear by a comparison with the IFT policy, which revealed a noticeable decrease for car transport. The effects on rail transport are similar as the IFT policy package, though it can be stated that in the BFT policy the increase is a bit stronger.

The BFT policy has some influence on the vehicle fleet, as it reduces the share of diesel cars and this is more significant in those macroregions where the price difference initially before 2000 was higher.

In general, this policy package shows a reduced growth in GDP and in the freight transport performance. The reason of such parallel decrease can be found in a reduction in investment caused by a reduction of air transport demand (a consequence of the kerosene tax) and of road freight transport demand (diesel tax). In the ASTRA macroeconomic model, investments are driven by modal transport demand and, even though transport demand is transferred between modes, there is no complete compensation in terms of investment. This happens because the specific investment per passenger-km are much higher for air transport than for other modes of transport. Less investment implies less capital stock and then less potential output and GDP. Thus in a few years lag the growth of GDP is reduced. The feedback is closed as GDP is the main driver for freight transport generation. It is evident that there are some effects that could compensate for the reduced investment that were not treated in the ASTRA model. In reality it could be expected that air industry would invest more in order to compensate the impact of a kerosene tax policy and in this way compensating, if not overcompensating, the gap of demand driven investment.

4.5.2.4 Policy package 4: fuel taxation and investment in TEN (Rail-TEN, All-TEN)

In this policy package, the taxation level is imposed to cover the expenses for the construction of the priority projects of the Trans-European Network (TEN). The taxation approach is similar to the IFT policy package, which means that the tax is imposed on all road modes of transport. The difference lies in the use of the revenues of such funds, which will be earmarked for TEN transport investments.

This package is implemented with two options: the first option is to implement only the TEN projects for rail mode (Rail-TEN policy) and the second option is to implement the TEN projects for all modes (All-TEN policy). For both options it is assumed that the implementation takes place according to the current plans between the years 2000 and 2015. As it takes some time to construct infrastructure, lags are implemented between the investment in new infrastructure and the improvement of transport by the new infrastructure e.g. reduced travel times. Fuel taxes are raised by the same percentage for all macro regions.

The results of the two policies (Rail-TEN, All-TEN) are very interesting as they demonstrate either the dependency of the modes from each other, e.g. taking a policy action for one certain mode can have strong effects on other modes, and the time dependency of different policy actions, e.g. leading to relative advantages of a mode in an initial stage but turning around the relative advantages between two modes in the long-run. Vehicles-km travelled reflect the different pattern of price changes and infrastructure improvements in four periods after the year 2000:

- In the first period from 2000 to 2004 taxes are increased for road transport by the highest percentage of all periods: consequently road vehicle-km are reduced while air and rail vehicle-km increase compared to the base scenario.
- In the period 2005 to 2010 the road tax level is slightly reduced and the rail infrastructure is improved such that rail travel times are reduced: the two main effects are that air vehicle-km are gradually reduced close to the level in the base scenario and rail vehicle-km strongly increase.
- With the beginning of the third period from (2010 to 2015), the additional road taxes are strongly reduced while rail travel times further improve through the provision of the new infrastructure. Now, air transport at 2011 falls below the level of the base scenario, while road transport over the period approximates the level of the base scenario. Passenger rail transport is growing further and reaches in 2015 in terms of pkm an increase of about 9%.
- After 2015 car transport in Rail-TEN and base scenario are nearly identically, while air mode is further reduced and the gap between base scenario and Rail-TEN policy is widening. For rail transport the transport performance is further growing such that at the end of the simulation, rail mode gained about 13% compared to the base scenario.

With reference to freight, rail mode increases its share of the modal-split from the year 2005 onwards, when the first rail infrastructure construction is completed. In 2015 the rail modal-split is increased by nearly 4% compared to the base scenario.

The investment multipliers for the Rail-TEN and the All-TEN policies are calculated comparing the change in GDP in the final year (2026) with the overall infrastructure investment. The figures (1.57 for Rail-TEN and 1.55 for All-TEN) indicate that in the long-run both policies are economically positive. However, the value of the multipliers do not foresee an “economic bonanza”. Looking at a regional scale, some variation can be expected, as there is an imbalance of regional source of tax revenues and location of investment. E.g. for region 3 the additionally collected taxes cover only about 70% of the investments made in this region, while in other regions more taxes are collected than investments are made. This means that regional cross-subsidisation is necessary to achieve the overall results.

