ASSIST

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

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Description of the ASTRA-EC model and of the user interface

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ASSIST

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1 Introduction

The ASSIST project has developed two methodological lines. One line addressed the analysis of transport policy measures, the other line dealt with modelling. This deliverable provides a description of the ASTRA-EC model, which is the major outcome of Work Package 4.

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], which has been developed and applied over the last ten years for the integrated assessment of transport strategies in Europe. Building on the ASTRA approach specific features of ASTRA-EC have been 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 characterised by the following main features.

- ASTRA-EC allows users to analyse 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.

- 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 for some indicators.

- ASTRA-EC has been designed to be more efficient in terms of model size and of computational power required than ASTRA.

- In ASTRA-EC specific structures to enable a linkage with other European tools like TRANS-TOOLS and POLES have been implemented. This linkage is meant in terms of data exchange.

- Last but not least, while ASTRA is a proprietary model accessible only by experienced users, ASTRA-EC is conceived to 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 fur-

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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/.

ther analysis. The model documentation includes a user guide for learning how to use the tool, to simulate scenarios, to change exogenous input and so on.

In this deliverable, all the main components of the ASTRA-EC model are described in some details. Section 2 provides an overview of the model and of its modular structure. Then, sections from 3 to 8 give a thorough description of each main module of ASTRA-EC. For each module it is explained which is its role, which is the methodology applied, which is the form of the main equations used and other information useful to understand how ASTRA-EC works. Section 9 is devoted to the presentation of the data sources used for the implementation and calibration of the model. The calibration process used for ASTRA-EC is described in Section 10, with the aim of clarifying the complexity of the process itself and the differences with respect to other types of models (calibration results are not part of this deliverable, they are part of Deliverable D5.1). Since ASTRA-EC is fundamentally a tool for simulating policy measures, Section 11 explains which Transport Policy Measures (TPMs) can be simulated and how they are modelled. Section 12 addresses the linkage with other European models: TRANS-TOOLS and POLES. It is explained which variables can be exchanged between models and how the external data are used in ASTRA-EC. Finally, Section 13 describes the user interface developed to make the model easily accessible. The main facilities of the interface are introduced (a full description of the user guide is provided as Deliverable D6.1). Some annexes are part of this deliverable, they contain details on the zoning system and on detailed values used in the model such as e.g. values of travel time, income distribution, etc. A list of key references ends the Deliverable.

2 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 of the model structure

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.

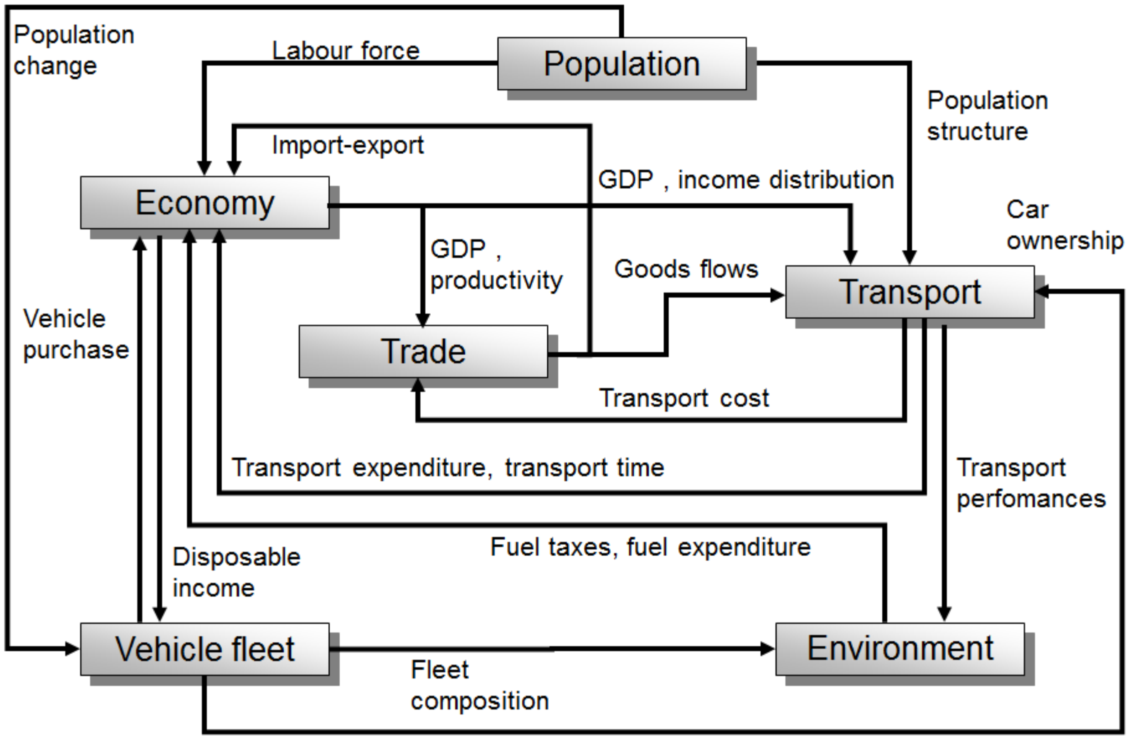
ASTRA-EC consists of different modules, each related to one specific aspect, such as the economy, the transport demand, the vehicle fleet. The main modules cover the following aspects:

- 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 behaviour 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 behaviour 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. A description of the modules is provided in the following chapters.



Source: TRT - Fraunhofer-ISI

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

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;
- The third categorization is built on the **NUTS II zones level**, applied in the transport modules (for trips generation) as well as for population;

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, resulting in a total of 29 states.

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

Table 2-1: 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.

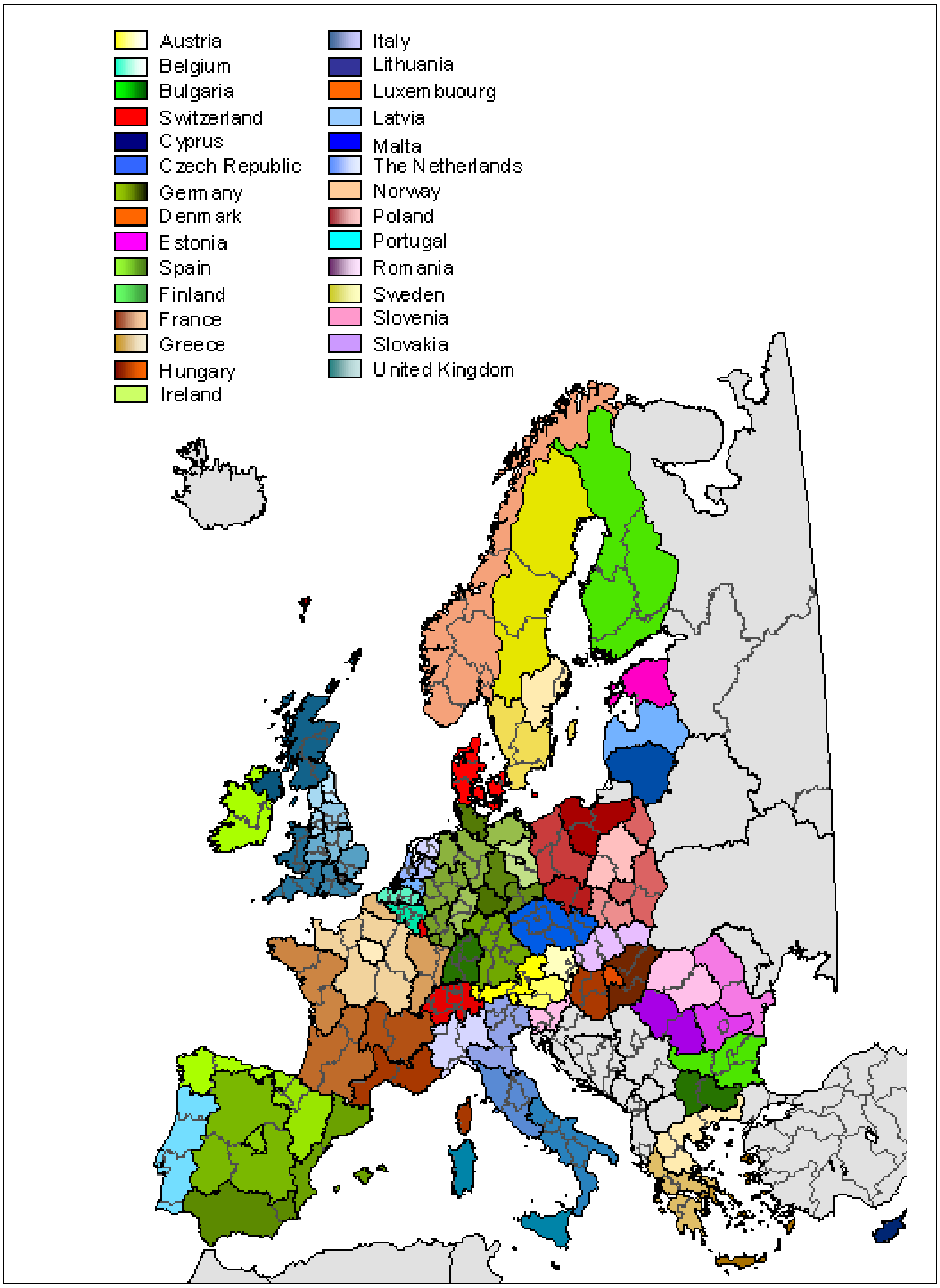
Therefore, the categorization by NUTS II zones can be implemented for transport demand generation only. For national transport demand matrices are estimated at NUTS I level. Instead, at international level intra-Europe transport demand is represented by country to country matrices, whose size is manageable. 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 of spatial differentiation in ASTRA-EC

