ASSIST

Assessing the social and economic impacts of past and future sustainable transport policy in Europe

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ASSIST

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Co-ordinator:

Fraunhofer-ISI

Fraunhofer Institute Systems and
Innovation Research, Karlsruhe, Germany
Dr. Wolfgang Schade

Partners:

FÖMTERV

Mernoki Tervezo ZRT, Budapest, Hungary

CNRS-LET

Centre National de la Recherche Scientifique, Lyon, France

NEA

NEA Transportonderzoek en – Opleiding BV, Zoetermeer, The Netherlands

ProgTrans

ProgTrans AG, Basel, Switzerland

TRT

Trasporti e Territorio SRL, Milan, Italy

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1 Introduction

The ASTRA-EC model is a simulation model at the European level for the strategic assessment of transport-related policies.

ASTRA-EC follows the approach of the ASTRA (ASsessment of TRAnsport Strategies) model[1], currently the strongest tool when it comes to the integrated assessment of transport strategies in Europe. The strength of ASTRA is that no other tool with this level of integration of transport – environment – technology – economy exists on European level. Other tools provide more detail in their specific fields (e.g. TRANS-TOOLS for transport), but without considering one or more of the other elements present in the ASTRA model.

Therefore, the design of the ASTRA-EC model builds on more than 10 years experience of applications for strategic policy assessment in the transport and energy field. The specific features of ASTRA-EC are designed to focus the model on the needs of the ASSIST project and to improve the user-friendliness of the tool. Namely, ASTRA-EC is characterized by the following main features.

- Firstly, ASTRA-EC allows users to analyze the social impacts of policies. Several variables reflecting mobility and consumer patterns in the field of transport are segmented by social groups differentiating people according to their income, age, gender and household type. This enables a detailed analysis of transport policy impacts on social groups.

- Secondly, ASTRA-EC is more detailed than ASTRA from a geographical point of view. A disaggregation into NUTS I or even into NUTS II zones is introduced. One particular advantage of this level of detail is that the linkage with other European tools is more straightforward.

- On this respect, ASTRA-EC is explicitly designed to enable a linkage with TRANS-TOOLS, but also with POLES and to take into account of a reference database like ETISplus. This linkage is meant in terms of data exchange. Therefore, key model components (e.g. transport modes, zoning system, trip purposes) are segmented taking into account the definitions used in the other tools, in order to ensure the consistency during the data exchange process. Also, the "interface variables" between ASTRA-EC and the other models are identified. Interface va-

1 A comprehensive description of the ASTRA model is provided in [Schade 2005] and [Krail 2009]. Documentation on the model and its application is available on the website http://www.astra-model.eu/.

riables are either variables whose values can be taken exogenously from the other models or variables whose values can be provided to other models as exogenous input.

- Furthermore, ASTRA-EC is designed to be more efficient in terms of model size and of computational power required than ASTRA. Although the model is large, unnecessary details or variables that have accumulated in ASTRA over the years are cleaned and several structures are redefined to save memory requirement.
- Finally, while ASTRA is a proprietary model accessible only by experienced users, ASTRA-EC is conceived as a tool that can easily be transferred to the European Commission and run by external users. The model is accessed through a user interface in which several leverages can be set to simulate policy scenarios and output can be read and compared in graphical or tabular format and exported for further analysis. The model documentation includes a user guide to learn easily how to use the tool, simulate scenarios, change exogenous input and so on.

In this deliverable, the features of the ASTRA-EC model are outlined. The primary goal is to make clear the basic principles used to design the model, the role of each component and how they are linked to each other (section 2). Also, the scope and the level of detail of the model are presented. Specific attention is paid to the main input data and the policy leverages available (section 3) and the main output (section 4). A specific aspect related to input and output data is the linkage between ASTRA-EC and TRANS-TOOLS, this aspect is discussed in section 5. Section 6 addresses the model calibration in terms of which type of data will be used and which results will be compared. Finally, section 7 provides an example of how the user interface might look.

2 The structure of the ASTRA-EC model

2.1 The modelling approach

The ASTRA-EC model is based on System Dynamics methodology. System Dynamics does not focus on the analysis of specific fields like economy or transport, but is a general methodology that can be applied to any kind of system meeting some basic conditions. In brief, a System Dynamics model consists of a set of hypotheses on the relationship between causes and resulting effects. Hypotheses may be based on theory or only informed by theory, but empirical inputs from statistics, surveys or other observations may also be used.

Relationships are represented by equations that are written and solved by mathematical simulation. In other words, a System Dynamic model does not have a specific set of unknown parameters or variables whose value is estimated as a solution of the model. Instead, most of the model variables change dynamically over time as an effect of the interaction of positive or negative feedback loops. This can be considered as the most important characteristics of any complex systems. System Dynamics models consist of three main types of variables: level, flow and auxiliary variables. The state of a variable is mainly calculated within level variables changed over time by inflows and outflows that are driven by auxiliary variables. Mathematically, level variables are solved with differential equations. Since, the solution of a system with a set of level variables is too complex, an approximation is applied by solving only the related difference equations. Nevertheless, the mathematical calculations in a large scale System Dynamics model like ASTRA-EC are challenging and demanding on the computational equipment.

As opposed to computed general equilibrium models, reaching a steady state or equilibrium in each stage of the simulation is not foreseen in System Dynamics models. Dedicated software allows the development of System Dynamics models concentrating on the causal relationships by means of intuitive graphical interfaces.

The ASTRA-EC model is therefore focused on the investigation of functional cause-and-effect relationships between the systems represented (transport, economy, environment) and connected through several feedback loops. The model is developed using Vensim® software.

2.2 Overview on the ASTRA-EC modules

The model covers the time period from 1995 until 2050. Results in terms of main indicators are available on a yearly basis via a user interface. Geographically, ASTRA-EC covers all EU27 member states plus Norway and Switzerland.

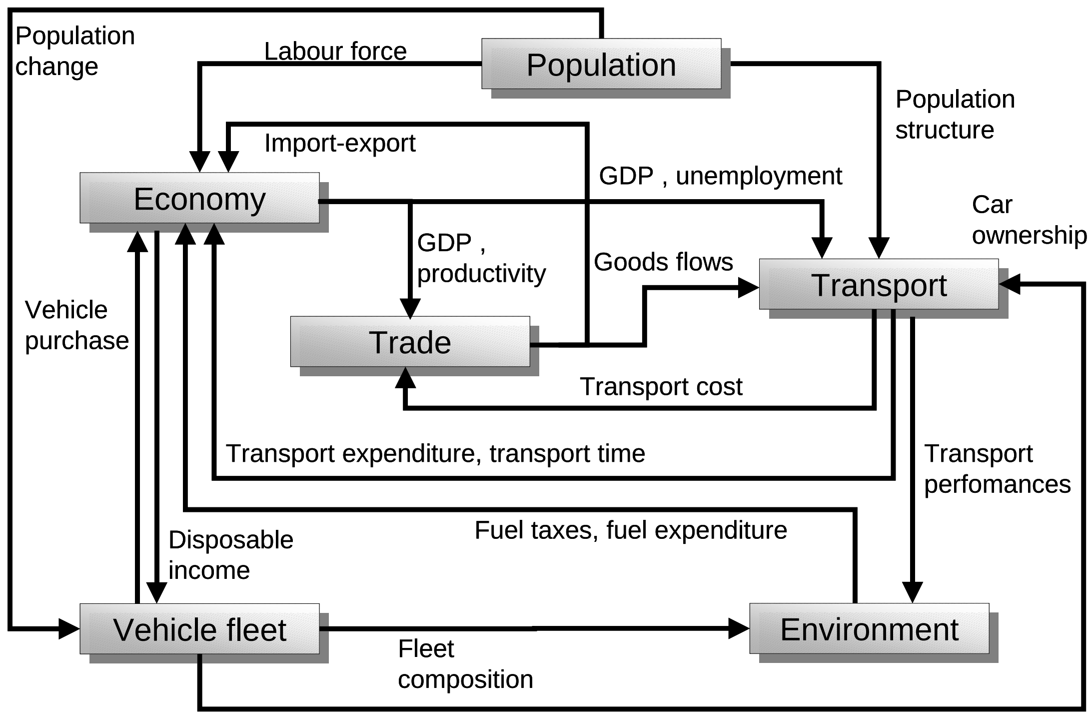
ASTRA-EC consists of different modules, each related to one specific aspect, such as the economy, the transport demand, the vehicle fleet. The main modules cover the following aspects:

- Population and social structure (household types and income groups),
- Economy (including input-output tables, government, employment and investment),
- Foreign trade,
- Transport (including demand estimation, modal split, transport cost and infrastructure networks)
- Vehicle fleet (road),
- Environment (including pollutant emissions, CO_2 emissions, fuel consumption).

A key feature of ASTRA-EC as an integrated assessment model is that the modules are linked together. Changes in one system are thus transmitted to other systems and can feed-back to the original source of variation. For instance, changes in the economic system immediately feed into changes of the transport behavior and alter origins, destinations and volumes of European transport flows. In turn, via some micro-macro bridges (see below), the changes in the transport system feed back into the economic system e.g. adapting the consumption behavior of households or the sectoral interchange of intermediate goods and services.

Since all modules are part of the same dynamic structure, the whole model is simulated simultaneously. The most appealing consequence is that there is no need of iterations to align the results of the various modules. All parts of the model are always consistent to each other throughout the whole simulation.

An overview on the modules and their main linkages is presented in the following Figure 2-1. The following table summarise the main differences between ASTRA-EC and ASTRA model and the changes required to simulate social impacts in each module. A short description of the modules is then provided below, in the following paragraphs.



Source: TRT / Fraunhofer-ISI

Figure 2-1: Overview on the linkages between the modules in ASTRA-EC

Table 2-1: Recoding plan of modules of the ASTRA-EC model

Module	**Structural changes (vs. ASTRA)**	**Change for social impacts**	**Change for linkage with TT**	**NUTS2 variables**
Transport	Yes (zoning system, distribution, mode split)	Yes (zoning system, income)	Yes (zoning system, matrices)	Yes (key result indicators)
Economy	No	Yes (income)	No	No
Trade	Yes (sectors)	No	No	No
Population	Yes (zoning system, income)	Yes (zoning system, income)	No	Yes (population, age cohorts)
Vehicle fleet	Yes (influence of income)	Yes (influence of income)	No	No
Environment	Yes (pollutants)	Yes (income)	No	No

Source: TRT / Fraunhofer-ISI

2.2.1 Population module

The population module simulates the demographic development for the 29 European countries covered in ASTRA-EC, including information on age structure, gender, household type and income group (see paragraph 2.4.1). Hence, important information is provided as input for the other modules (economy, transport and vehicle fleet). Socio-demographic indicators like the number of persons in different age classes are important drivers of the economy. The differentiation of the population according to the above mentioned attributes provides valuable information for the generation of transport as it allows different mobility patterns to be taken into account.

There are two different options for the ASTRA-EC population module: The first option would work with exogenous inputs in terms of population on national, NUTS I and II level per age cohort. This would further optimize the model size. The second alternative consists in an endogenous population model on different spatial level that is driven by exogenous inputs like the fertility rate and migration. Household structure and income distribution will in both versions be modeled as far as possible endogenously. Hence, ASTRA-EC will provide a more detailed spatial differentiation (at NUTS I and NUTS II level) and segmentation (by gender, household structure and income group) compared with the previous ASTRA model.