4.5.2.5 Integrated policy programme (IPP)

The integrated policy programme comprises most of the measures of the previously described policy packages. Only the increase of the kerosene tax to balance it with the gasoline tax and the All-TEN policy package is not integrated into the policy programme.

In terms of passenger modal-split in EU15 countries based on transport performance, car modal-split is significantly reduced by the IPP policy package. The reason is that this policy

imposes the highest tax increase (+25% for road fuel + balanced diesel tax + tax for funding Rail-TEN) and in parallel improvements for the competing rail mode. Nevertheless it seems that at the final years of the simulation the gap of car share on modal-split between base scenario and IPP shrinks, which is due to the economic improvements of the IPP increasing also income and subsequently car-ownership.

In general the integrated policy programme provides synergies between the integrated single policy packages or measures. Though it generates the highest tax revenues in a 15 years period the growth in GDP is higher than for other packages and the adverse effects of several environmental impacts (e.g. CO₂, accident fatalities) are reduced to a wider extent than for other packages.

4.5.3 The comparison of policy packages results

In this section for a set of major variables an overview of results of all policy packages for EU15 is presented. With reference to the development of GDP aggregated over all EU15 countries, three groups can be identified:

- the top group with integrated policy programme (IPP), which seems to develop synergies, Rail-TEN policy closely followed by improved emission and safety policy (ISE);
- the middle group with base scenario and increased fuel tax policy (IFT) and
- the package with the poorest performance the balanced tax policy (BFT).

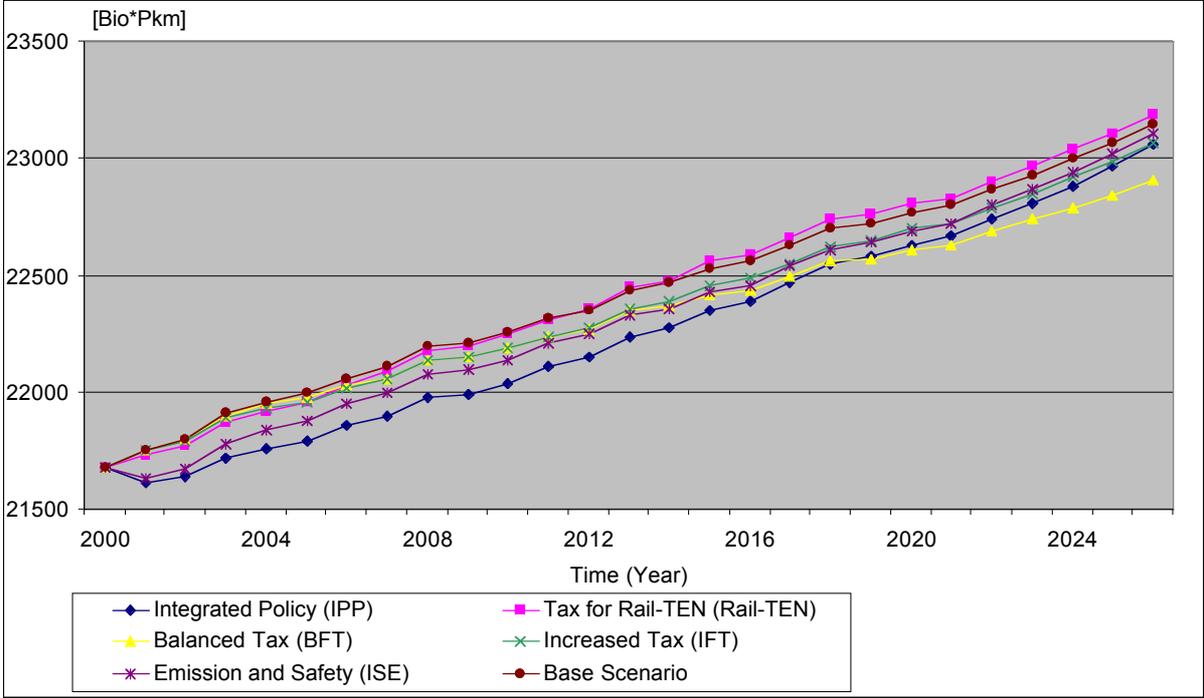


Figure 16: Passenger transport performance in EU15 countries (2000 to 2026)