2.4 Sectoral differentiation

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

The NACE system corresponds to international classifications like *ISIC* (International Standard Industrial Classification), such that also data following these categorisations could be used, and is available as NACE with 17, 25 or 44 sectors. Three main reasons suggest using the NACE-CLIO version with 25 sectors (see following table): firstly, in ASTRA-EC the use of harmonised input-output tables for the EU27+2 countries is of significant importance to reflect the economic interactions that are induced in all sectors of the national economies by influences of policies in those sectors that are directly related to transport demand. Eurostat provides such tables for most of the EU27 countries plus Norway and Switzerland for 1995. Values for 1995 are required as the sectoral interweavement is initiated by data. Input output tables of upcoming years are endogenously calculated based on changing final use (see chapter 4.3). They are not calibrated against input output tables of following years. Secondly, the split into 25 sectors offers five sectors that are directly related to transport demand changes and that would be affected by transport policies. These sectors are sector 2 Refined petroleum products and Electric power, gas, etc. influenced by private expenditures for fuel; sector 10 Transport Equipment affected by private car purchase and investments in any other kind of vehicles; sector 16 Building and Construction driven among others by investments in transport facilities (e.g. container terminals or stations) and transport networks; sector 19 Inland Transport Services influenced by expenditures for bus, rail, road freight transport and inland waterway transport; sector 20 Maritime and Air Transport Services affected by ocean ship transport and air transport. Thirdly, among the 25 sectors are already 9 service sectors which enable the model to take account of the ever increasing importance of services for the European economies. A conversion table from the NACE Revision 2 classification of economic sectors (65 sectors) to the NACE-CLIO version called IOSector (25 sectors) can be seen in Annex 4.

Table 2-2: Differentiation into 25 economic sectors in ASTRA-EC

Nr.	IOSector	TradeSector
1	Agriculture	T Agriculture
2	Energy	T Energy
3	Metals	T Metals
4	Minerals	T Minerals
5	Chemicals	T Chemicals
6	Metal Products	T Metal Products
7	Industrial Machines	T Industrial Machines
8	Computers	T Computers
9	Electronics	T Electronics
10	Vehicles	T Vehicles
11	Food	T Food
12	Textiles	T Textiles
13	Paper	T Paper
14	Plastics	T Plastics
15	Other Manufacturing	T Other Manufacturing
16	Construction	not included
17	Trade	T Other Services
18	Catering	T Other Services
19	Transport Inland	T Transport Services
20	Transport Air Maritime	T Transport Services
21	Transport Auxiliary	T Transport Services
22	Communication	T Other Services
23	Banking	T Other Services
24	Other Market Services	T Other Services
25	Non Market Services	T Other Services

Source: Fraunhofer-ISI

3 The Population module

The objective of the Population module (POP) is to enable a differentiation of population groups that are relevant for analysing transport and economic patterns. Therefore, the POP module simulates the demographic development as well as the distribution of income for the EU27 countries plus Norway and Switzerland (EU27+2) on different levels of detail. On the one hand, the demographic development of each EU27+2 country is modelled on country level. On the other hand there is a more detailed differentiation into population on NUTS II level which is mainly used as input for the passenger transport model. Finally, the population model also distinguishes the national population by income groups. The structure of each module is described in detail in the following.

3.1 Population on country level

The EU27+2 population on country level is simulated with one-year-age-cohorts, such that the population of a country is subdivided into one-year-person-groups starting with babies and ending with persons older than 80 years. The differentiation into age cohorts is crucial as there is a significant difference between mobility patterns of persons with different age (Krail 2009). Mathematically, the population model simulates the population even in quarter-year steps such that there are actually 320 cohorts. A comparison of the model size showed that a quarter year basis does not significantly extend the overall model size and the computation time such that this structure remained in ASTRA-EC. In principle, the core of the POP module can be described by equation 1 which computes the age structure of the population per country. Persons enter the level variable either by birth or by immigration and leave the variable by death and emigration. The number of births depends on fertility and infant mortality rates and a share of women in the age between 15 and 49 that are able to bear children. Technically, the number of children with age below one is calculated by adding the number of births per time period and subtracting the number of children reaching their first birthday. Additionally, persons change their age cohort every time step and join the following age cohort.

Technically, the population stock called *POP_PopulationConveyor* is modelled within one variable which is differentiated by the subscripts *Cohort*s and *Country*.

$$POP_{i,c=0}(t) = (1 - IM_i * HI(t)) * SW_i * FR_i * \sum_{c=15}^{49}\left[POP_{i,c}(t-dt)\right] - POP_{i,c+1}(t-dt)$$

$$POP_{i,c\in[1,16]\vee c\in[45,80]}(t) = (1 - DR_{i,c-1}) * POP_{i,c-1}(t-dt) - POP_{i,c}(t-dt)$$

$$POP_{i,c\in[17,44]}(t) = (1 - DR_{i,c-1} * HI(t)) * POP_{i,c-1}(t-dt) + MB_{i,c}(t) - POP_{i,c}(t-dt)$$

$$POP_{i,c=80}(t) = (1 - DR_{i,c-1} * HI(t)) * POP_{i,c-1}(t-dt) + (1 - DR_{i,c}) * POP_{i,c}(t-dt) - DR_{i,c} * POP_{i,c}(t-dt)$$

Eq. 1

With:

With:	POP =	number of persons per country i and age cohort c
	IM =	infant mortality at birth
	SW =	share of woman in child bearing age
	HI =	future health improvement
	FR =	fertility rate
	DR =	death rate of age cohort c
	MB =	migration balance into age cohort c
	dt =	time differential to previous point of time for difference equations
	i =	index for EU27+2 countries
	c =	index for cohorts 0 to 80

The model with the population level in its centre depends on country-specific fertility rates, death rates and migration balances. According to Eurostat birth statistics the countries are differentiated into countries with early bearing women (age between 15 and 40 years), medium bearing women (age between 20 and 45) and old bearing women (age between 24 and 49). Trends observed in the past years, such as growing life expectation or decreasing infant mortality rates, are integrated in the simulation of population. Based on the age structure modelled by the one-year-age-cohorts, important demographic information is provided to several other modules. Therefore, different age groups that are relevant as input into other ASTRA-EC modules are aggregated. The number of persons in the working age which is called labour force in the following is used as input in the Economic module. The number of persons in defined age classes serves as input for the simulation of age specific mobility behaviour in the transport module. The development of adult population provides a valuable input for the Vehicle Fleet (VFT) module. The POP module is calibrated to fit Eurostat population statistics and baseline projections until 2050. For this reason, parameters like country-specific death rates, future fertility rates, the age structure of immigrants and emigrants and a factor simulating the future life expectancy and health improvements reducing infant mortality rates are adjusted over the pathway until 2050. They are not constant and can be changed in their time profile.