2.2.2 Economic module

The economic module provides the national macro-economic framework. It consists of various elements, including the economic interactions between several economic sectors, demand-supply interactions, employment as well as the four major components of final demand: consumption, investments, exports-imports and the government consumption. The economic module in ASTRA-EC contains neo-classical elements like Cobb-Douglas production functions as well as Keynesian elements, e.g. the dependency of investments on consumption and other influences like exports. Moreover, also characteristics of Endogenous Growth Theory can be found within it, e.g. the dependency potential output on technical progress in terms of total factor productivity. Furthermore, the economic module also shows attributes of an econometric model. The main output indicator of the MAC module is the gross domestic product (GDP) per country. In contrast to computable general equilibrium (CGE) models, the GDP is driven by the demand and supply side of an economy.

The supply side model reflects influences of three production factors: capital stock, labour and natural resources as well as the influence of technological progress that is modelled as total factor productivity. Endogenised Total Factor Productivity (TFP) depends on investments, freight transport times and labour productivity changes. Investments are affected by a major positive loop as investment increase capital stock and total factor productivity (TFP) of an economy, leading to growing potential output and GDP that, in turn, drives disposable income and consumption feeding back to an increase of investments. However, this feedback loop could also be influenced by other interfering loops that would break the growth tendency:

- The existence of the ‘crowding out’ effect is considered in ASTRA-EC. Therefore, increasing government debt could provide a negative impact on investment.
- Exports, e.g. influenced by growing transport cost, could decrease which can inducing a reduction of investments.
- Changes in transport demand per mode, e.g. modal-shifts due to policies that would shift demand from modes with high investment needs to modes with low investment needs per unit of demand can also reduce investments.
- Different growth rates between the supply side (potential output) of an economy and the demand side (final demand) change the utilization of capacity. In case of demand growing slower than supply utilization would be reduced affecting also the investment decisions. Finally that would lead as well to a decline of investments.

Another element of the economic module is constituted by the employment model that is based on gross value added as output from input-output table calculations and labour productivity. Final demand per sector is the result of private household consumption, investment, exports and government consumption. Both consumption and investment are distinguished between their private and public component and are segmented into several economic sectors. In the calculation of final demand there are various “micro-macro bridges” considered. These provide a link between results at the “micro” level produced mainly in the transport and vehicle fleet module and macro-economic variables. For instance, the expenditures for bus transport or rail transport of one origin-destination pair (OD) become part of final demand of the economic sector for inland transport within the sectoral interchange model.

Thanks to the “micro-macro bridges”, the ASTRA-EC model has the advantage that feedback loops, which commence on the micro- or meso-level in one of the modules and then end up with an effect on the national level can influence the originating module such that the feedback loop is closed. In the example above, transport expenditures in the transport module produce changes in sectoral consumption and GDP at national level: closing the feedback loop therefore implies to establish either macro-micro bridges (e.g. from GDP and sectoral output to goods flows) or vice versa micro-macro bridges (e.g. from transport investments into vehicle fleets to overall investments).

The main micro-macro bridges link:

- Passenger transport and sectoral consumption
- Transport and sectoral investment
- Transport and sectoral employment
- Freight transport and total factor productivity
- Transport and intermediate inputs of input-output tables
- Transport and exports.

Also government revenues and expenditures are differentiated as far as possible into categories that can be modelled endogenously by ASTRA-EC and one category covering other revenues or other expenditures. Categories that are endogenized comprise e.g. VAT and fuel tax revenues, revenues of transport charges, transport investments.

Intermediate demand is modelled by means of an explicit Input-Output mechanism which describes the technical coefficients between the economic sectors.

The economic module provides several important outputs to other modules. The most important one is Gross Domestic Product (GDP). This is for instance required to calculate sectoral trade flows between the European countries. Other examples are employment and unemployment representing two influencing factors for passenger transport generation. Sectoral production value is driving national freight transport generation. Disposable income exerting a major influence on car purchase affecting finally the vehicle fleet module and even passenger transport emissions.

In general, the approach and the variables of the economic module are the same as in the ASTRA module, with a as far as possible further differentiation in terms of income groups for private household consumption. Due to significant differences in consumption between lower and higher income groups, the consideration of income distribution will increase the quality of this module. It allows furthermore identifying possible transport policy impacts on essential consumption like for housing, energy, food and mobility.

ASTRA initializes in the year 1990 while ASTRA-EC will start in 1995. This requires a time-consuming update of the supply and demand-side sub-modules in the economic module. Especially the adjustment of the sectoral interweavement module is challenging, as the input-output tables need to be adjusted to the latest available tables for each country.

2.2.3 Trade module

The trade module includes two parts: one for intra-EU trade and the other for EU to rest-of-the-world (RoW) trade. The intra-EU trade model depends on endogenous and exogenous factors. Averaged generalized cost of passenger and freight transport between the countries is one of the endogenous factors, acting as accessibility indicator for transport between the countries. The difference between labor productivity per sector and GDP of importing and exporting country is another driver of intra-EU exports. The intra-EU model provides the input for international freight generation and distribution within the transport module

The EU-RoW trade model is mainly driven by relative productivity between the European countries and the rest-of-the-world regions. Since, transport cost and time are not modeled for transport relations outside EU29 transport is not considered in the EU-RoW model. The modeling approach in the trade module of the ASTRA-EC model differs only marginally from the ASTRA model. The request for making ASTRA-EC robust and the spatial extension of the transport module can be compensated by aggregating service sectors and less important manufacturing sectors. The aggregation is carried out by analyzing in a first step the share of the 25 economic sectors implemented in ASTRA on total exports. Hence, less important sectors are clustered, which does not lead to a decreasing quality of the foreign trade module.

2.2.4 Transport module

The transport component of the ASTRA-EC model consists of adapted classical 4-stage transport models both for passenger and freight transport. While the first three stages – generation, distribution and modal split – are modeled state-of-the-art in a detailed way, the last step – the assignment stage – is not modeled in ASTRA-EC, due to the geographical scope implemented. The linkage with network models (e.g. TRANS-TOOLS) allows for taking into account this last step indirectly.

The model considers endogenous reactions in all four stages i.e. there is no fixed generation and no fixed OD matrix. It adjusts the estimation of the generation, distribution and modal split phases on the basis of parameters differentiated by demand segments.

Namely, passenger trip generation is performed individually for each NUTS II zone, applying trip rates to several population groups based on employment situation, age and income group. Generated passenger demand evolves over time depending on population size and structure, whereas trips rates are generally kept as fixed[2] even if they can change over time for some countries (e.g. new member states facing economic growth).

Passenger trip distribution is the result of a progressive breakdown of generated demand. At first, travel demand is distinguished between intra-NUTS II and extra-NUTS II trips. Then, intra-NUTS II trips are further divided into local, very short, short trips. Extra-NUTS II trips are allocated into three categories: national, European and intercontinental trips (see paragraph 2.5.1 for further details). The allocation depends in each step on the dimension of the NUTS II zone (in terms of population), modified over time via elasticities with respect to the variation of two main aspects: generalized cost and an attractor indicator (differentiated by purpose).

The modal split process is calculated separately for each spatial domain (intra-NUTS II local, intra- NUTS II very short, etc.). Despite logit is the most widely used algorithm for mode choice, in ASTRA-EC a different solution is chosen. Direct and cross elasticities to cost variation and time variation (implemented separately) are used. Additional elasticity parameters can be implemented to reflect the contribution of other significant determinants of modal split. For instance, a specific parameter related to the increase of car ownership can be used for those countries where a huge increase of the motorization rate, starting from current low values, is observed.

The choice of elasticities rather than a logit formula is motivated by an improved robustness and a better control of the model behaviour. The experience in applying the ASTRA model as well as from other models has taught that an aggregated level of analysis requires to use rough values of average times and costs by mode. Such average values are often too coarse measures of the relative competitiveness of transport modes. Therefore, calibrating observed modal shares (which are the results of sometimes very different choices on detailed routes) can be demanding. The calibration of a reasonable sensitivity of the modal split algorithm can be even more challenging. Sensitivity to changes is the most relevant feature for a model that should be able to measure the impact of alternative measures. Using elasticities makes the reactions of the model more consistent to expectations.

For freight transport, the demand is generated and distributed on the basis of international freight transport flows (in monetary terms) and to the value of production at na-

2 Travel surveys show very similar values for total yearly or even daily total mobility across different geographical areas and over time. See for instance Metz, 2008.

tional level for different goods categories (provided by the economic and trade modules). The transfer into volume of tons is performed by applying value-to-volume ratios.

Freight demand distribution is the result of a progressive breakdown of generated demand, with the same approach of passenger demand (see paragraph 2.5.1 for further details).

The simulation of freight modal split is also based on the application of direct and cross elasticities to cost variation and time variation likewise passengers.

As mentioned in paragraph 2.2.2, transport expenditures influence the economic module in terms of variation of consumption patterns, while changes in transport times and costs are transferred to the trade module such that they can influence the exports at intra-EU level. As a consequence, impacts are transferred to total factor productivity and aggregate demand as well.

With respect to the ASTRA model, ASTRA-EC will provide a more detailed spatial differentiation (at NUTS I and NUTS II level) and segmentation (partly by income group) of transport demand; in addition, despite a classical 4-stage transport model is applied as in ASTRA, the methodology is consistently modified, in line with the different geographical dimensions implemented.

2.2.5 Vehicle fleet module

The vehicle fleet module simulates the development of the stock of road vehicles in terms of overall size and composition. The most detailed segmentation is modeled for cars, while other road modes – buses, light-duty vehicles and heavy-duty vehicles are more aggregated (see paragraph 2.5.4).

The common structure implemented for road vehicles (car, light-duty vehicles, heavy-duty vehicles and buses) is characterized by a feedback between new vehicle purchases per year, the number of vehicles of the stock, the scrapping of vehicles per year and a generated demand regulating the change of vehicle fleets and the replacement of scrapped cars and, therefore, the new registered vehicles per year.

The purchase of new vehicles forms an input to the economic module in the sector vehicle production. New cars purchased by private households are accounted to private household consumption while the purchase of business cars is assigned to investments. The vehicle fleet composition together with the transport performance drives the estimation of fuel consumption, greenhouse gas and pollutant emissions.

As opposed to the other road vehicle fleet models, new car registrations depend on several social and economic factors like the development of average income, of the demographic structure and of average prices for buying and operating a car. ASTRA-EC will also consider the income group dynamics as a driver of new car registrations. E.g. an increasing share of population in lower income groups means a stronger saturation of new car sales. New registrations of HDV, LDV and buses are driven by the development of transport performance. Assuming an average mileage per year the required number of vehicles is derived and the need for new vehicles calculated.

Based on the year of first registration all road vehicles are assigned with a pre-defined probability to an emission standard. Furthermore, the car fleet model distinguishes between different technologies. The following car categories are considered in the car technology choice model:

- Gasoline cars (incl. mild hybrids),
- Diesel cars (incl. mild hybrids),
- Compressed natural gas (CNG) cars,
- Liquefied petroleum gas (LPG) cars,
- Bioethanol (flexi-fuel) cars, i.e. cars that can run on 85 % bioethanol (E85),
- Advanced hybrid electric vehicles,
- Battery electric vehicles, i.e. smaller cars running in battery-only mode and
- Hydrogen fuel cell vehicles.