Figure 16 presents the passenger transport performance for EU15. The time axis starts at 2000 as the developments until this year are nearly the same for all policies. Until 2012 the base scenario shows the highest transport performance, which is after 2014, only overtaken by the

Rail-TEN policy (rectangles/pink curve). The IFT and the BFT (crosses/green curve and triangles/yellow curve) belong in the beginning also to the top group, but over time the gap to the base scenario increases such that at the end of the simulation the BFT has the lowest transport performance.

A reason for this is surely the poorest economic performance of the BFT policy but also the fact that it is dampening the air transport growth most successfully. On the other hand the ISE and IPP (stars/lilac and diamonds/blue curve) show the biggest gap to the base scenario in the period 2000 to 2010. But afterwards they start to close the gap, for which also their good economic performance is one reason.

Similar results as for passenger transport are obtained for freight transport performance. However, for freight the three economically most successful policies (ISE, Rail-TEN, and IPP) show a higher transport performance than the base scenario already around the year 2010.

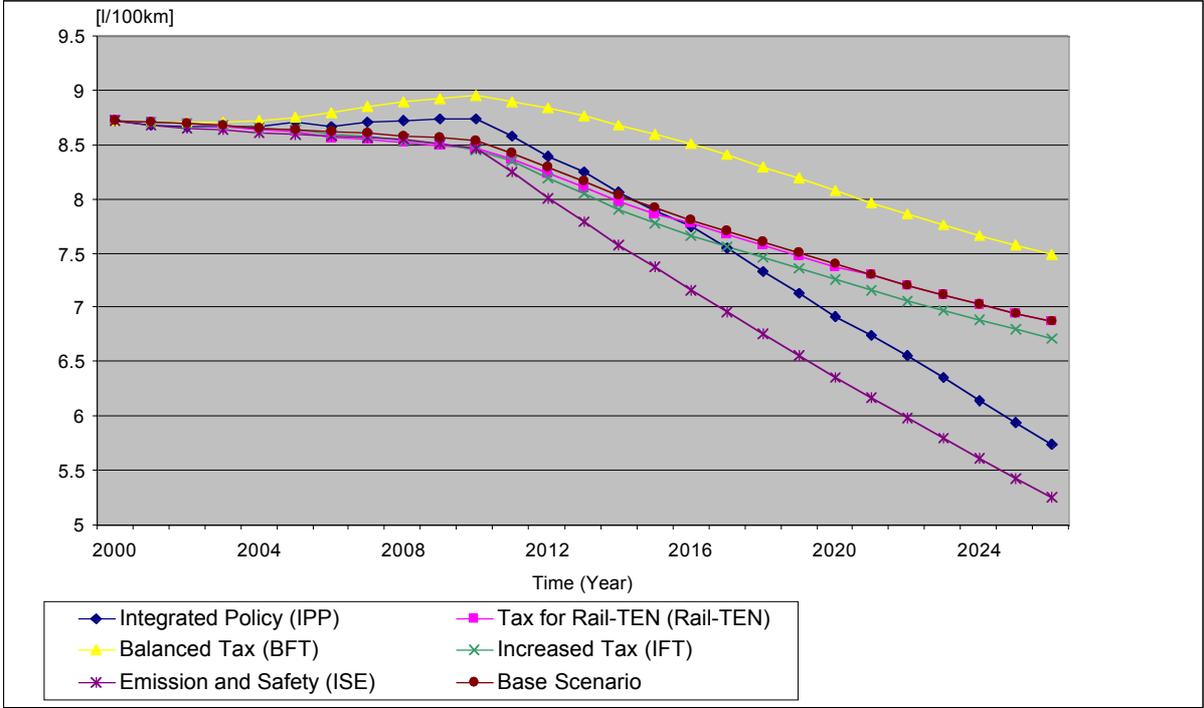


Figure 17: Average fuel consumption of gasoline cars in region 1 (A, D)