3.2 Population on NUTS-II level

The simulation of the demographic structure on NUTS-II level is based on the same principles as the national population model. The stock of the population is differentiated by one-year age cohorts and by the 276 NUTS-II zones. In order to limit the size of the model, the age cohorts are only computed annually and not on a quarter year basis like for the population model on country level. Therefore, the subscripts differ from the country level model: *Age_NUTS II* representing the 81 age cohorts and *NUTS II* for the 276 NUTS-II zones in EU27+2. Another difference between the country and the NUTS-II level population model lies in the consideration of migration. While for the country level population model only international migration is accounted, the NUTS-II level model needs to consider also domestic movements from one zone to another. Further differences concern the availability of projections for migration until 2050. For the population model on country level these projections are taken into account. For the migration in the NUTS-II model, the national trends were used to assess the trends for each NUTS-II zone. In practical terms this means that a trend towards a positive migration balance on national level can be also found on the sum of all NUTS-II zones in this country. Nevertheless, there might be some NUTS-II zones with a negative migration balance.

3.3 Income distribution model

Income and its distribution among the population play a significant role in the assessment of transport demand. According to a statistical analysis carried out by Krail (2009) mobility patterns depend on age, income, employment status and car availability. As the latter three are interrelated, it makes sense to point out just one attribute. For ASTRA-EC, income distribution has been selected. Income differs strongly among different economic sectors. Hence, the employment status seems to be not detailed enough for an assessment of passenger transport demand. Income is one of the main drivers of motorization. Income can be differentiated into four categories (Frenkel and John 1999):

- earned income by employed persons (wages and loans),
- gained income by self-employed persons (gains, rents, etc.),
- capital income (interests, dividends, etc.) and
- transfer income (social benefits, etc.).

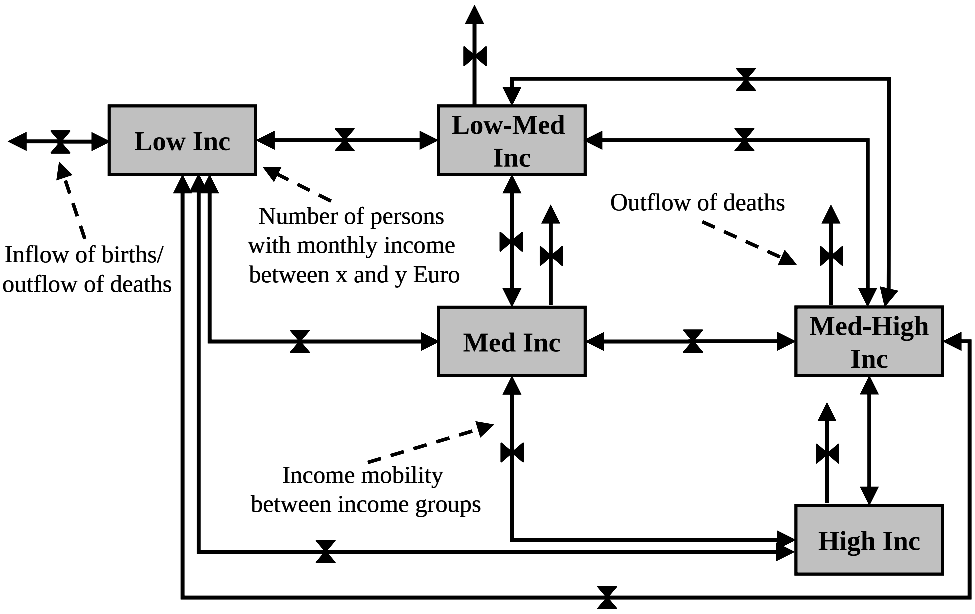
The first two categories can be assigned to income from employment. The income distribution in ASTRA-EC only considers income from employment plus income from transfers. Capital income is not taken into account as there is no database available on a European level. The most detailed database for income distribution is the Luxembourg Income Study (LIS) micro database (2008). The distribution of labour and transfer income is based on this database. As the LIS database covers only datasets for 23 of the EU27+2 countries, the distribution of income was estimated for the rest. Based on less detailed data for income distribution from Eurostat, the final distribution of income was assessed for the remaining 6 countries.

The structure of the income distribution model was mainly determined by the existing European travel surveys. Krail (2009) explains the decision-making process in detail. The income distribution model in ASTRA-EC simulates the personal income mobility between fixed income groups. Furthermore, the income distribution model relates to income ranges of persons instead of households.

According to the income steps defined in the relating travel surveys, the ranges of income were defined for five different income groups:

- persons with low income (Low Inc),
- persons with low to medium income (Low-Med Inc),
- persons with medium income (Med Inc),
- persons with medium to high income (Med-High Inc) and
- persons with high income (High Inc).

In order to transfer the income steps individually also for those countries were no travel survey was available, the steps were harmonised by transport price indexes per country from Eurostat (see Annex 5).



Source: Fraunhofer-ISI

Figure 3-1: Overview of income distribution model structure

Krail (2009) identified several drivers on income mobility based on theories of income distribution and modelling examples. Most drivers like the supply and demand balance of work places with certain job specifications cannot be used by ASTRA-EC as a macro-level to assess income mobility. Nevertheless, there are a number of indicators that have the potential to explain the dynamics of income distribution. Education plays a significant role in this context. Krail (2009) illustrates the statistical dependency between average wages and the highest level of education. The historical development of alumni reaching a certain highest education level (ISCED2, 3 and 5) is taken from Eurostat[2]. The share of alumni reaching a certain highest education level at the age of 16 (ISCED 2), 19 (ISCED 3 and 4) and 25 (ISCED 5) is then multiplied with the population in the respective age cohorts coming from the ASTRA-EC population model. The share is implemented with a lookup function and therefore changing during the statistical period from 1995 to 2005. After 2005 the share is kept constant but can be changed for simulating scenarios. Alumni with a higher level of education have a higher probability of starting in one of the higher income groups while persons with a low level of education are assumed to fill mainly the lower income groups. The following equation describes the computation of income mobility from Low Inc into all four higher income groups due to transfer from students to workers:

[2] Based on Eurostat data series ‘edat lfse 07’

$$IMED_{i,dig} = \sum_{ed} potAL_{i,ed} * shAL_{i,ed} * cIMED_{i,dig,ed} \qquad \text{Eq. 2}$$

With:
- IMED = number of alumni per country i that enter destination income group *dig*
- potAL = total population that reaches specific alumni age per country i and education level *ed*
- shAL = share of population in specific age group that reached highest education level *ed*
- cIMED = calibration parameter representing the probability for income mobility in *dig*
- dig = index for five possible destination income groups
- ed = index for three considered ISCED 1997 education levels
- i = index for modelled EU27+2 countries

Apart from personal skills reflected on a meso-level via ISCED 1997 education levels, another socio-economic indicator has been detected in the course of the model development: the age structure of the population. Blümle (1975) demonstrates that there is a correlation between the level of income and the age. Therefore, the population is allocated into five age classes: 18 to 29 years, 30 to 39 years, 40 to 49 years, 50 to 59 years and 60 years and older. According to Eurostat data, all EU27+2 countries possess at least a growth of average income with increasing age until the age of 60. Considering persons older than 60 years, half of the countries are characterised by a slight reduction of income, while the rest shows still increasing average incomes compared to younger workers. Regarding recent trends, observed for example in Germany which indicate declining correlation between age and average income, the continuation of the depicted status from 2002 in the future is at least in its clearness questionable. As this trend is only visible in some countries, the factor age can be considered as an important prospective driver of income distribution and mobility. Hence, the depicted age-income correlation is adopted in the ASTRA-EC income distribution model. Even if a continuous growth of average net income per person is most likely, a step-wise growth of income is implemented in ASTRA-EC. Based on the trend of the year 2002, all employed and self-employed persons for all five age classes per country are assigned according to their most probable, basic income group. For example, the highest share of employed persons between 18 and 29 years are allocated in the Low Inc group.