The technology choice in the ASTRA-EC car fleet module is driven by the development of variable and fixed costs for operating and owning an average car with one of the covered technologies. In order to take into account the density of the filling station network for different fuel types, so-called procurement costs are estimated and added to the average costs per vehicle-km for each car technology. Finally, a logit function is implemented to simulate the probabilities of the choice of a certain technology. Hence, new purchased cars are differentiated by emission standard and the car technology.

ASTRA-EC considers the average income as one of the most important drivers of new car registrations. ASTRA-EC calculates the average income per country using the national accounting framework starting from GDP. Hence, growing GDP leads ceteris paribus to increasing average income. The previous ASTRA model does not distinguish between income groups and therefore all adults are assumed to have growing income when the average income is increasing. An exogenous dampening factor needed to be implemented to control the growth of motorization, especially in countries with high economic growth. ASTRA-EC replaces this exogenous factor by using the information from the income distribution model. In ASTRA-EC, the upper limit of motorization is estimated by analyzing the potential numbers of car owners based on the different income groups.

2.2.6 Environmental module

The environment module uses input from the transport module (in terms of vehicle-kilometers-travelled per mode and geographical context) and from the vehicle fleet module (in terms of the technical composition of vehicle fleets), in order to compute fuel consumption and greenhouse gas and pollutant emissions from transport. ASTRA-EC will simulate annual emissions for CO_2, NO_x, CO, VOC and $PM_{2.5}$. Currently, average fuel consumption and emission factors are used and derived from HBEFA 3.1[3] for road transport and from other sources for rail, ship and air transport. Emission and fuel consumption factors from HBEFA 3.1 are in line with those factors from COPERT IV.

Tank-to-wheel CO_2 emissions depend directly on fuel consumption. ASTRA-EC also estimates the upstream emissions (well-to-tank) due to fuel production and vehicles production. Therefore, well-to-wheel emissions can be provided on top.

The monetary values for the estimation of the economic value of CO_2 and pollutant emissions reduction are taken from the “Handbook on estimation of external costs in the transport sector” (IMPACT D1), and are fed into the model as exogenous data. Therefore, existing values can be replaced with alternative data sources or updates.

In principle, the environmental module of ASTRA-EC follows the same approach of the ASTRA model. Nevertheless, the possibility of replacing the emissions factors and monetary values is an enhanced feature of the module. Furthermore, ASTRA-EC will enable the differentiation of emissions by income group.

2.3 Geographical scope and zoning system

Different levels of spatial categorizations are applied in parallel in ASTRA-EC:

- The first categorization is based on the **country level** spatial differentiation, applied in all the modules of the model;
- The second categorization is founded on the **NUTS I zones level**, which is applied in the transport module to represent national trips;

3 HBEFA 3.1: Handbook Emission Factors for Road Transport, www.hbefa.net.

- The third categorization is built on the **NUTS II zones level**, applied in the transport modules (for trips generation) as well as for population and for a few selected socio-economic indicators;

Further differentiation within NUTS II zones is provided in some modules like e.g. the transport module. Finally, for intercontinental trade and transport demand an aggregated zoning system is applied to non-European areas, including the following world regions: Arab-African Oil Exporters, Asian Oil Exporters, Brazil, China, East Asia, India, Japan, Latin America, North America, Oceania, Russia, South-Africa, South-Asia, Turkey, Rest-of-the-World.

At European level, each country is treated separately in the model (while in the ASTRA model Belgium and Luxembourg were aggregated). Nevertheless, an alternative approach which might be considered for limiting the model size would aggregate the small countries (e.g. Luxembourg and Belgium, Cyprus and Malta, the Baltic countries). The aggregated approach is already used in other models, like POLES.

The specific application of spatial categories in the modules of ASTRA-EC is shown in the following Table.

Table 2-2: Summary of spatial categorizations used in different modules of ASTRA-EC

Spatial category	**Population**	**Macro-economic**	**Trade**	**Transport**	**Vehicle fleet**	**Environment**
Country	X	X	X	X	X	X
NUTS I	X			X		
NUTS II	X			X		
Urban context				X		
World regions			X	X		

Source: TRT / Fraunhofer-ISI

As highlighted in the table above, the transport module includes the most detailed level of spatial categorization, while in the other modules (except the population module) the variables are mainly defined at country level.

NUTS I and NUTS II is not a very detailed level of spatial segmentation for transport demand, but it is consistent with the scale of the tool. To a large extent transport data differentiated into detailed spatial categories for all European countries is provided by

EUROSTAT on NUTS II level. Availability on NUTS III level or even on lower levels from national statistical offices is increasing, ETISplus will provide matrices between NUTS III zones and the TRANS-TOOLS model will work at NUTS III level. However, this level of detail cannot be used in a strategic, integrated assessment model like ASTRA-EC.. The computational burden is a key factor. NUTS II level consists of 276 zones for the EU27+2 countries. Using NUTS II throughout the whole model is not feasible due to both, soft- and hardware restrictions. In fact, e.g. at international level the OD-matrices would have more than 70,000 elements, a number that would even increase when it comes to consider different modes and trip purposes.

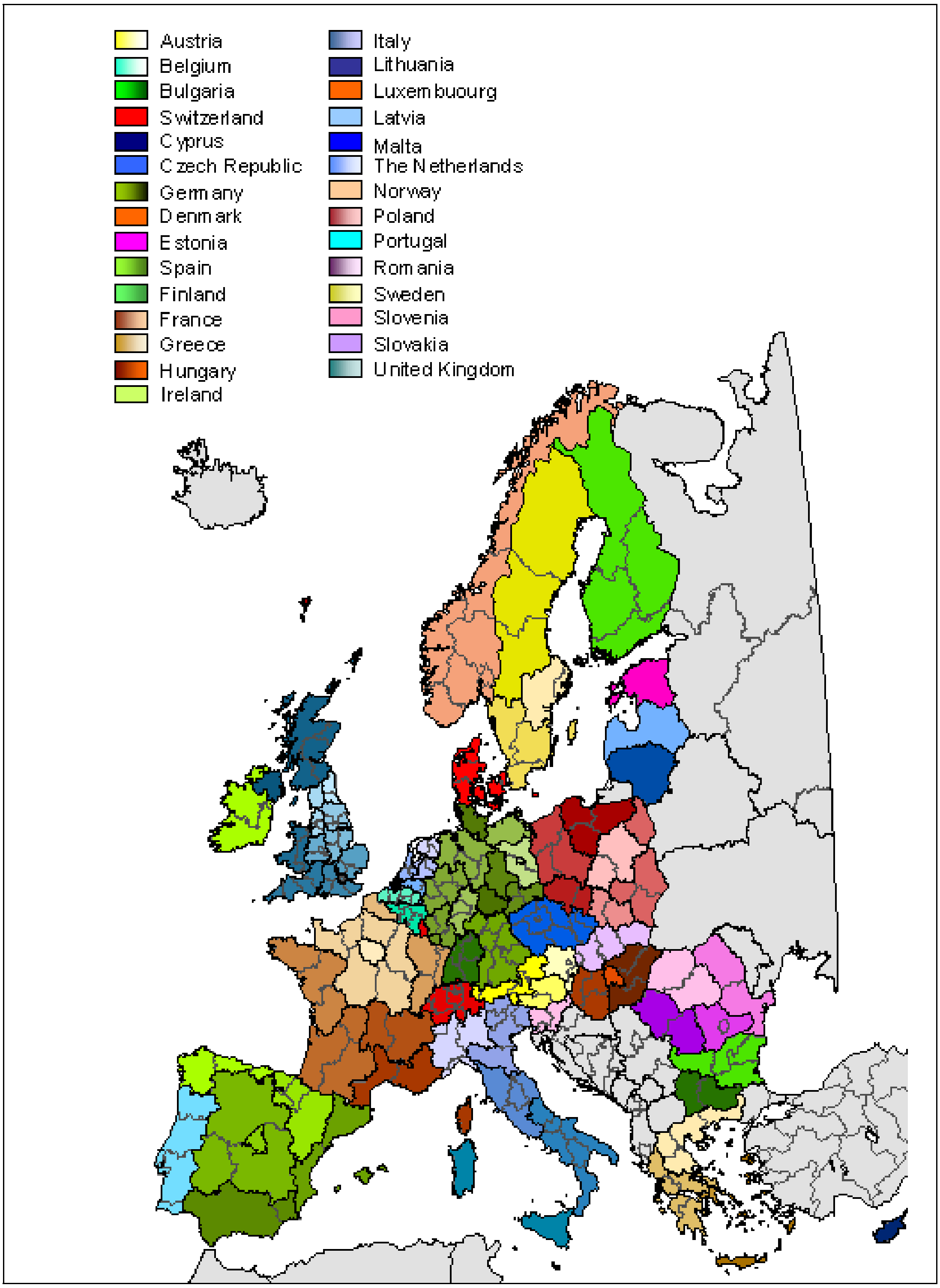
Therefore, the categorization by NUTS II zones can be implemented for transport demand generation only. For national transport demand matrices are estimated at NUTS I level. Instead, at international level intra-Europe transport demand is represented by country to country matrices, whose size is manageable. For intercontinental transport demand the country level is used for EU27+2 zones (and world regions for the rest-of-the-world).

The following Figure 2-2 shows the NUTS I and NUTS II zones for the 29 countries covered by the model.

The reason why the transport module has the most detailed geographical segmentation is twofold. On the one side, ASTRA-EC is pivoted around transport. It is aimed at providing indications on the impacts of transport policy measures. Therefore, the model should be able to simulate transport demand at an adequately detailed level. Policy leverages can be better simulated if local demand is distinguished from long distance demand and the latter is described in terms of (although aggregated) origin-destination pairs. Furthermore, using some detail at the NUTS level allows for a better use of data sources like the ETISplus database and a more straightforward linkage with a transport network model as TRANS-TOOLS.

It would be desirable that the same level of spatial detail is available also for the other modules, but this is not feasible within a System Dynamics model calculating each variable for every time step from 1995 to 2050. When NUTS I and NUTS II level is used to describe transport demand, the size of the model becomes already quite big. Using the same detail throughout the model would lead to unsustainable computational problems due to the overall model size.

Therefore, the implementation of more detailed spatial categorizations only in the transport module results from a balanced judgment of factors: model requirements, soft- and hardware capabilities, data availability. Outside the transport module, the NUTS level is used only for selected socio-economic indicators.



Source: TRT-Fraunhofer-ISI

Figure 2-2: Overview on spatial differentiation in ASTRA-EC

2.4 Socioeconomic segmentation

2.4.1 Segmentation into income groups

An income distribution model is implemented which simulates the complex coherences between socio-economic trends and income distribution. Based on the age structure of society, educational skills, the dynamics in household structure, employment per sector and the development of demand and supply side of economies, the population is allocated dynamically into five characteristic income groups. The age structure plays an important role as income depends significantly on the age respectively the experience of the employed person. Average income differs as well significantly between economic sectors, e.g. employed persons in the agriculture sector earn on average less than in the banking sector. The household structure is as well a driver of income distribution as e.g. many single parents households can only work part-time. Income also depends strongly on the level of education. Finally, the balance between demand and supply side of the economy influences income distribution. In times of low unemployment rates and booming economy, workers can request higher wages while in times of crisis wages stagnate or even decrease.