Figure 17 shows the average fuel consumption of gasoline engined cars in region 1 (A, D) from 2000 to 2026. Before 2000, the development is nearly the same for all policies. Three effects can be observed. First in ISE and IPP (stars/lilac and diamonds/blue curve) the additional reduction in fuel consumption after 2010, which is a policy measure of the ISE, leads to a significant decrease of average consumption after 2010. Second, higher fuel prices in the policies induced by the taxes provide incentives for faster technological progress in terms of increased fuel efficiency (this can especially be observed for IFT – crosses/green curve - compared to the base scenario – circles/brown curve). Third the balancing of diesel tax with gasoline tax leads to a higher average gasoline consumption as the relative share of gasoline cars with cubic capacity over 2000 cc increases in the gasoline car fleet (triangles/yellow and diamonds/blue curve). Though for IPP (diamonds/blue curve) the initial

increase by the shift from diesel to gasoline cars is overcompensated after 2015 by the technological improvements induced by the prices (IFT) and the regulation policy (ISE).

In Figure 18 the yearly transport CO₂ emissions in EU15 countries are shown. The first observation is that the base scenario produces the highest quantity of CO₂ emissions. Nevertheless, three other policy packages (IFT, BFT and Rail-TEN) also produce continuously growing transport CO₂ emissions of nearly the same quantity. Besides this high emission level group there is another group with ISE and IPP (stars/lilac and diamonds/blue curve) that shows more or less stable emissions at the 1990 level. For these policy packages it seems that the growth in transport is compensated by the taken measures in terms of emissions. It should be mentioned that the IPP produces the “low” emission quantities mainly since the ISE is part of its measures.