In a second step, the average net income distances per person are computed out of the described age-specific average net incomes and assumed prospective income trends for the five age classes. The probability that an employed or self-employed person of a certain income group moves to a higher or a lower income group is estimated in the final step. Therefore, average net income distances to higher and lower income groups are calculated based on the assumption that persons respectively their incomes are equally-distributed within the five income groups and the assessed net income bounds of the five income groups. The following equation describes the estimation of income mobility due to ageing of employed and self-employed persons into the higher income group (if income increases from one age class to another) respectively the lower income group (if income decreases from one age class to the following). Based on Eurostat statistics on average income per age of employed and self-employed persons, only persons reaching an age of 60 years have to face a decreasing income. For all other age borders, there is an increase assumed.

$$IMAE_{i,ig} = \sum_{ab} \left[\frac{(nY_{i,ab+1} - nY_{i,ab})}{disIG_{i,ig}} * EMP_{i,ig,ab} \right] * cIMAE_{i.ig} \qquad \text{Eq. 3}$$

With:
- IMAE = employed per country i that move to lower/higher income group ig-1/ig+1
- nY = average net income per country i and age class under age bound ab
- disIG = average monetary distance to lower/higher income group
- EMP = employed/self-employed persons per country i, income group ig and age bound ab
- cIMAE = calibration parameter representing the probability for income mobility due to ageing
- ig = index for five possible original income groups
- ab = index for age bounds of the five age classes
- i = index for modelled EU27+2 countries

Apart from the ageing of employed persons between 18 and 65 years, the age in which employed persons retire constitutes another incident which induces income changes. Retired persons do not get anymore salaries from their employer but pensions from the state or private insurances. According to net replacement rates at average earnings per income class and country derived from the OECD database the former wages can be transformed into pensions.

As the income distribution model does not differentiate explicitly persons within an income group into age cohorts, at first, all employed persons which reach the age of 65 have to be assigned to the five income groups. This is necessary to calculate the people moving from a certain income group to a lower income group when they start their retirement. Under consideration of the correlation between wage and age, it is obvious that the current share of all employed persons per income group cannot be taken for 65-year-old persons. The share of 65 year old persons still working is significantly lower that for younger age cohorts. The resulting share indicates a more realistic distribution of 65-year-old persons on the five income groups. The second step in the simulation of income mobility caused by transfer from wages to pensions is the determination of the probability that a pensioner declines no, one, two or even three income groups compared to the former situation as an employed. Retired persons in Denmark, UK, Ireland and Czech Republic that belong to the highest income group (High Inc) have to compensate the highest decline in income by three income groups. Assuming that employed persons who reach the age of 65 are distributed equally within the income group, probabilities that the new pension leads to a decline by one, two or even three income groups can be estimated with the help of net replacement rates at average earnings. Similar to the implementation of ageing and education impacts on income mobility, the final number of persons declining from an income group to another is calculated under consideration of elements of uncertainty such as the existence and dimension of additional private pensions. Thus, the resulting probabilities include a calibration parameter which is able to vary the original probabilities in order to meet the statistical development of persons per income group between 1995 and 2009. Regarding the development of pensions and ageing societies in many European countries that are characterised by increasing ratios of retired persons compared with labour force, a trend factor considering the drop of pensions is included as well. The government model within the ASTRA-EC Economic module computed average pensions based on the revenues, expenditures and government policy.

The application of outputs from the income distribution model for the purpose of mobility analysis requires that the income distribution model covers the whole population, not only employed or retired persons. Therefore, also children have to be considered. The ASTRA-EC Population module provides the number of births per time step which enter the Low Inc group, even if at least young children do not have an own income. At the opposite, also deaths have to be extracted from the level variables representing the number of persons per income group. In contrast to births the implementation is more complex. Actually, detailed information about the income status of people in different age classes plus the age-specific death rates would be necessary for distributing deaths among income groups. As at least the needed micro-level data was not available, the share of deaths per income group is derived from the total share of persons per income group. This information allows the determination of outflows caused by death of all five income groups.

$$IMRET_{i,ig-n}(t) = shRET_{i,ig} * RET_i(t) * decIG_{i,ig-n} * cIMRET_{i.ig} * trPEN_i(t)$$ Eq. 4

With: IMRET = new retired persons per country i that move from ig to lower income group ig-n

shRET = share retired persons per country i and basic income group ig

decIG = probability that a new retired person declines by n income groups in country i

RET = number of persons that reach the age of 65 per country i

cIMRET = calibration parameter representing the uncertainty of pensions at retirement

trPEN = factor representing the development of pensions per country i

ig = index for five possible original income groups

n = index for possible decline of income group (n= 0,…,4)

i = index for modelled EU27+2 countries

The loss of a job or a new engagement finishing a period of unemployment represents a further incidence that might induce changes of income distribution. The employment model embedded in the economic module simulates the dynamics of the EU27+2 labour markets. Besides full-time, part-time and full-time-equivalent employment per sector the number of unemployed is one of the main outputs of this model. The change of unemployment respectively the number of new unemployed or the number of new employed constitutes the major input for the modelling of income mobility in this context. As opposed to the impact of retirement, the model assumes that income difference due to unemployment compensations is stronger limited such that new unemployed persons are only moving by a certain probability to the first lower income group. The probability that they have to cope with a strong decrease of income coming from unemployment compensations is definitely higher that for people reaching their retirement. Unemployment can occur in every income group, even well-paid employees in the High Inc group might become unemployed. Therefore, an equal distribution of new unemployed persons among income groups is presumed. The resulting share can be varied in the calibration process such that the final distribution to income groups and, hence, the probability for a decline of one income group might differ. The following equation depicts the described coherence and the computation of income mobility to a lower respectively higher income group caused by new unemployment respectively new employment.

$$IMUE_{i,ig}(t) = (unEMP_i(t) - unEMP_i(t-1)) * cIMUE_{i.ig} * trUEC_i(t) \quad \text{Eq. 5}$$

With:
- IMUE = new unemployed/employed persons per country i that move from ig to lower/higher income group ig-1/ig+1
- unEMP = unemployed persons per country i
- cIMUE = calibration parameter representing the distribution of unemployed per income group ig
- trUEC = factor representing the development of unemployment compensation per country i
- ig = index for five possible original income groups
- i = index for modelled EU27+2 countries

According to Kuznets (1965) and Harrison and Bluestone (1990) the structural transfers of employment from primary to secondary respectively secondary to tertiary sector can be considered as main driver of income inequality. This theory is also represented in the ASTRA-EC income distribution model. Eurostat provides information about the average monthly wages per economic sector. Based on this empirical data and the number of employed persons per sector, the model estimates the total income generated by all employees and self-employed persons of all sectors. Total monthly income changes due to structural changes of the labour market and income trends that are implemented as exogenous factor determining the prospective development of income per sector.

The income distribution model assumes that the difference between total income of period t and the previous period t-1 determines the number of persons that move to a lower or higher income group. Ergo, the model divides total income difference per country by the average distance to the next higher (if income increases) or next lower income group (if income decreases). The resulting number represents the potential number of persons that move to a lower respectively higher income group induced by sectoral employment changes. Similar to the approaches applied for the distribution of potential income mobility to an original income group, the potential persons moving to other income groups are distributed to their origin income group according to a calibration parameter. The following equation points out this approach:

$$IMSE_{i,ig}(t) = \frac{\sum_{s}\left[nY_{i,s} * trnY_{i,s}(t) * (EMP_{i,s}(t) - EMP_{i,s}(t-1))\right]}{disIG_{i.ig}} * cIMSE_{i.ig} \qquad \text{Eq. 6}$$

With: IMSE = new unemployed/employed persons per country i that move from ig to lower/higher income group ig-1/ig+1

nY = average net income per country i and sector s

disIG = average monetary distance to lower/higher income group per country i

EMP = employed/self-employed persons per country i and sector s

cIMSE = calibration parameter representing the probability for income mobility from income group ig to lower/higher income group

ig = index for five possible original income groups

s = index for 25 economic sectors covered in ASTRA-EC

i = index for EU27+2 countries

Another driver of income inequality detected by Harrison and Bluestone (1990) is coming from the number of single parent households in an economy. Due to limited time budget for working the share of part-time employed is very high in this group. Hence, a probability of income mobility from a higher to a lower income group is implemented via a calibration factor.