Since income inequality differs significantly among the single EU member states, an income distribution with fixed income thresholds in real terms is chosen to be the best way to simulate mobility patterns. Thresholds are adapted by country-specific power purchasing parities such that the absolute threshold is different in each country. The income distribution model covers income from work, gained income and transfer income.

ASTRA-EC considers income distribution as an important input to simulate passenger transport in the generation and distribution stage. In fact, the analysis of personal mobility trend shows that income distribution has a visible impact on transport mobility habits. In addition, the development of motorization as well as the technology choice is influenced by income and its distribution.

At the same time, different income groups allows for modelling that some transport policy measures can affect affluent and poorer individual differently and income distribution can be altered. On this respect, it is important the role of the micro-macro bridges within ASTRA-EC. As an example, an increasing expenditure for transport (e.g. due to tax increase) reduces disposable income for purchasing other goods and services. In ASTRA-EC the reduction of the disposable income due to e.g. road charging depends on mode share of car and price elasticities of the different income groups. The outcome of the measure in terms of income distribution ex-post can therefore be appreciated.

There are also feedback effects on the economic growth. The reduction of disposable income due to road pricing can easily be larger for poorer individuals, which are those spending the largest share of their income for consumption. Therefore the negative effect on aggregated demand of road pricing can be larger than e.g. of taxing air fuel.

2.4.2 Economic sectors

Sectoral disaggregation in ASTRA-EC is used in the macroeconomic and in the foreign trade module. Sectors are based on NACE-CLIO coding system, where NACE stands for the General industrial classification of economic activities within the European communities and CLIO for Classification and nomenclature of input-output. Both are used in EUROSTAT statistics. The reason for not applying the most recent NACE revision in ASTRA-EC is that the Manufacturing sector is not further differentiated in Revision 2. The generation of freight transport in three goods categories requires a detailed differentiation of manufacturing into a number of sectors. Freight demand is generated in ASTRA-EC by national production values and by exports per sector. On the other hand, service sectors play a minor role for the generation of freight demand. In order to improve the robustness in ASTRA-EC and to enable a more detailed geographical simulation of transport, less important manufacturing as well as service sectors are aggregated in the foreign trade module.

The following table presents the list of the 25 sectors used in ASTRA-EC. It is indicated which sectors belong to goods sectors and therefore generate freight transport flows. The five sectors that are directly influenced by changes of transport demand are also marked. It should be noted that both via the exchange of intermediate products from other sectors to these five sectors and via transport cost changes affecting the supply of intermediate products from the five sectors to all other sectors also all sectors will be influenced by changes in the transport system that might emerge on a level as detailed as a single OD-pair.

Table 2-3: 25 economic sectors used in ASTRA-EC derived from NACE-CLIO

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

Source: Fraunhofer-ISI

Although the 25 sectors in the table are the main segments used in the macroeconomic model, a further differentiation of the transport sectors according to specific transport modes is introduced in the model where significant. Especially, the further differentiation of the three transport service sectors (Transport Inland, Transport Air Maritime and Transport Auxiliary) by mode is envisaged in the labor market module as well as in the demand side indicators consumption of private households and investment. The same applies for including in some cases the split of the construction sector between “transport infrastructure” and “other construction”.

2.5 Transport module segmentation

2.5.1 Geographical dimensions for transport demand

In the transport module of ASTRA-EC, demand is segmented according to the zoning system introduced above (see paragraph 2.2). More in details, passenger transport demand is generated at NUTS II level, including also very short trips, and then segmented in the distribution phase.

National passenger demand at **intra NUTS II** level is further divided into:

- **Local distance** (intra NUTS III level with travelling distance lower than 3 km);
- **Very short distance** (intra NUTS III level with travelling distance higher than 3 km);
- **Short distance** (extra NUTS III level);

There are a couple of reasons for generating all demand, including local trips. First, a large part of mobility takes place at local level, on short distances. Second, since trips are generated through fixed trip rates applied to population groups, it is more consistent to generate the total transport demand

National passenger demand at **extra NUTS II level** is represented by NUTS I to NUTS I matrices while international passenger demand is further divided into:

- International European passenger demand, represented by Country to Country matrices;
- Intercontinental passenger demand represented by Country to world macro-region matrices.

Domestic freight transport is generated at the national level and then segmented in the distribution phase as described in the following. National freight demand at **intra NUTS II** level is further divided into:

- **Local distance** (intra NUTS III level);
- **Short distance** (extra NUTS III level);

National freight demand at **extra NUTS II level** is represented by NUTS I to NUTS I matrices).

International European freight demand is represented by Country to Country matrices and intercontinental freight demand is represented by Country to world macro-region matrices.

The following table summarizes the spatial segmentation of transport demand in the distribution phase. It is useful to note that the definition of spatial segments is consistent to the level of detail used in ETISplus, where NUTS III matrices are being estimated and intra-NUTS III passenger trips are further divided into distance bands, whose shortest one is below 3 km.

Table 2-4: Segmentation of transport demand

	National – intra NUTS II			**National –extra NUTS II**	**International European**	**Intercontinental**
	Intra NUTS III		**Extra NUTS III**			
Passenger demand	Local (< 3 km)	Very short (> 3 km)	Short	National (OD at NUTS I level)	International (OD at Country level)	Intercontinental (Country – world region)
Freight demand	Local		Short	National (OD at NUTS I level)	International (OD at Country level)	Intercontinental (Country – world region)

Source: TRT

2.5.2 Transport modes

In terms of transport mode availability, ASTRA-EC models different options for both passenger and freight demand.

Passenger transport modes in ASTRA-EC are:

- Slow modes (pedestrian and cycling),
- Car,
- Bus/Coach,
- Train and
- Air.

Freight transport modes in ASTRA-EC are:

- Truck,
- Train,
- Inland Waterways, and
- Maritime.

Not all modes are available in all spatial dimensions. The following tables summarize the available combinations for passenger and freight demand.

Table 2-5: Modes available for passenger demand by spatial dimension

	Local	**Very short**	**Short**	**National**	**International**	**Intercontinental**
Slow	X					
Car	X	X	X	X	X	
Bus	X	X	X	X	X	
Train	X[1]	X	X	X	X	
Air				X	X	X

Note: 1 Tram and metro
Source: TRT

Table 2-6: Modes available for freight demand by spatial dimension

	Local	Short	National	International	Intercontinental
Truck	X	X	X	X	
Train			X	X	
Inland Waterways			X	X	
Maritime			X	X	X

Source: TRT

The following assumptions are considered in ASTRA-EC:

- Tram and metro are not explicitly modeled as separate modes. They are considered within the mode “Train” (NOT within the mode “Bus”). Nevertheless, the geographic context where the mode “train” is used helps to recognize part of the demand for tram and metro: trips in the intra-NUTS II distance band < 3km can be safely considered to be by tram or metro.
- Inland waterway is modeled in a simplified way. For countries where this mode is relevant, its share is computed as part of the non-road inland demand.
- For intermodal freight trips, the concept of “main mode” is used. For instance, a trip made by rail, maritime and truck is considered part of the mode “Maritime”. A trip made by road and rail is considered part of mode “Rail”.
- For both passengers and freight, ferries are part of road mode (car or truck), not of maritime.

2.5.3 Transport demand segments

In the ASTRA-EC model different segments for both passenger and freight demand are included. For passenger demand different trip purposes are distinguished. The basis for ASTRA-EC trip purposes is ETISplus, where the following definitions are used:

- Commuting: home-based working and educational trips made on regular basis towards a fixed destination with return in the same day,
- Business: working trips made on a non regular basis towards variable destinations with return in the same or in a different day,
- Private: non-working trips whose return trip is made before of four days (therefore, this segments includes trips for leisure, shopping, etc. as well as short vacation trips),
- Holiday: non-working trips whose return trip is made after five days or later.

Nevertheless, in order to avoid the increase of model size, only three purposes are explicitly included in the ASTRA-EC model code: commuting (CO), business (BU) and personal (PE). The “personal” purpose includes both private and holiday trips. It can be assumed that the “holiday” purpose is dominant for international/intercontinental trips and whereas the “private” purpose represents the majority of private trips at local level.

In addition to purpose, passenger demand is also segmented according to income groups (see paragraph 2.3) depending on the population group originating the trip. Information on the car availability (yes, no, shared) is also included indirectly in the transport demand generation step, by the definition of the income groups.

Freight demand is segmented into three groups of commodity: bulk, general cargo and unitized cargo. Such groups are defined as aggregation of the more detailed groups defined within ETISplus and based on NST/R chapters.

Table 2-7: Conversion between ETIS commodity groups and ASTRA flows

ETIS Commodity group	ASTRA flow
Agricultural products	General cargo
Foodstuffs	Unitized
Solid mineral fuels	Bulk
Crude oil	Bulk
Ores, metal waste	Bulk
Metal products	General cargo
Building minerals & material	Bulk
	Unitized
Fertilizers	General cargo
Chemicals	Bulk
Machinery & other manufacturing	Unitized
	General cargo
Petroleum products	Bulk

Source: TRT

2.5.4 Vehicle fleet categories

In the ASTRA-EC model the vehicle fleets related to passenger car, bus, light duty vehicle (LDV) and heavy duty vehicle (HDV) are represented for EU27 plus Norway and Switzerland. Various categories are specified in the model with different levels of details depending on the fleet.

The passenger car fleet is modeled with the higher level of details, including eight categories: Gasoline and Diesel, Compressed Natural Gas (CNG), Liquefied Petroleum Gas (LPG), Advanced Hybrid Electric, Battery Electric, Bioethanol, Hydrogen (fuel cells) combined with the emission standard of the vehicle (from Euro1 to Euro7[4]).

For the LDV fleet, three categories (gasoline, diesel and battery electric vehicles) are implemented, combined with the emission standard.

For the HDV, a differentiation based on gross vehicle weights is implemented (above or below 12 tons), combined with the emission standard.

For bus, only the emission standard differentiation is included in the model.

2.5.5 Greenhouse gas and pollutant emissions

The ASTRA-EC model estimates transport related emissions of carbon dioxide (CO_2), carbon oxide (CO), nitrous oxides (NO_x), volatile organic compounds (VOC) and particulate matters ($PM_{2.5}$). All emissions are estimated up stream such that ASTRA-EC allows the differentiation between Tank-to-Wheel (emissions during operation with hot engine and cold-start emissions) and Well-to-Wheel emissions.

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4 The fictive Euro7 standard is introduced for allowing the implementation of future emission limits.

3 Exogenous input and policy leverages

ASTRA-EC simulates endogenously a wide range of process related to economy, transport and environment. Nevertheless, additional exogenous data are required from the model to run both reference and policy scenarios. The following paragraph high-lights the main exogenous data implemented in the model, while paragraph 3.2 reports the policy leverages available for scenario simulations and paragraph 3.3 provides some examples of how the ASTRA-EC model reacts to the implementation of policy measures.

3.1 Main exogenous data

ASTRA-EC requires for simulating scenarios a set of major elements which are not computed within the model itself.

One of the main exogenous variables is the resource fuel price trend, often provided by the simulation of the POLES energy model in terms of resource price for gasoline, di-esel, LPG, hydrogen, CNG, electricity, bioethanol, biodiesel and kerosene.