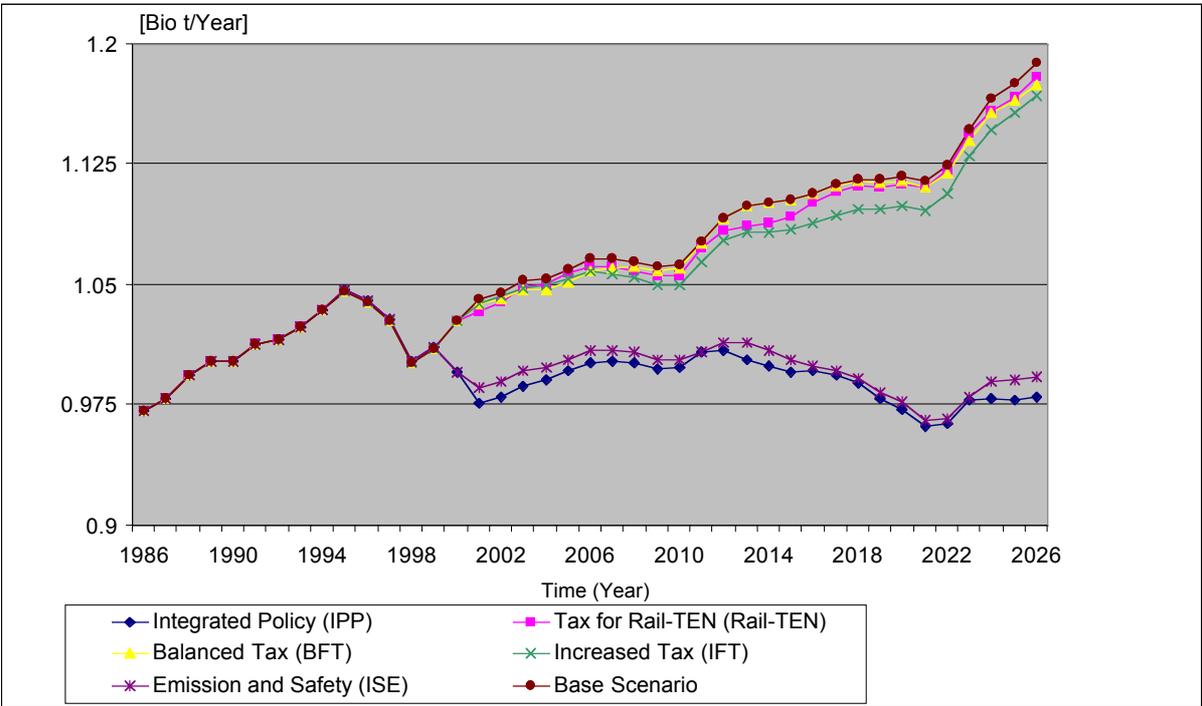


Figure 18: Yearly transport CO₂ emissions in EU15 countries

The curves in Figure 19 presenting the percentage of transport externalities on GDP for region 1 (A, D), show a similar structure for two groups. The group with the higher level again includes the base scenario, IFT, BFT and Rail-TEN, while the group with the better performance includes ISE and IPP. For all policy packages the percentage of externalities on GDP is reducing. However, this does not mean that absolute externalities are reduced over time. The reason for the decrease of the percentage is that GDP grows faster than transport externalities. The two packages with the worst situation in the final decade of the simulation are BFT and Rail-TEN. Though the reasons for this outcome are different. For BFT the economic performance is poorest such that the baseline for the relative percentage (GDP) is smaller. For the Rail-TEN economic performance is quite well compared with the other packages, but the growth in transport performance is highest driving also the externalities.

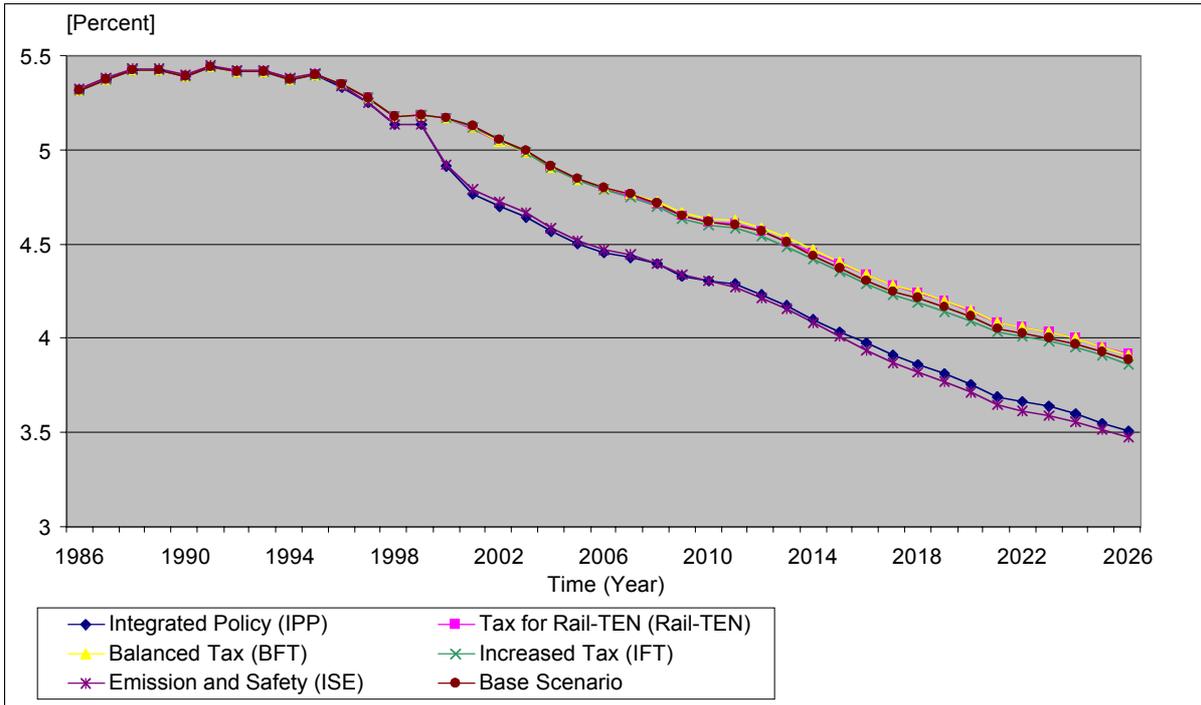


Figure 19: Percentage of transport externalities on GDP for region 1 (A, D)

Summarising, the results for the different macro regions are in general similar to the whole EU15. However, regional differences of the single policy packages can be observed. For instance in terms of GDP, three regions 1, 2 and 4 have the highest growth with the integrated policy programme IPP, while for region 3 this is realised with the All-TEN policy package. A ranking for the economically best policy is shown in Table 2.