The last effect considered as driver of income distribution is the development of direct taxes and social contributions. Initiated by redistribution policies of governments, changes of direct taxes and contributions directly impact the composition and structure of income distribution. The chosen approach for the integration of impacts of direct tax and social contribution changes is similar to the described approach for the integration of sectoral employment changes. The only difference from this approach is constituted by the fact that social contributions and direct taxes depend on the level of income. Hence, the distribution of effects to persons of different income groups is not linear. Based on income specific taxes in each country, the financial burden is estimated and distributed to the persons in the respective income groups. For this purpose, the average income under consideration of equal distribution of incomes within the five income groups is taken. Similar to the impacts of sectoral employment changes, changes in direct taxes and social contributions generated in the government model of the Economic module might cause for a certain number of employed a decline or an ascent of one income group.

$$IMTAX_{i,ig}(t) = \frac{(TAX_i(t) - TAX_i(t-1)) * EMP_i(t) * shEMP_{i,ig}}{disIG_{i.ig}} * cIMTAX_{i.ig} \qquad \text{Eq. 7}$$

With:

IMTAX =	new employed persons per country i that move from ig to lower/higher income group ig-1/ig+1 because of taxation changes
TAX =	average direct tax and social contribution per person per country i
disIG =	average monetary distance to lower/higher income group per country i
EMP =	employed/self-employed persons per country i
shEMP =	share of direct taxes and social contributions to be paid by income group
cIMTAX =	calibration parameter representing the probability for income mobility from income group ig to ig+1/-1 group caused by taxation changes
ig =	index for five possible original income groups
i =	index for modelled EU27+2 countries

The final change in terms of income mobility between the five income groups is determined by summing all the milestones in the life of a person that could have an impact on the income. Starting with reaching a certain education level, the persons move with a certain probability to a higher income group due to the correlation between age and income which is realistic due to increasing knowledge and experience in their jobs. Changing unemployment can cause further negative impacts in income as well as getting retired. At least in a number of EU member states the average pensions are lower than the average wages during the period of being employed before. Changes of employment between sectors coming from the ASTRA-EC employment model further impact income distribution and are accounted dynamically to the other changes. Finally, the taxation policy can induce positive or negative changes for employed people. The result is the allocation of the whole population to income groups respectively the income mobility over time.

4 The Economic module

The main objective of the Economic module (MAC) is to simulate the national economic framework estimating important indicators that are essential for a comprehensive modelling of all other modules. Regarding the original vision of the ASTRA-EC model development – the assessment of transport strategies – the macroeconomic module has to simulate the impacts of money flows and compensation mechanisms which are induced by transport policies. These impacts can be initiated by new transport infrastructure investments, additional road charging expenditures, energy price developments, changes of taxation, etc.

Originally, the ASTRA-EC Economic module was developed under consideration of several economic theories. Thus, it cannot be categorised explicitly into only one economic category of models for instance a neo-classic model. The MAC module 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 MAC module also shows attributes of an econometric model. The main output indicator of the MAC module is the gross domestic product (GDP) per country. According to the neo-classical theory of growth, the potential output is equal to the real output or spoken in other words it is equal to GDP. The assumption of efficient production processes leads to this equilibrium. The basic model of balanced growth was developed by Solow and Swan in 1956 (Solow 1956). As opposed to the ASTRA-EC model, technical progress is supposed to be an exogenous driver in this theory. Another important theory explaining the growth of GDP is given by the model of Samuelson and Hicks (Allen 1968). It is derived from the Keynesian multiplier and accelerator model and tries to simulate business cycles. System Dynamics as underlying methodology allows to combine both theories. This allows overcoming the critical assumptions of the Solow model. GDP is not per se equal to the potential output which is closer to reality. The ASTRA-EC model follows this approach described by Schade (2005). In contrast to computable general equilibrium (CGE) models, the GDP is driven by the demand and supply side of an economy.

The following equation demonstrates the implemented dependency of both sides.

$$GDP_i(t) = \begin{cases} wFDa_i * FD_i(t) + (1 - wFDa_i) * PO_i(t) \rightarrow FD_i(t) > PO_i(t) \\ wFDb_i * FD_i(t) + (1 - wFDb_i) * PO_i(t) \rightarrow FD_i(t) \leq PO_i(t) \end{cases} \quad \text{Eq. 8}$$

With:
- GDP = gross domestic product
- FD = final demand
- PO = potential output
- wFDa = weight of final demand if FD>PO
- wFDb = weight of final demand if FD<=PO
- i = index for EU27+2 countries

As opposed to CGE models, the ASTRA-EC MAC module does not simulate the development of prices. Hence, all monetary values of the MAC module and all other ASTRA-EC modules are based on the real term concept and express their values in constant prices of the year 2005.

Regarding the structure of the MAC module, the variables can be assigned to six major sections according to their functionality. These six sections are further disaggregated. Each sub-section is clearly allocated such that the title of the section can be identified by the prefix of the variables (e.g. *MAC_gdp_Gross_Domestic_Product* is a variable in the MAC_gdp sub-section). The main six sections are:

- The demand-side model depicts private household consumption, government consumption, investments and exports-imports and, hence, all four components of final demand.
- The supply-side model simulates influences of the production factors labour, capital stock, natural resources and technical progress on potential output of an economy.
- The sectoral interchange model reflects the interweavements between 25 economic sectors of the national economies.
- The employment model computes the development of EU27+2 labour markets in terms of full-time, part-time and full-time-equivalent employment based on labour productivity and gross value-added as output from sectoral interchange model.
- The government model accounts all revenues, like all forms of taxes, contributions of citizens and revenues from transport charges, and expenditures, e.g. transfers, government consumption and interest payments, of the governments and represents the government behaviour.
- The micro-macro bridges link all micro- and meso-level models, e.g. the Transport module (TRA) or the Vehicle Fleet module (VFT), with the MAC module and vice-versa.

4.1 Demand side model

Final demand is the aggregation of the major demand side indicators: consumption of private households, investments, government consumption and export-import balance. The basic approach is to calculate those variables on the sectoral level and then aggregate them, where necessary, to country level. Consumption and investment are split into a share that is independent from transport (meso- and macroscopic view) and a share that is dependent on the development of the transport markets provided by the Transport (TRA) module and the Environmental (ENV) module (e.g. fuel consumption). Government consumption is calculated within the government model and develops roughly according to GDP and employment development in the government sector. Exports and imports are calculated in the Foreign Trade (FOT) module.

$$FD_{i,s}(t) = C_{i,s}(t) + I_{i,s}(t) + EX_{i,s}(t) - IM_{i,s}(t) + GC_{i,s}(t) \qquad \text{Eq. 9}$$

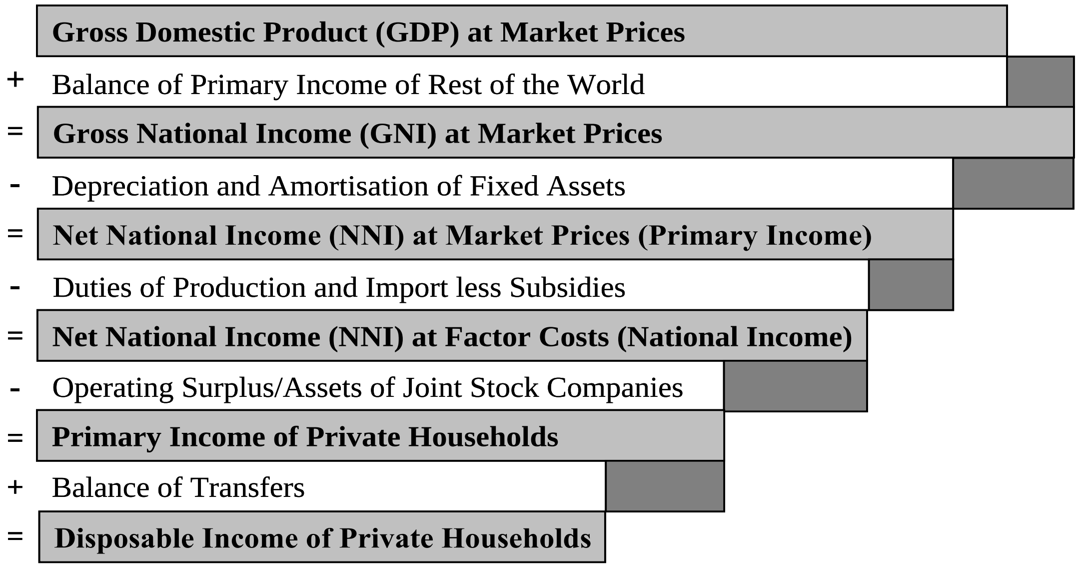
With:
- FD = final demand
- C = consumption of households
- I = investments
- GC = government consumption
- EX = exports
- IM = imports
- s = index for 25 economic sectors
- i = index for EU27+2 countries

The calculation of the components of final demand are presented in the following sections starting with disposable income and taxation as these provide inputs for consumption of private households followed by consumption itself. Then, the investment and the government model are described. The assessment of export and import in the ASTRA-EC Trade module development is described in the chapter 5.