Another key element which is not computed by ASTRA-EC is the population trend as a whole: within the model some mechanisms for adjusting the structure of the population (as reactions of the economic scenario) are implemented, but the overall base trend is an exogenous data. Reference data is provided by EUROSTAT.

On the economic side, non-transport tax revenues besides VAT and import tax reve-nues are exogenous variables for which reference data is provided by EUROSTAT. The level of these tax revenues is expressed as a constant fraction of GDP. In fact, including also these aspects in the macro-economic module would require a consistent increase of its complexity, well beyond the scope of the ASTRA-EC model.

Despite ASTRA-EC estimates endogenously the GDP trend, the model allows to switch to exogenous GDP trend data. Nevertheless, it should be taken into account that in this case the macro-economic module results are not sensitive to most additional policy implemented in the model as many feedback loops contain GDP.

On the environmental side, the emission factors by vehicle type are exogenous para-meters. The original set of parameters provided with the ASTRA-EC model can be re-placed by alternative sources.

Finally, the values of the major indicators at the initial year of simulation (1995) are implemented as exogenous data, segmented according to the requirements of the model.

3.2 Policy leverages

The concept of ASTRA-EC allows the implementation of a wide range of policies, also setting the specific time period of application (e.g. from 2012 to 2050). Some policies can be directly implemented in the model through the correspondent variables of the ASTRA-EC model (e.g. fuel taxes). Other policies have to be simulated indirectly, under assumptions which allow implementing them in terms of variation of variables existing in the model (e.g. Railway liberalization or infrastructure construction). Finally, some of the transport policies identified in the impact assessment accompanying the White Paper and analysed in the Work package 1 of the ASSIST project cannot be simulated with the ASTRA-EC model.

The analysis of TPM in Work Package 1 of the ASSIST project is derived from a number of impact assessment studies using a large variety of different impact assessment tools. Different underlying assumptions as well as different model structures or considered effects can lead to differences in the impact assessment of TPM with ASTRA-EC. Hence, a reproduction of outcomes of the desk research line of work in ASSIST is not feasible. Nevertheless, ASTRA-EC as a tool combining economy, transport, technology and environment is able to provide comprehensive and robust results for a large set of TPM. The policy leverages available to the users of the ASTRA-EC model are listed in Table 3-1, following the same categories of Work Package 1.

Table 3-1: Policy leverages available in the ASTRA-EC model

Policy category	**code**	**Policy**	**Modeled**		**Not modeled**
			Direct	**Indirect**	
Pricing	1	Infrastructure charging - heavy-duty vehicles		X	
		Infrastructure charging - car road charging schemes		X	
		Infrastructure charging – urban road user charging / access restrictions		X	
	2	External costs charges (for all modes)	X		
	3	Public funding of transport (subsidies)	X		
	4	Other / New financing instruments			X
Taxation	5	Fuel taxation (indentify energy and CO_2 component)	X		
	6	Transport taxation (vehicle taxation, company car taxation)	X		
		Transport taxation - Feebates	X		
Infra-structure	7	European TEN-T core network: cross border missing links		X	
	8	European TEN-T core network: key bottlenecks		X	
	9	European TEN-T core network: multi-modal freight corridor structures			X
	10	EU transport infrastructure in view of energy efficiency needs and climate change challenges			X
	11	Planning procedure (timing, communi-cation framework, environmental is-sues)			X
	12	Capacity and quality of transport sys-tems – accessibility for elderly /reduced mobility people			X
		Capacity and quality of transport sys-tems – improving frequency and relia-bility of service		X	
	13	Intelligent Transport Systems (ITS)			X

Policy category	code	Policy	Modeled		Not modeled
			Direct	Indirect	
Internal Market	14	Internal Market (intra-modal) - road		X	
	15	Internal Market (intra-modal) – rail (e.g. liberalization)		X	
	16	Internal Market (intra-modal) – inland waterways		X	
	17	Internal Market (intra-modal) - maritime		X	
	18	Internal Market (intra-modal) - air		X	
	19	Transport security - cargo			X
	20	Transport security - passenger			X
	21	Transport security – land transport			X
	22	Transport security – “end-to-end”			X
	23	Multimodal transport (e.g. e-Freight)			X
Efficiency standards and flanking measures	24	Standard - Transport safety			X
	25	Standard – Passenger rights			X
	26	Standard – environment (e.g. efficiency for vehicles)	X		
	27	Flanking – promotion, information, dialogue			X
	28	Flanking – regulation (e.g. LDV speed limit)		X	
Transport planning	29	Mobility strategies and plans (disruptive events)			X
	30	Urban mobility – plans & audits			X
	31	Urban mobility – certification			X
	32	Urban mobility – management & monitoring (urban freight)			X
	33	Urban mobility – urban logistic strategies		X	
	34	Urban mobility – “zero emission” strategies		X	

Policy category	code	Policy	Modeled		Not modeled
			Direct	Indirect	
Research and innovation	35	Technology - vehicle		X	
	36	Technology – transport infrastructure / system (alternative fuel strategy)		X	
	37	Technology – transport information system, management & service			X
	38	Framework - Transport safety			X
	39	Framework – promotion & incentives (e.g. increased replacement rate of inefficient and polluting vehicles)		X	
	40	Framework – technology and infrastructure			X
Other	41	Job quality & working conditions - Truck driver regulations		X	
	42	Job quality & working conditions - Promotion of flexible work hours and opening conditions			X
	43	Job quality & working conditions - Promotion of telecommuting (working from home)		X	

Source: TRT / Fraunhofer-ISI

Table 3-1 shows that the ASTRA-EC model is able to simulate a reasonable part of the transport policy measures listed and analyzed within Work package 1 and 2 of the ASSIST project. More in details, the model provides leverages to implement TPMs related to the pricing and taxation categories, as well as some of the measures which belong to the infrastructure field. The TPMs of the Internal Markets are implemented indirectly in the model, while among intra-modal measures transport security policies cannot be simulated. With reference to Efficiency standards and flanking measures, only a couple of measures, related to vehicle standards and speed limits can be simulated with ASTRA-EC indirectly. Finally, concerning measures related to Transport planning and Research, only some of them may be implemented in the model, again in an indirect way. In addition, some policies concerning Job quality and work conditions may be simulated (e.g. Truck driver regulations and telecommuting).

This overview is consistent with the scope of the ASTRA-EC model, which can provide the assessment of transport policies integrating transport – environment – technology – economy systems with national / regional level of details. Therefore, policies addressed specifically to local/urban context or strongly influenced by local conditions cannot be included in the framework simulated with the model.

3.3 Policy simulation and impacts

This section shows how the structure of the model allows the assessment of social and economic impacts of the main types of TPMs mentioned in paragraph 3.2 and identified in Work Package 1.

3.3.1 Pricing/taxation policy – road charging and fuel taxation

Both road charging and fuel taxation affect directly transport costs. In a similar way, there are impacts on the transport system and its linkage with the economic part of the model. For that reason, the two measures are treated together in this paragraph.

In terms of implementation, road charges (differentiated by car and trucks) can be explicitly implemented in the transport module of ASTRA-EC. Tolls can be related to just some part (e.g. motorways) or to the whole road network. As the ASTRA-EC model do not include a detailed transport network, this distinction is applied under the assumption that, depending on the geographical dimension, a share of the road traffic flow travels on the motorway network. The share is estimated on the basis of data from network models (e.g. TRANS-TOOLS). Tolls are implemented in terms of €/vkm per mode (i.e. car, light duty vehicle, high duty vehicle, bus) and can change over time.

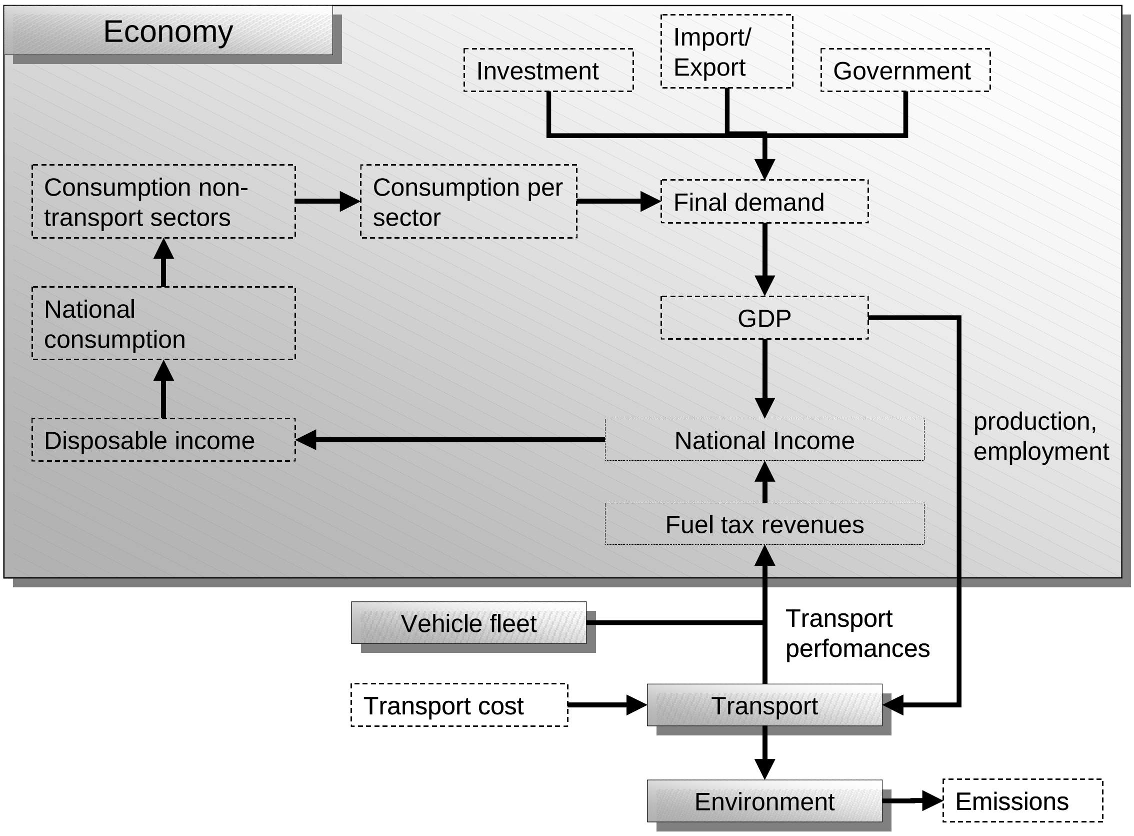
Fuel taxation can be changed directly in ASTRA-EC as well. Fuel taxes are differentiated by fuel type (gasoline, diesel, CNG, etc.). They induce increasing transport cost for all motorized transport modes (car, truck, bus, air, ship).

Growing transport costs of the corresponding modes influence modal split as an effect of the implemented elasticity parameters. Different social groups are affected in a different way, according to their elasticity and their specific mobility patterns. In addition, the distribution of trips is influenced as well (e.g. longer distance trips could be discouraged). As a consequence of increased transport expenditure, a larger share of income is required for mobility, reducing the remaining disposable income for consuming other goods and services. This effects the consumption of private households, the aggregated final demand and, finally, GDP (at national level).

At the same time, government tax and road charge revenues increase. Higher revenues can be used whether to reduce government debts or to reduce direct taxes. Both have an impact on the demand side of the economy. A better government balance impacts investments positively whereas a reduction of direct taxes enables more consumption.