The best performance of the integrated policy programme (IPP) in terms of GDP is obtained despite the fact that the policy generates the highest tax revenues in a 15 years period. This package is prevailing also in terms of accumulated CO₂ emissions over the period 1986 to 2026, where the ranking is the same for all policy packages, with ISE and IFT respectively in second and third position, in all macro regions.

Table 2: Ranking of policies for the different regions

	Region 1 (A, D)	Region 2 (B, F, L, NL)	Region 3 (E, GR, I, P)	Region 4 (DK, FIN, IRL, S, UK)
Ranking based on GDP				
First best policy	IPP	IPP	All-TEN	IPP
Second best policy	ISE	All-TEN	IPP	All-TEN
Third best policy	All-TEN	ISE	Rail-TEN	ISE
Ranking based on accumulated CO ₂ emissions				
First best policy	IPP	IPP	IPP	IPP
Second best policy	ISE	ISE	ISE	ISE
Third best policy	IFT	IFT	IFT	IFT

In general terms, the change of average yearly GDP growth rate over 25-30 years of policy simulation period is at maximum 0.2% between the best (IPP) and the worst (BFT) development. This seems to be a plausible range for the effect of transport policies that do not imply harsh changes of the societal and economic framework: for instance, the recent increase in oil prices over about 8 months covered a similar or even higher percentage increase than in ASTRA policy packages (where the increase takes a longer time period).

It should be added that the development of environmental effects is ambivalent. On the one hand the NO_x emissions at ground level will be reduced, coming at least very close to a sustainable level in the next decade. On the other hand the picture is less brilliant for the CO₂ emissions. Greenhouse gases emissions continue to increase for most policy packages and the best result was a stabilisation at the 1990 level for IPP and ISE, which is not enough considering the Kyoto requirements or the longer term targets of the OECD-EST project.

With reference to the development of modal split, it is important to notice that air transport is already the fastest growing transport mode and accelerates significantly its growth rate in all policies, which increase road transport costs. In some cases, as for the IFT policy, the growth counterbalance most of the environmental benefits of the reduction of road transport and leads to a development of CO₂ emissions very similar to the reference scenario pattern.

4.6 The viewpoint of policy makers

Some of the most important features for ASTRA are the stepwise and incremental policy implementation, the multiple policy package construction, the time-path indicators and intensity indicators. Looking at the constructed scenarios it becomes evident how important these features are for practical policy testing. All policies are defined as functions of time, i. e. there is not one policy, which is implemented once and remains unchanged. ASTRA allows for testing two different procedures for investigating policy packages or programs: First of all the decision maker can start with defined intensity indicators for the different policies and the associated implementation schedules over time. The simulation process for the impact analysis then runs over the defined time horizon. Scenario results can be compared with the reference scenario or with previously computed scenarios to measure the progress achieved with respect to objectives defined. This procedure characterises a *forward* calculation (forecasting). Secondly it is possible to start from a list of goals defined for a future period of time and then derive a set of measures, which move the system to this future situation with low costs and little disturbance of the regional and macro-economy. This procedure can be called *backcasting* and includes basically some type of an optimisation calculus.

ASTRA can do both. The policy maker can choose his favoured approach or apply both of them. An easy-to-handle sensitivity analysis can be used to check the stability of results and generate the most relevant figures for risk analysis.

In principle for every variable of the system time profiles are generated. Therefore the policy maker can immediately check either using forecasting or backcasting whether a policy package, which e.g. is the most effective to reduce externalities, is influencing other variables negatively, such as GDP or employment. This means that *trade-offs* between advantages and disadvantages can be developed dynamically to prepare a decision which is not in conflict to the most essential goals defined by the policy maker.