Disposable income

The calculation of disposable income of private households is the baseline for the assessment of consumption of private households in ASTRA-EC. Therefore, it is accounted to the consumption model (*MAC_con*). It follows the principles of the National Accounting Framework (see Figure 4-1). Considering the payments balance between foreigners employed in a country and nationals employed abroad the gross national product is derived. The payments balance is taken exogenously. It might even be omitted as it represents only a small number compared to the totals of GDP or national income. In the following step depreciation, which is calculated endogenously by the capital stock model, is subtracted and one receives the net national product. Subtracting the indirect taxes (including VAT, fuel tax, import taxes and other taxes) and adding subsidies the national income is calculated.

In subsequent steps disposable income is calculated based on national income. Firstly, direct taxes and social protection payments paid by employees and employers are subtracted and secondly transfer payments to households are added. Finally, based on disposable income and employment figures average income per employee and, using the number of adults, the average income per adult are calculated.



Source: Fraunhofer-ISI

Figure 4-1: Income terms in the context of National Accounting Framework

Taxation and other government revenues

The tax model simulates the development of direct and indirect taxes. It is closely related to government balance, as taxes build the major input to government revenues. Hence, the calculation of taxation is assigned to the government model (*MAC_gov*).

The calculation of direct taxes follows a simplified approach that uses trend shares of direct taxes on GDP. Historically, these shares are taken from the Eurostat database. The total amount of direct taxes is then computed by multiplying these country-specific shares with the endogenous GDP.

Indirect taxes are treated differently and more sophisticated as they are stronger influenced by transport. Indirect taxes are distinguished into seven categories of which six could be calculated endogenously based on different categories of consumption expenditures (fuel, transport, non-transport), on fuel consumption, on imports and on transport demand. The remaining part of indirect tax revenues is calculated as percentage share of GDP.

The revenues from the value added tax on fuel consumption are calculated by considering fuel consumption and the fuel price including fuel tax rates and the pure fuel price for different types of fuel. The VAT revenues from transport consumption stem from two sources: first private car purchase are used to calculate VAT revenues from transport production and second the demand for transport services (bus, rail, air) is used to calculate VAT revenues from transport services. The calculation of VAT revenues from non-transport consumption is based on non-transport consumption in the consumption model. Fuel tax revenues depend on fuel consumption and fuel price. Total fuel price for all fuel types is calculated in the ENV module. Import taxes depend on the sectoral imports of each country. An average import tax rate is derived from the OECD Online Database.

Another type of government revenues considered in ASTRA-EC is coming from transport charges. Existing charges like road tolls in some European countries are combined with the transport performance for each mode that is calculated in the TRA module.

The output of the taxation models is used manifold like in the calculations of national income, of disposable income, of shifting private consumption between transport and non-transport consumption and in the government model.

Consumption of private households

The consumption model in ASTRA-EC aims at simulating the consumption expenditure of private households for goods and services in each of the 25 economic sectors covered by ASTRA-EC. The first step in the calculation of consumption consists in the differentiation of total disposable income into total income available for each income group. Therefore, a factor is implemented reflecting the share of income per income group. This factor is linked to the income distribution model and changes due to its dynamics. Total disposable income of private households per income group is used to calculate the potential national consumption of households considering private savings and non-national consumption expenditures. The basic equation for national consumption derived from disposable income is:

$$pC_{i,ig}(t) = DI_{i,ig}(t) * (1 - rS_{i,ig}(t) - rnC_{i,ig}(t) + sh\mathrm{Im}_{i,ig}(t)) \qquad \text{Eq. 10}$$

With:
pC = potential domestic private consumption [Mio*EURO 2005]
DI = disposable income [Mio*EURO 2005]
rS = savings ratio as fraction
rnC = ratio of non-national consumption on disposable income as fraction
shIm = shift from imports to national consumption as fraction if imports decrease
ig = index for five possible original income groups
i = index for EU27+2 countries

The ASTRA-EC consumption model is differentiated into two main parts. As the Transport module, the Vehicle fleet module and the Environmental module simulate car purchase, fuel consumption, expenditures for transport services, for insurances as well as for maintenance of cars, these detailed inputs are used in the consumption model on aggregate national level. It has to be taken into account that either net values e.g. for the price of cars or fuel has to be taken or that taxes, especially VAT, have to be subtracted later on as the calculated changes in consumption are at some point affecting the input-output table, which excludes VAT.

$$TC_{i,ig}(t) = ((1 - shBT) * \sum_{cc}(CP_{i,cc}(t) * VP_{i,cc}(t)) + \sum_{m}(TP_{i,m}(t) * TCost_{i,m}(t)) + \sum_{f}(fFC_{i,f}(t) * netfFP_{i,f}(t))) * shTCI_{i,ig} \qquad \text{Eq. 11}$$

With:
TC = net consumption expenditures for transport [Mio*EURO 2005]
shBT = share of business trips on car trips as fraction
CP = car purchase
VP = net vehicle price excluding VAT etc. [EURO 2005/car]
TP = passenger transport performance [Mio*pkm]
TCost = net unit transport cost excluding VAT [EURO 2005/pkm]
fFC = fuel consumption [Mio*l]
netFP = net fuel price excluding VAT and fuel tax [EURO 2005/l]
shTCI = share of total consumption expenditures spent by income groups
ig = index for five possible original income groups
cc = index for car vehicle categories
m = index for passenger service modes (bus, rail, air)
f = index for fuel types
i = index for EU27+2 countries

Non-transport consumption includes all domestic private consumption excluding all consumption expenditures for private transport purposes. The difficulty in calculating non-transport consumption lies in the difference of taxation between non-transport consumption and transport consumption. Prerequisite for the calculations non-transport domestic consumption is that transport consumption in the current period *t* is determined by the micro level transport model on the base of the modal-split and car-purchase decisions of passenger transport users. This enables to calculate the delta between transport consumption in the current period and the previous period as a first indicator for the shift of consumption between transport and non-transport consumption. This indicator then has to be adjusted for the taxation differential between the two consumption purposes, which is made by multiplying it with the ratio of total tax on transport consumption and total tax on non-transport consumption. The first term calculates the non-transport consumption on the base of the share of non-transport consumption and total consumption in the previous period (*t-dt*). If there happens to be no change in transport demand this term would be equal to the current non-transport consumption.

$$nTC_{i,ig}(T) = \frac{nTC_{i,ig}(t-dt)}{C_{i,ig}(t-dt)} * pC_{i,ig}(t) + \left[TC_{i,ig}(t-dt) - TC_{i,ig}(t)\right] * rTnT_i(t) \qquad \text{Eq. 12}$$

With:

With:	nTC=	non-transport domestic consumption [Mio*EURO]
	C =	total domestic consumption
	pC =	potential domestic consumption
	ig =	index for five possible original income groups
	rTnT=	ratio taxation of transport consumption to non-transport consumption
	i =	index for EU27+2 countries

Finally, non-transport consumption is disaggregated into the 25 economic sectors using exogenous split factors for each of the five income groups. These split factors represent one of the most important exogenous inputs to ASTRA-EC. The data for these consumption split factors is derived from Eurostat.

Two issues should be clarified: firstly, the consumption split factors are relevant only for those sectors or shares of sectors that are not affected by transport. Secondly, sectoral composition of consumption varies due to two different reasons: either by changes in the split factors that come exogenously into ASTRA-EC or by changes in the transport consumption that depends on the transport model. The equation for the sectoral split looks rather simple:

$$nTC_{i,ig,s}(t) = nTC_{i,ig}(t) * CS_{i,ig,s}(t) \qquad \text{Eq. 13}$$

With: nTCs =sectoral domestic non-transport consumption [Mio*EURO]

nTC = total domestic non-transport consumption

CS = consumption split factors

ig = index for five possible original income groups

s = index for 25 economic sectors

i = index for EU27+2 countries

Final step in the consumption model is to compose the total sectoral consumption per country out of the two elements: sectoral non-transport consumption and different categories of transport consumption. The latter affects sectors that are directly influenced by transport, which are the energy sector including fuel products, the transport equipment sector including car manufacturing and the two transport service sectors including passenger transport services (inland transport sector: bus and rail expenditures; air and maritime transport sector: air expenditures).

$$C_{i,ig,s}(t) = nTC_{i,ig,s}(t) + \begin{cases} FC_{i,ig}(t) \rightarrow s = 2 \\ CC_{i,ig}(t) \rightarrow s = 10 \\ TSC_{i,ig,m}(t) \rightarrow s = 19 \wedge m = bus, rail \\ TSC_{i,ig,m}(t) \rightarrow s = 20 \wedge m = air \\ 0 \rightarrow s \notin [2,10,19,20] \end{cases} \qquad \text{Eq. 14}$$

With: C = sectoral domestic private consumption [Mio*EURO]

nTCs = non transport sectoral domestic consumption of households

FC = private fuel consumption expenditures

CC = private car consumption expenditures

TSC = private transport services consumption

m = index for modes providing passenger transport services (bus, rail, air)

ig = index for five possible original income groups

s = index for 25 economic sectors

i = index for EU27+2 countries

Investment model

The investment model constitutes one of the most important models for long-term development of ASTRA-EC. Investments are influenced either by decisions in the transport system or by macroeconomic influences. In total seven influences are considered:

- Investment in transport vehicles (business cars, buses, trucks, trains, planes, ships),
- Investment in transport facilities like stations or container terminals,
- Transport network investment as part of government investments,
- Trends in private sectoral consumption,
- Sectoral exports,
- Government debt influencing the interest rate development,
- Utilisation of production stock reflected by ratio demand to potential output.