The change on the economic side is fed back in the transport module, where generated demand is affected by elements such as total production and employment. As an effect, transport energy consumption and emissions change as well.

These impacts can be observed starting in the first period of implementation of the measures and continue over the whole simulation. Even if the measures are applied for just one period, the impacts can be observed also in the following periods. Indeed, given the dynamic nature of the model, the value of each variable depends on its time path.



Source: TRT / Fraunhofer-ISI

Figure 3-1: Feedback loops in ASTRA-EC for fuel tax policies implementation

3.3.2 Pricing - public funding of transport (subsidies)

Public funding of transport can be introduced in the ASTRA-EC model in terms of subsidies, e.g. to local public transport.

The first order impact is a change of the transport cost for local bus, therefore affecting modal split through the elasticity parameters differentiated by demand segment. Social groups react differently, according to their specific mobility patterns. Since within low income groups public transport users are generally overrepresented, they can be more affected – positively or negatively – by the policy. Their disposable income can change more than for other groups giving rise to the chain of impacts already mentioned for road tolls and fuel taxation. On the government side, public subsidies affect the government expenditure, therefore the aggregate demand and the national income, with a feedback loop on the other element of the economic system. Of course, subsidies can be financed by the revenues of some transport charge, such as the public budget is unchanged. In the model there is difference between subsidies covered by tax and charges subsidies covered by reducing some other public expenditure (or just by increasing public expenditure). In the former case private expenditure is increased and the income for non-transport consumption is reduced. In the latter case this effect does not take place but national income is nevertheless affected through a reduction of public investments or consumptions.

In ASTRA-EC there is also a difference between increasing subsidies or public investment (e.g. to improve public transport). In both cases public expenditure in increased, but investment can have a positive effect on other sectors through the input-output links.

3.3.3 Research and innovation measures - Technology: supporting alternative fuel strategy

New transport technologies, in particular low or zero emission technologies, are expected to emerge over the next decades, supported by dedicated policy measures: the electrification of road transport (e.g. plug-in hybrid vehicles, battery electric vehicles or hydrogen fuel cell vehicles) is an example of this approach.

ASTRA-EC allows to simulate this kind of policy indirectly, covering however the various aspects involved by the measure (investments, learning curves, purchasing cost, etc.). On the vehicle fleet side, new technologies are available on the “car market” simulated in the model, with the corresponding performance and purchase cost. Subsidies on new technologies can be easily implemented and change via lower investment or operating costs the diffusion of these technologies.

Efficiency standards policies like setting higher environmental standards can be simulated indirectly via reducing average emission factors.

3.3.4 Other - Promoting job quality & working conditions: Truck driver regulations

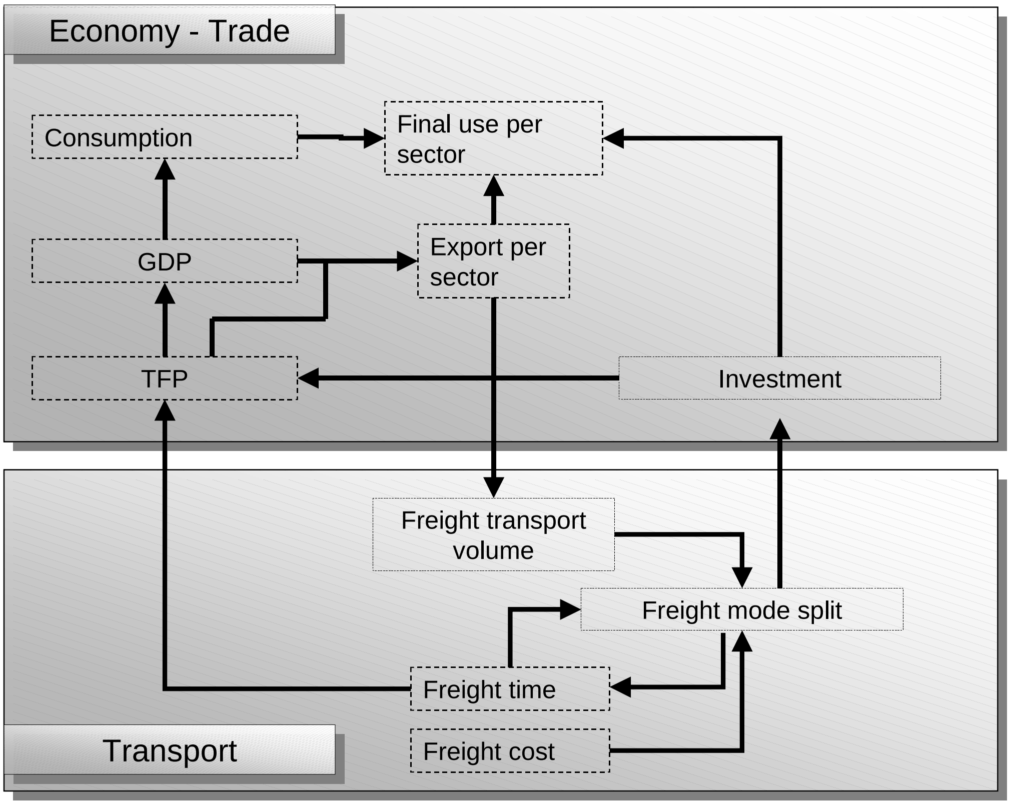
Truck driver regulation can be implemented indirectly in ASTRA-EC, under the assumption that travel cost for the truck mode is increased. More in details, it is assumed that labour cost is increased, therefore impacting on the production cost proportionally. Stricter rules for the resting time of drivers might also cause an increase of the overall shipment time. Also this effect could be implemented in ASTRA-EC. The change can be different from country to country, as enforcing driving rules can result in different operating cost depending on the conditions in the haulage sector (e.g. countries with many individual hauliers can be affected more than countries with more structured forwarder companies).

In terms of transport system, the first impact expected from increased cost (and time) is a different freight modal split. This impact is larger for those geographical dimensions where there is more competition between road and other modes.

At the same time, on the economic side, increasing transport costs and times would exert a negative impact on total factor productivity (TFP), arguing that freight transport constitutes an important element of today's production processes. As a result, decreasing TFP would slow down growth of GDP, production and consumption leading to reduced final use.

The feed-back on the transport side is that less freight demand is generated. Furthermore, also the distribution of freight demand is affected. Lower transport distances could be expected. All in all, a lower number of road freight vehicles-km would be generated. Therefore, energy consumption, emissions and accidents would be reduced.

Another possible impact on the economic side could be a change of the composition of investment in the transport vehicle sectors. Investment in road vehicles could be reduced in favour of investment in other modes such as rail and shipping. As far as the input-output links are different, the intermediate consumption by sector can change as well as value added.



Source: TRT / Fraunhofer-ISI

Figure 3-2: Feedback loops in ASTRA-EC for freight cost (and time) variations

4 Main output indicators

The indicators that ASTRA-EC can produce cover a wide range of impacts, in particular transport system operation, economic, environmental and social indicators.

The variety of indicators estimated with the ASTRA-EC model and the fact that these indicators are provided as time series offer the opportunity to apply different assessment schemes to support the development of European energy, transport and climate policies. Furthermore, the additional value of using system dynamics for transport modeling enriches the analysis with respect to a traditional transport model, thanks to the linkage with the modules related to economic and technological aspects. Therefore, direct and indirect impacts are simulated and interact with each other.

The following tables illustrate the main output indicators provided by the simulation of the ASTRA-EC model. The tables make reference to the classification of impacts used in WP1. With reference to the social indicators, it should be noticed that some of the indicators included in the transport, economic or environmental field, could be part of the social field as well.

Table 4-1: Summary of main transport output indicators of ASTRA-EC

Impact	Modeled	Indicator	Level	Unit
Modal share	Yes	Passenger transport activity generated in the country/domestic by mode	Country or NUTS II	Pkm/year
		Freight transport activity generated in the country/domestic by mode	Country or NUTS II	Tkm/year
		Passenger modal split	Country or NUTS II	%
		Freight modal split	Country or NUTS II	%
		Passenger road vehicle-km in the country by mode	Country or NUTS II	Vkm/year
		Freight road vehicle-km in the country by mode	Country or NUTS II	Vkm/year
		Passenger transport volumes generated in the country by mode	Country or NUTS II	Pass/year
		Freight transport volumes generated in the country by mode	Country or NUTS II	Ton/year
		Car ownership	Country	Vehicle / 1000 pers
Transport – vehicle fleet	Yes	Car fleet composition per fuel type	Country	% or abs.
		Bus fleet	Country	abs.
		Light duty vehicles composition	Country	% or abs.
		Heavy duty vehicles	Country	abs.

Source: TRT / Fraunhofer-ISI

Table 4-2: Summary of main economic output indicators of ASTRA-EC

Impact	Modeled	Indicator	Level	Unit
Mitigation of external costs	Yes	Economic value of CO_2 (and air pollutant) emissions reduction	Country	Mio. Euro/ year
Effects on the sectoral competitiveness	Yes	Labour productivity per sector	Country and sector	Euro/Pers
		Share of transport on average product costs	Country and sector	%
Effects on the spatial competitiveness	Yes	GDP	Country	Mio. Euro/ year
		Consumption	Country	Mio. Euro/ year
		Investments	Country	Mio. Euro/year
		Exports	Country	Mio. Euro/ year
Tax revenues for governments	Yes	Fuel taxation revenues	Country	Mio. Euro/ year
		Road charging revenues	Country	Mio. Euro/ year
Individual costs for mobility	Yes	Households transport expenditure	Country and income group	Euro /pers. year
Time savings	Yes	Change of average transport time per trip per country by mode	Country and income group	%
Health service (i.e. due to accidental injuries)	No			
Insurance (i.e. due to accidental damages)	No			

Source: TRT / Fraunhofer-ISI

Table 4-3: Summary of main environmental output indicators of ASTRA-EC

Impact	Modeled	Indicator	Level	Unit
Climate	Yes	CO_2 transport emissions by mode (tank-to-wheel/well-to-wheel)	Country	tons/year
		Average tank-to-wheel CO_2 emissions of car fleet	Country	g/Vkm
Pollutant emis-sions	Yes	NO_x transport emissions by mode (tank-to-wheel/well-to-wheel)	Country or NUTS II	tons/year
		VOC transport emissions by mode (tank-to-wheel/well-to-wheel)	Country or NUTS II	tons/year
		CO transport emissions by mode (tank-to-wheel/well-to-wheel)	Country or NUTS II	tons/year
		$PM_{2.5}$ transport emissions by mode	Country or NUTS II	tons/year
Fuel consumption	Yes	Transport fuel consumption by mode and fuel type	Country, fuel type and mode	Mio l or Mtoe
Noise emissions /diffusion	No			

Source: TRT / Fraunhofer-ISI

Table 4-4: Summary of main social output indicators of ASTRA-EC

Impact	Modeled	Indicator	Level	Unit
Historical / cultural / land resources	No			
Social cohesion	Yes	Income distribution per income group	Country and income group	%
		Share expenditures for mobility on total consumption per income group	Country and income group	%
		Unemployment	Country	persons
Community cohesion	No			
Security (crime, terrorism)	No			
Construction disruption	No			
Relocation	No			
Visual quality /intrusion	No			
Choice of travel modes	Yes	Change of passenger modal split per income group	Country and income group	%
		Passenger transport performance per income group	Country and income group	Mio*pkm /year
		Average distances per income group	Country and income group	pkm/ year
Accessibility	Yes	Potential accessibility by mode	Country / NUTS I and income group	%
Safety	Yes	Accidents (fatalities, injuries) by mode	Country and mode	persons
Health (Noise, Emissions)	No			
Standards and rights related to job quality	No			
Employment (or job generation)	Yes	Employment	Country	Pers

Source: TRT / Fraunhofer-ISI

5 Linkage between ASTRA-EC and TRANS-TOOLS

The ASTRA-EC model is expected to allow a connection with the TRANS-TOOLS model in terms of data exchange. With this linkage the economic and social dimensions can be added to the impact assessment of transport policy measures simulated on a network basis.