5 List of deliverables

The following table 3 presents the output of the ASTRA project. Deliverable 1 to 5, the Annex to Deliverable 4 and the Final Report are public output of the project. The ASTRA model (ASP) is available for co-operations. Additionally to these formally required output a deliverable 3a and an itthink ASTRA model was prepared, which are both not public available. Finally the ASTRA-TIP was developed, which can be used as an interface to review results of the ASTRA demonstration examples. To apply the ASTRA-TIP the Vensim Venapp licence is required, which can be purchased for less than 50 EURO from Ventana Systems.

All public output can be downloaded from the ASTRA website:

<http://www.iww.uni-karlsruhe.de/ASTRA/>.

Table 3: List of deliverables (date of approved version) and other output of the ASTRA project

Output	Date	Title	Availability
Deliverable 2	Mar 1998	Design and Specifications of a System Dynamics Model	P
Deliverable 1	Sep 1998	Review of Existing Tools	P
ASTRA WebSite	Oct 1998	Establishment of the project website by the co-ordinator at http://www.iww.uni-karlsruhe.de/ASTRA/	P
Deliverable 3a	Jan 1999	The ASTRA System Dynamics Model Platform (ASP) – Part: Passenger Transport Model	R
Deliverable 3	Apr 1999	The ASTRA System Dynamics Model Platform (ASP)	P
Deliverable 4 (Draft)	Jan 2000	ASTRA Methodology (Draft)	R
ASTRA model (ithink)	Apr 2000	ithink ASTRA model (iAM)	R
ASTRA model (Vensim)	Jul 2000	ASTRA System Dynamics Model Platform (ASP) (Including base run and 6 policy runs)	CO
Deliverable 4	Oct 2000	ASTRA Methodology	P
Deliverable 4 (Annex)	Nov 2000	ASTRA Methodology – Appendices (Annex to D4)	P
Deliverable 5	Oct 2000	Summary and Conclusions integrated as sections into D4	P
ASTRA-TIP	Nov 2000	ASTRA Tool for Implemented Policies	P, S
Final Report	Dec 2000	Final Report of the ASTRA project	P

P = public, R = restricted, S = affordable software tool required, CO = availability for co-operations

In addition to the deliverables a series of papers has been written and presented to a set of national and international conferences.

6 Results and conclusions

The final output of the ASTRA project is an operational model for the given spatial representation for which policies could be tested. This is the result of a complex process for designing, calibrating and testing the model using a common approach, the System Dynamics Modelling, by four different partners, each one with its own technical and modelling background. Obviously there are a number of points where the ASTRA model could be improved in the future and several fruitful ideas about additional feedback links and interrelationships have been raised.

Four transport policy packages and an integrated package were tested and gave interesting results for all three dimensions of sustainability: society, environment and economy. The most important points might be resumed as follows:

- The policy packages show a plausible range for their effect on economic performance: the change of average yearly GDP growth rate over 25-30 years of policy simulation period was below 0.2%.
- None of the tested “soft policy” packages is able to lead to the fulfillment of Kyoto requirements for greenhouse gases emissions: the best result is a stabilisation at the 1990 level due to the measures included in the emission and safety policy.
- NO_x emissions on ground level will be reduced coming at least very close to a sustainable level in the next decade in the reference scenarios and all policy packages.
- No further significant improvement can be identified for road accidents including fatalities.
- The integrated policy programme provides synergies between the single policy measures and generates the highest growth in GDP, but not in all four macro regions.
- Air transport growth is significant in all policy packages and in some cases it counterbalances most of the policy environmental benefits of the reduction of road transport.
- The investment multipliers for the Rail-TEN and the All-TEN policies indicate that in the long-run both policies are economically positive, even though they do not foresee an “economic bonanza”.

Summarising it can be said that the results of the ASTRA demonstration examples reveal that the model is able to simulate the implementation of policy packages consisting of policy measures that are taken at different points of time and with varying intensity.

The choice of the System Dynamics methodology allows a long-term assessment of the transport policy packages and provides inherently consistent indicators that are necessary to control the development towards a sustainable transport system. The usage of time-path indicators and the variety of provided indicators encourage a direct assessment by the policy maker without any additional assessment scheme. However, the possibilities to feed separate or to integrate conventional assessment schemes like cost-benefit or multi-criteria analysis are excellent.

7 Acknowledgements

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