Different to the consumption model investments are not limited by a ceiling, which in the case of consumption is given by disposable income of private households. Nevertheless, the model should reveal sectoral shifts of investments that are driven by the various sectoral influences affecting the investment model.

Table 4-1: Overview of investing sectors and sectors producing investments

Investing sectors	**Sectors producing investment goods/services**
Agriculture	Metal products
Energy	Industrial machines
Chemicals	Computers
Vehicles	Electronics
Food	Vehicles
Trade	Other manufacturing
Communication	Construction
Banking	Trade
Other-market services	Other-market services
Non-market services	

Sectoral demand for investment and sectoral production of investment goods are both unevenly distributed between the sectors. Therefore, ASTRA-EC considers ten major economic sectors that are mainly driving the demand for investment in goods and services. Similarly to the demand there are nine sectors which produce the majority of investment goods and services. Those sectors are highlighted in Table 4-1.

Since production of vehicles is calculated in dependency from the developments of the transport system only eight sectors have to be considered for implementation with a detailed investment model, while contributions to investments from the other sixteen sectors could be modelled by an aggregate model. In the following first the complex model is presented followed by the simple model. Both are combined in equation 17.

The first and one of the most important influences on investments following Keynesian approaches remains private consumption. Hence, in ASTRA-EC a linkage is implemented between consumption and investment by taking the trends of sectoral consumption of the 10 sectors showing the highest investment demand, amplifying these to make the model more sensitive and multiplying it with a matrix of calibrated coefficients. The resulting matrices of changes are aggregated for the sectors producing investment goods. Schade (2005) describes this in detail. This function is shown in the following equation:

$$tCI_{i,s8}(t) = \sum_{s10} \left[e^{\left[10 * \left[\frac{dC_{i,s10}(t)}{dT} - trC_i \right] \right]} \right] * CIM_{i,s10,s8} \qquad \text{Eq. 15}$$

With:

- tCI = trend influence of consumption on investments for investing sectors [dmnl]
- dC/dT = change of sectoral consumption in the last year
- trC = minimum change required to have a positive impact on investment
- CIM = matrix of calibrated coefficients linking the consumption changes of each of investment demanding sectors to major investment producing sectors
- s8 = index for 8 economic sectors that produce investment goods
- s10 = index for 10 economic sectors that demand investment goods
- i = index for EU27+2 countries

The second influence of the detailed investment model is provided by exports. Again the trends of exports of the 10 sectors showing the highest investment demand are taken and multiplied by a matrix of calibrated coefficients to calculate the aggregated change of investments for the sectors producing investment goods.

$$tEI_{i,s8}(t) = \sum_{s10} \frac{dE_{i,s10}(t)}{dT} * EIM_{i,s10,s8} \qquad \text{Eq. 16}$$

With: tEI = trend influence of exports on investments for investing sectors [dmnl]

dE/dT =change of sectoral exports in the last year

EIM = matrix of calibrated coefficients linking the export changes of each of investment demanding sectors to major investment producing sectors

s8 = index for 8 economic sectors that produce investment goods

s10 = index for 10 economic sectors that demand investment goods

i = index for EU27+2 countries

The influences of the aggregated investment model that is applied for the calculation of investment production of the remaining 16 sectors are provided by the trends of total consumption and total exports that are multiplied by calibrated coefficients per sector to generate changes of investments for these sectors. The trends for influences of consumption are extrapolated for half a year into the future to reflect that investment decisions to some extent depend on the future expectations of investors, where consumption accounts for one of the most important factors to influence expectations. The resulting functions for investments of sectors excluding the vehicle sector are shown in the following equation:

$$nvI_{i,s24}(t) = I(t-dt) * \begin{cases} EXT(tCI_{i,s8}(t)) + tEI_{i,s8}(t) \rightarrow s24 \in s8 \\ EXT\left(\frac{dC_{i,s16}(t)}{dT}\right) * cCI_{i,s16} + \frac{dE_{i,s16}(t)}{dT} * cEI_{i,s16} \rightarrow s24 \in s16 \end{cases} \qquad \text{Eq. 17}$$

With: nvI = sectoral investments excluding the vehicle sector [Mio*EURO 2005]

EXT = function to extrapolate a given trend half a year into the future

tCI = trend influence of consumption on investments for investing sectors s8

tEI = trend influence of exports on investments for investing sectors s8

dt = integration period of ASTRA-EC is equal to one quarter

T = simulation period of ASTRA-EC is equal to one year

dC/dT = change of sectoral consumption in the last year

dE/dT = change of sectoral exports in the last year

cCI = calibrated coefficients linking the change of total consumption to the 16 sectors that produce investment goods only to minor extent

cEI = calibrated coefficients linking the change of total exports to the

16 sectors that produce investment goods only to minor extent

s8 = index for 8 economic sectors that produce investment goods to large extent

s16 = index for 16 economic sectors that produce investment goods only to minor extent

s24 = index for 24 economic sectors excluding vehicle sector

i = index for EU27+2 countries

Investments for the vehicle sector are calculated on the base of inputs from the transport module and the vehicle fleet module. For non-road modes the demand for each mode determines the needed investments into vehicles. This approach presumes that capacity bottlenecks are solved by investment and neglects either capacity adjustments by organisational improvements or the existence of capacity reserves. On the other hand the applied investment coefficients are derived from investment and performance statistics. For road modes a similar approach is followed making the needed vehicle fleet dependent on demand. However, the needed investment is then calculated considering additionally scrappage of vehicles to estimate the total new registrations, which is calculated in VFT module.

The investment for facilities follows for all modes the same approach by using transport demand as the driver for needed investments that is multiplied by a specific investment factor that is either related to transport performance (pkm or tkm) or to volumes (trips or tons). E.g. in the case of air transport demand for facilities depends on trips determining the take-off and landing requirements and not on performance.

Finally, investments per sector are composed out of the single components. In this final step the influences of government debt and utilisation enter the picture.

4.2 Supply side model

The supply side model in ASTRA-EC is providing a limiting and stabilising element in the MAC compared with the demand side represented by final demand. Basic element of the supply side is constituted by a production function of Cobb-Douglas type calculating potential output that incorporates the three major production factors labour supply, capital stock and natural resources as well as technical progress referred to as total factor productivity (TFP). Labour supply, capital stock and total factor productivity are calculated endogenously. The influence of natural resources is yet considered exogenously and is kept close to negligible as so far no sufficient option could be developed to endogenise this link. Since, labour supply, capital stock and to less extent TFP are items that develop more smoothly compared to the more erratic influences of final demand like investment or exports that supply side represented by potential output accounts for a stabilising element in ASTRA-EC.

On the other hand the long-term trend of the model to large extent depends on the supply side as it incorporates three of the most important stock variables of ASTRA-EC, which are capital stock, total factor productivity and population via the input from labour supply. Labour supply in the production function stands for an aggregate of the potential labour force determined by the population model and the total number of yearly worked hours. The latter is based on total employment, another stock, calculated by the employment model and the number of average yearly worked hours.