TRANS-TOOLS is the EC reference tool for transport demand analysis and will be improved in the research project TRANS-TOOLS (Version 3) in parallel with the ASSIST project.

ASTRA and TRANS-TOOLS have been used together in the iTREN-2030 project. The linkage in iTREN-2030 was different as only TRANS-TOOLS transport results could be used as reference trend within the ASTRA model. The TRANS-TOOLS model version developed in TEN-Connect (TTv2) could not be integrated within the iTREN-2030 modeling runs because of incompatibility problems in the freight model and of insufficient documentation. The objective in this project is to make a step beyond this experience, allowing actual exchange of data between the two models.

A working connection between the two models requires:

- The major basic assumptions and definitions used in the models need to be comparable and the meaning of relevant variables used in the models requires a correct understanding.
- The linkage between the models needs to be defined in functional terms (i.e. interface variables are identified; their data format is established; etc.).

5.1 Basic assumptions and definitions

With reference to the requirement of applying comparable basic assumptions, the content of the chapter 2 should be used as reference for the TRANS-TOOLS developers and users.

In particular, the transport module segmentation (in terms of definition of passenger purposes, modes and geographical dimensions) is one of the key elements for the set up of the linkage between the models. In addition, the aspects related to time period of simulation and to the data used for the base year should be addressed.

In fact, it should be taken into account that ASTRA-EC runs simulations from year 1995 to year 2050 on a yearly basis, while Trans-Tools runs for a base year and for some future years. It would be advisable that the base year of TRANS-TOOLS is used for calibration purpose in ASTRA-EC. The ETISplus project (which will be one of the main reference data sources for ASTRA-EC) is building reference databases for the year 2005 and 2010. It is expected that the base year of TRANS-TOOLS (Version 3) will be 2010, using ETISplus data as well. This would guarantee that the two models are consistent to each other and would allow developing ASTRA-EC by using data directly from the ETISplus database rather than waiting for the matrices provided by TRANS-TOOLS.

Furthermore, it should be taken into account that the exchange of data between a static model (like TRANS-TOOLS) and a dynamic model (like ASTRA-EC) requires the definition of procedures for exchanging and interpolating the value of variables in a time series.

Another general point concerns the zoning system. It is expected that TRANS-TOOLS works at NUTS III level for both passenger and freight. ASTRA-EC is not able to use that level of detail: as mentioned in paragraph 2.2 and 2.4.1, the higher level of detail is at NUTS II level. Therefore the detailed input provided from TRANS-TOOLS has to be aggregated. In case data from ASTRA-EC is needed for TRANS-TOOLS, it should be considered the level of detail available.

5.2 Definitions of the functional linkage between ASTRA-EC and TRANS-TOOLS

In order to define the conceptual linkage between ASTRA-EC and TRANS-TOOLS, it should be highlighted the role of ASTRA-EC. The major contribution expected is to widen transport policy analysis. As mentioned above, the integration of elements related to transport – environment – technology – economy available in ASTRA-EC should mainly enable the assessment of the economic and social impacts of transport policies simulated in detail with the transport network model TRANS-TOOLS.

In principle, also a reverse linkage could be considered, i.e. ASTRA-EC could provide Trans-Tools with some input data. This linkage is conceivable for:

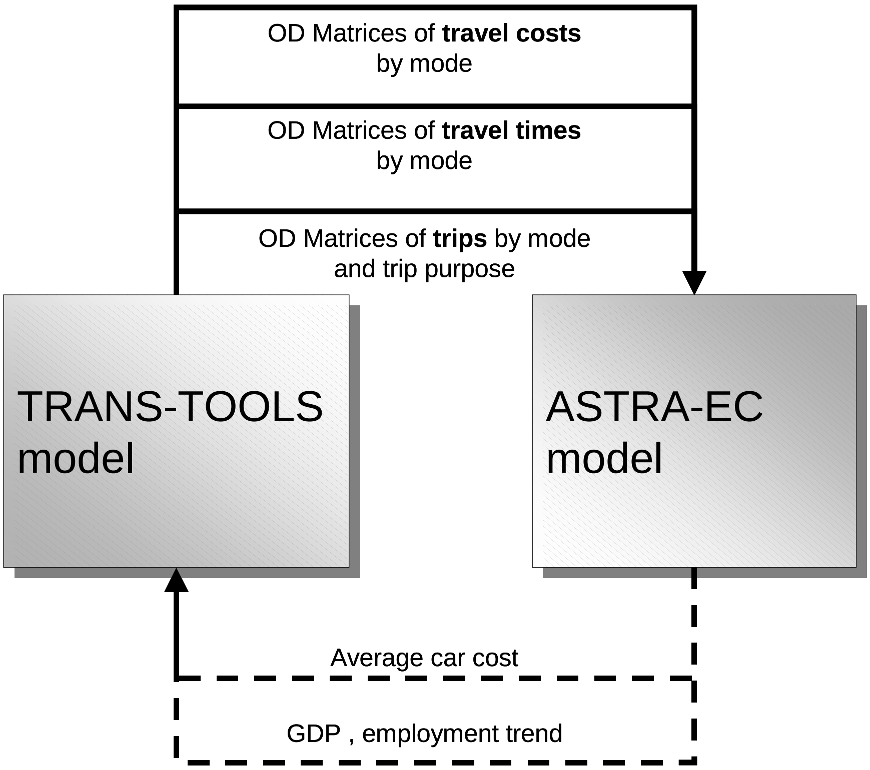
- Policies that affect car fleet composition (e.g. promotion of innovative technologies): If fleet composition is very different, average car cost is changed and modal split can be affected. ASTRA-EC might provide TRANS-TOOLS with average car cost (Euro/vehicle-km) in the policy scenario.
- Updating demand matrices: If generation and distribution steps in TRANS-TOOLS depend on some variables that ASTRA-EC compute endogenously (e.g. GDP trend, intra-EU trade, population), the relevant variables could be provided by ASTRA-EC for a policy scenario (e.g. trend of GDP by country or employment if investments in new vehicles are made). In some cases (e.g. population) the variables might be provided at NUTS II level.

With reference to the first type of linkage, assuming a flow of information from TRANS-TOOLS to ASTRA-EC, basically three main elements can be expected as part of the exchange of data:

- Matrices of trips by mode and trip purpose,
- Matrices of travel times by mode and
- Matrices of travel costs by mode.

The clarification of the definitions mentioned above is a major condition to ensure that input is used properly. An additional step is avoiding misunderstanding on minor aspects like e.g. data format, unit of measurement, period of time. Relevant points to be clarified are mentioned in the previous paragraph.

The following figure summarizes the possible linkages between the models in the cases mentioned above.



Source: TRT- Fraunhofer-ISI

Figure 5-1: Overview on possible linkages between ASTRA-EC and TRANS-TOOLS models

6 Model calibration

The calibration of the ASTRA-EC model will be achieved in two phases. In a first phase, the modules (or groups of few modules) described in chapter 2.1 will be calibrated separately in order to set the elasticity of each element isolating the reactions from possible indirect feedback. In this phase exogenous data evolving over time will replace the input required from the other parts of the model.

In a second phase, the ASTRA-EC model will be calibrated in the full model context for the historic period from 1995 to 2010, and for a future scenario. Therefore, at this stage, the calibration will be focused on reproducing the observed trend during the historic time period and adjusting the reactions of the model in the future to comply with expected forecasts and trends. The baseline representing the trends up to the year 2050 will be defined in agreement with DG MOVE and JRC IPTS experts and will build on the 2010 White Paper scenario.

In the calibration phase, other tools will be used as reference to ensure a consistency between the various models available. For instance, TREMOVE results in terms of e.g. development of emissions standards, energy consumption and vehicle fleet composition will be taken into account. Other reference sources for past data might be the EC pocketbook and ETISplus data.

In terms of future trends, the following documents and projects might be taken into account for calibrating the reference scenario: Transport White Paper 2010, iTREN-2030 project and PRIMES results. The policies investigated among the line of desk research of the ASSIST project will provide an input for checking the response of the model in these cases.

The source and approach for validation will be agreed with the European Commission. More in details, the model will be calibrated comparing the key variables in Table 6-1 to the reference data provided by the sources mentioned above.

Table 6-1: Summary of key variables for ASTRA-EC calibration

Module	Variable	Level	Unit
Transport	Passenger transport activity generated in the Country by mode	Country and mode	Pkm/year
	Freight transport activity generated in the Country by mode	Country and mode	Tkm/year
	Passenger trips by mode	Country and mode	Pass/year
	Freight trips by mode	Country and mode	Tons/year
	Passenger modal split	Country	%
	Freight modal split	Country	%
Vehicle fleet	Car fleet stock	Country	vehicle
	Car fleet composition per fuel type	Country and fuel type	%
	Bus fleet stock	Country	vehicle
	Light duty vehicles stock	Country	vehicle
	Heavy duty vehicles stock	Country	vehicle
Economy	GDP	Country	Mio $€_{2005}$/year
	Employment per sector	Country and sector	Persons
	Consumption of private households per sector	Country and sector	Mio $€_{2005}$/year
	Investment per sector	Country and sector	Mio $€_{2005}$/year
	Gross value added per sector	Country and sector	Mio $€_{2005}$/year
	Foreign trade per sector	Country pair and sector	Mio $€_{2005}$/year
Population	Income distribution	Country and income group	Pers/group
Environment	CO_2 transport emissions by mode	Country	tons/year
	Transport fuel consumption per fuel type	Country and fuel type	Mio l or PJ

Source: TRT / Fraunhofer-ISI

7 The user interface

The user interface of the ASTRA-EC model provides the possibility of accessing the model to the users (including non-modeling experts) for carrying out simulations by changing model parameters (e.g. transport pricing, car prices), read results and compare different scenarios.

The interface is developed using the internal Vensim® language. It consists in two main parts: one concerning the inputs to set up the simulation of scenarios, and the other concerning the outputs of a simulation. For both input and output parts, the components and the features of the interface have to be defined in strict cooperation with DG MOVE and JRC IPTS, in order to identify the list of input parameters that should be made available to users and which output variables should be accessible from the interface.

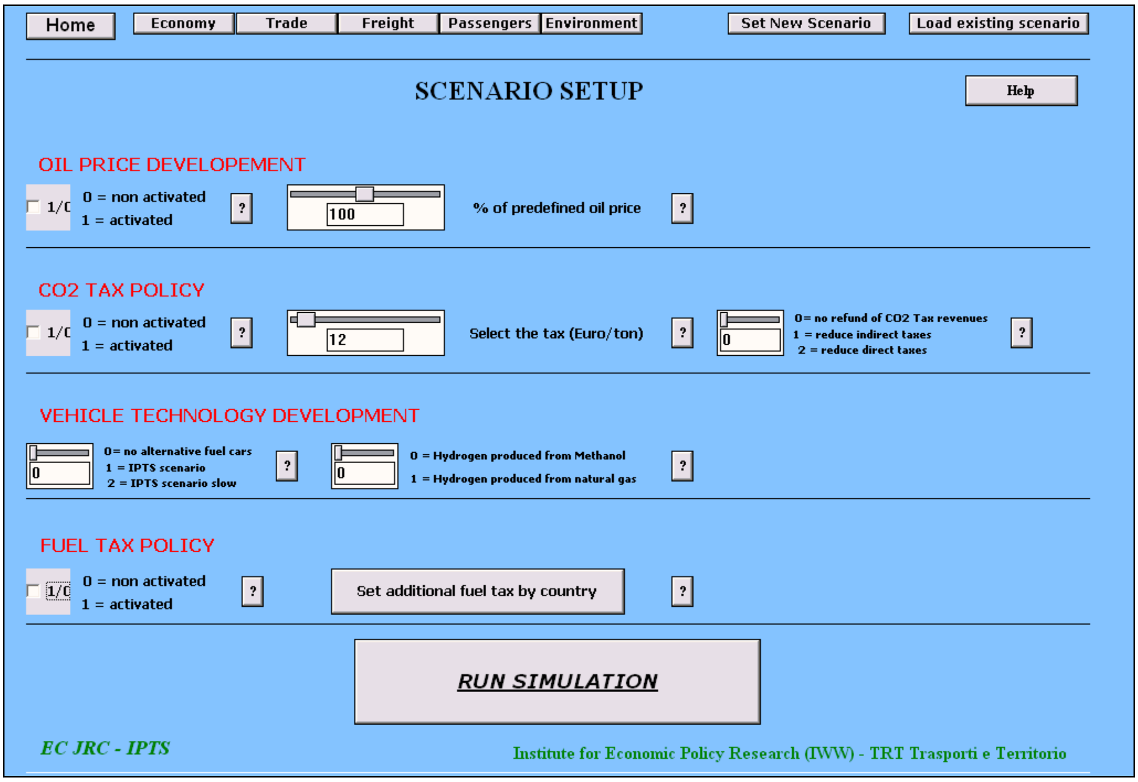
The input side allows to set-up a new scenario:

- By changing the value of the leverage variables used for describe the policy scenario to be simulated (see paragraph 3.2);
- By changing the value of the exogenous data used for the simulation (see paragraph 3.1).

The value of the input parameters can be set in a pre-defined range of variation, in order to keep the consistency of the model unchanged.

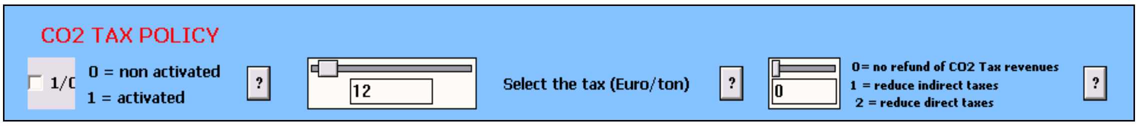
An additional feature supported by the Vensim® interface is the possibility of performing sensitivity analysis on specific parameters. Nevertheless, it will be investigated whether the size of the ASTRA-EC model do not represent a constraint for running this kind of functionality.

The following figures, related to the LOTSE project (Krail et al. 2003), provide an example of the page for setting the parameters for simulating a policy scenario, with a focus to the implementation of the value of a leverage variable with a slider. The example in figure 7.5 refers to the CO_2 tax policy, where the user can choose to activate a CO_2 tax expressed in euro/ton. The user can also decide whether revenues of such a tax is either balanced by reducing indirect taxes or direct taxes or is not balanced in any way.



Source: ASTRA-LOTSE project (2003)

Figure 7-1: Example of interface for scenario set up



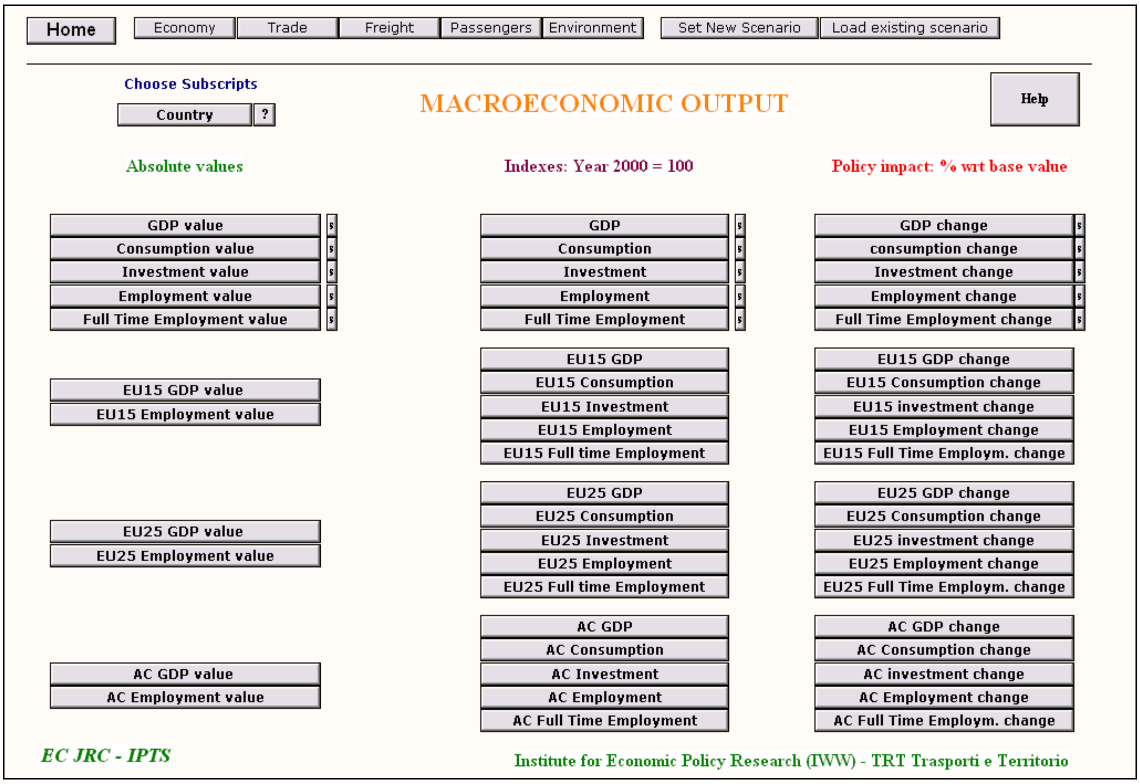
Source: ASTRA-LOTSE project (2003)

Figure 7-2: Example of the controls to set a CO_2 tax policy

The output side of the ASTRA-EC interface allows to:

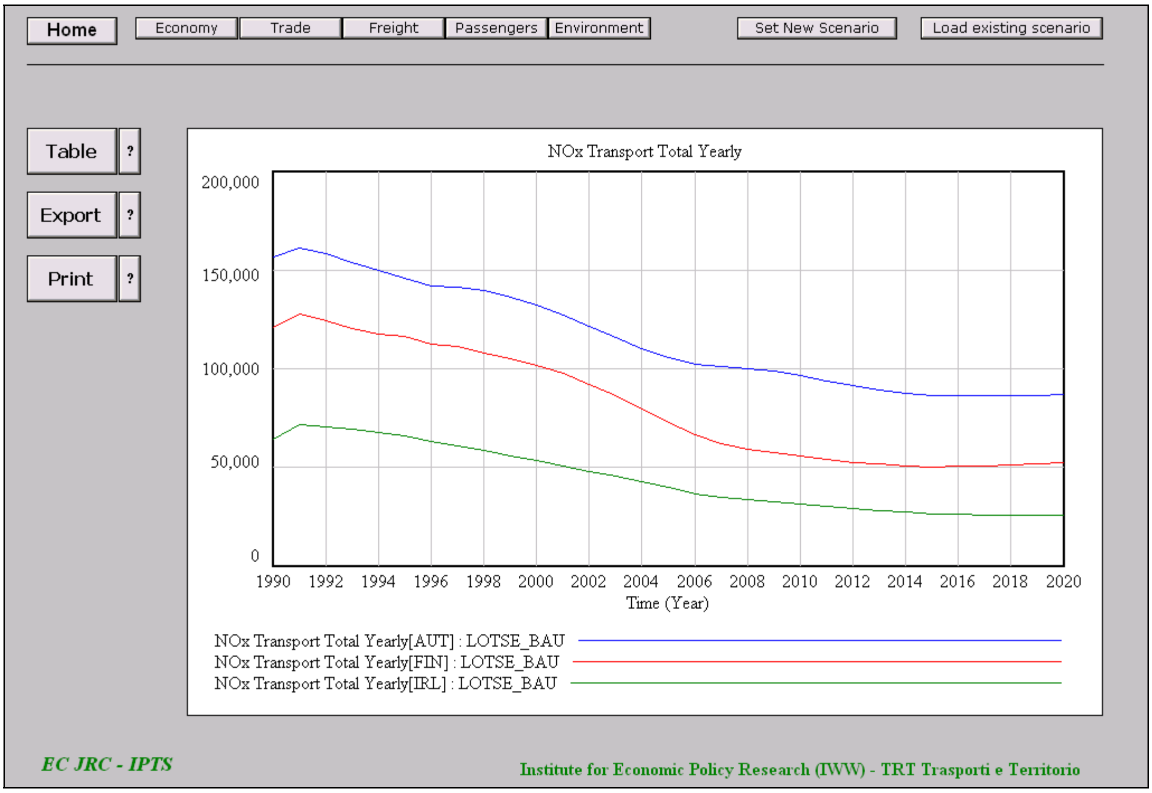
- Read the outcome of the simulation of a given scenario, i.e. looking at the values assumed over the simulation period by the main variables of the different sub-systems: environment, economy, transport, etc. (see chapter 4);
- Compare two scenarios, i.e. listing the differences in the input variables existing in two different runs.

The values are reported in terms of tables and graphs (see figures below). For selected variables, an additional feature for representing results on maps is provided. Results in table format can be copied and pasted in Excel for further processing (while graphs are exported as images).



Source: ASTRA-LOTSE project (2003)

Figure 7-3: Example of interface for reading scenario results



Source: ASTRA-LOTSE project (2003)

Figure 7-4: Example of scenario results in graph format

References

Krail M. (2009): *System-Based Analysis of Income Distribution Impacts on Mobility Behaviour.* NOMOS-Verlag, Baden-Baden, Germany.

Krail M., Schade W. (2003): *LOTSE – Quantification of Technological Scenarios for Long-Term Trends in Transport*. Final Report of the LOTSE project on behalf of DG JRC, IPTS, Seville, Spain.

Metz D. (2008): *The Limits to Travel. How Far Will You Go?*. Earthscan, London, UK.

Schade W. (2005): *Strategic Sustainability Analysis: Concept and application for the assessment of European Transport Policy*. NOMOS-Verlag, Baden-Baden, Germany.