Capital stock depends on initial gross capital stock, investment (capital goods including transport investments) and scrappage of the capital stock. Total factor productivity in ASTRA-EC is mostly endogenised considering sectoral labour productivity changes, as the only exogenous parameter, weighted by endogenous sectoral gross-value-added (GVA), endogenous sectoral investments that are weighted by their sectoral innovation potential and changes in freight transport times differentiated for the different goods categories. The resulting extended Cobb-Douglas function is presented in the following equation

$$PO_i(t) = bPO_i + cPO_i * TFP_i(t-dt) * (L_i(t-dt))^{\alpha} * (CS_i(t-dt))^{\beta} * (NR_i(t-dt))^{\gamma} \quad \text{Eq. 18}$$

With:

PO =	potential output
bPO =	calibrated parameter for base level variable
cPO =	calibrated parameter for trend factor
TFP =	total factor productivity
L =	labour supply in working hours
CS =	capital stock
NR =	natural resources (exogenous)
α=	calibrated production elasticity labour supply
β =	calibrated production elasticity capital
γ =	production elasticity natural resources
i =	index for EU27+2 countries

In contrast to standard Cobb-Douglas functions the elasticities of capital and labour need not add to 1 since calibration is not performed by regressions, but with the Vensim® optimiser, which does not has any restrictions on the functional forms of equations, besides that one should limit the number of parameters calibrated by one optimisation to avoid excessive running times.

The components of potential output are modelled separately within the *MAC_gdp* model. The calculation of total factor productivity, gross capital stock as well as labour supply is described in the following sections.

Total factor productivity model

The consideration of technical progress is of key importance for ASTRA-EC. Initial attempts in the model followed the approach depicted by Solow (1956) using an exponential function both with an exogenous technological progress and the time variable in the exponent. However, this incorporates two difficulties: Firstly, in the long-run the exponential economic growth tends to explode uncontrollable, and secondly it does not at all react to policies.

This brings us to the requirements for developing a model for technological progress, which we will call total factor productivity (TFP) in the following as it stands in ASTRA-EC for an aggregate productivity figure of an economy. The first requirement would be that influencing variables of TFP should be part of ASTRA-EC. In the literature patent statistics are seen as relevant indicator to measure and drive innovations (e.g. Grupp 1997) but modelling patents would be beyond the scope of ASTRA-EC. A second requirement would be that literature or at least plausibility suggests using these variables as influence on TFP.

The first variable selected by these criteria is represented by sectoral labour productivity, which in itself constitutes a productivity measure and hence should be considered for being an influence on TFP. However a sector with high productivity but low relevance for an economy e.g. expressed by its share on national gross-value added should exert lower influence on TFP than a sector with low productivity and a high share on national GVA. Since sectoral GVA is provided endogenously by ASTRA-EC as an output from the sectoral interchange model it could be used to calculate a weighted sectoral productivity as impact on TFP.

The second influence should come from investments as it could be argued that productivity improvements are either induced by improved organisation or by improved "production" technology in a very broad sense. Obviously new technology needs investments but the argument could also be extended to organisational measures that often require investments in consultancy support, which would appear as investment into the sector other-market services in ASTRA-EC. A difficulty remains to aggregate the sectoral investments into a national total factor productivity indicator. For this purpose sectoral weights are introduced. The weights are assumed to be on a scale between 0 and 10 with 10 providing the highest increase of TFP per unit of investment.

Today freight transport forms an important element of production processes that often are carried out in a sequence of production steps at different locations all over the world. Therefore a freight transport system connecting these production locations is part of the overall production process and the general productivity driving the production potential of an economy. Hence, freight time-savings are used as the third input factor of Total Factor Productivity (TFP).

The three drivers of TFP described in the previous paragraphs are aggregated either from detailed sectoral level or from the differentiation into modes, goods categories and distance categories into three blocks of country-specific values that are composed to one aggregated change of TFP per country using one weighting factor per block.

Capital stock model

The objective of the capital stock model is to provide two outputs: firstly, gross capital stock that is used as production factor to calculate the potential output by the adapted Cobb-Douglas function, and secondly, depreciation that depends on net capital stock and would be required for the calculation of national income. Two categorisations are relevant for capital. On the one hand capital could be distinguished into private and public capital, which makes a difference e.g. in terms of depreciation periods as public capital most often consists of buildings and other infrastructure with long usage and depreciation periods. On the other hand given the two required outputs a differentiation into gross and net capital becomes necessary.

Gross as well as net capital stock is represented via level variables in ASTRA-EC initialised with data of the year 1995. The calculation of private and public gross capital is shown in the following equations. Private gross capital at time *t* is calculated by adding total investments *I* in *t* to the private gross capital of the previous period *t-dt* and subtracting public investments *GI* as well as the depreciated investments of the year *t-prAl* whereas *prAl* represents the average life time of private capital:

$$prGC_i(t) = prGC_i(t-dt) + \left(I_i(t) - GI_i(t) - I_i(t - prAL_i)\right) \qquad \text{Eq. 19}$$

With: prGC = private gross capital stock [Bio*EURO 2005]

I = total investment [Bio*EURO 2005]

GI = government investment [Bio*EURO 2005]

prAL = average life time of private capital [Year]

$$puGC_i(t) = puGC_i(t-dt) + \left(GI_i(t) - I_i(t - puAL_i)\right)$$ Eq. 20

With: puGC = public gross capital stock [Bio*EURO 2005]
GI = government investment [Bio*EURO 2005]
puAL = average life time of public capital[Year]
i = index for EU27+2 countries

The detailed calculation of private and public gross capital requires information about investments made many years before the initial year of simulation 1995. As an example public investments made in 1966 with an average life time of 30 years are subtracted by the stock in the year 1996. This represents the depreciation. As ASTRA-EC only starts in 1995, the depreciation for the first 20 to 30 years of simulation are an exogenous input to ASTRA-EC which need to be estimated as no statistics exist for the time period from 1965 to 1990.

Finally, gross capital is composed out of its two elements:

$$GC_i(t) = puGC_i(t) + prGC_i(t)$$ Eq. 21

With: GC = gross capital stock [Bio*EURO 2005]
puGC = public gross capital stock [Bio*EURO 2005]
prGC =private gross capital stock [Bio*EURO 2005]
i = index for EU27+2 countries

Net capital stock shows one significant difference to the calculations of gross capital stock. Depreciation is not affected by delays as scrappage. It starts directly after the investment is made by depreciating capital linearly with a fraction that depends on the depreciation period of capital. Another important output of the net capital stock model is constituted by total depreciation in the economies that is required to derive national income from GDP.

Labour supply

The second important production factor in the calculation of potential output is labour supply. The development of human resources in terms of labour supply depends on the dynamics within the EU27+2 labour markets. Labour supply is expressed in Million hours worked per year by all employed and self-employed persons in an economy. The number of full-time-equivalent employment is the baseline for its calculation. Average annual working hours per full-time equivalent employed are taken from Eurostat. The number of full-time-equivalent employed persons is calculated in the ASTRA-EC Employment model.

Especially in times of crisis, labour supply contains more information about the labour market then just employment. Reduced working hours as a strategy in times of decreasing demand for products and services can be reflected via this production factor.

4.3 Sector interchange model

The main objective of the sectoral interchange model is to simulate the indirect effects of developments within the modelled 25 economic sectors. This sectoral differentiation is also used in the ASTRA-EC Consumption, Investment and Employment model. Shifts between sectors of consumption and investment impact the sectoral interweavement such that the basic input-output tables are not being kept constant over time. Changes in sectoral final use composed out of sectoral household and government consumption, sectoral investments and sector exports influence the structure of the input-output tables as well as transport and energy price changes. This impact is implemented by updating the inverse input coefficients, the so-called Leontief Inverse, (Leontief 1966) under the assumption that a constant relationship between value-added and total use exists. This process is repeated after each change of the intermediates matrix. Then, the re-calculation of the matrix of intermediates is based on the matrix of updated inverse input coefficients. This approach is derived from the ESCOT model (Schade et al 2002).

The sectoral interchange model is based on domestic input-output tables taken from Eurostat for each EU27+2 country. For the initial year 1995, domestic input-output tables extracted from Eurostat are used. The change of input-output table structure over time is then derived by the approach described above. Hence, it cannot simulate immediate changes of the structure due to the success of a certain technology in the future.

Two major outputs emerge from the sectoral input-output-model: sectoral gross-value-added that is used for the calculation of employment and sectoral production value that forms an input for the freight transport generation model. The production value is composed out of sectoral final use and sectoral output of intermediates. Accordingly gross-value added (GVA) is derived from production value subtracted by the input of intermediates in each sector.

$$IO_{i,is,os}(t) = \mathrm{IO}_{i,is,os}(\mathrm{t-dt}) * \Delta \mathrm{TCost}_{i,is}(\mathrm{t}) + \mathrm{invKO}_{i,is,os}(\mathrm{t}) * \Delta \mathrm{FU}_{i,is,os}(\mathrm{t})$$ Eq. 22

With: invKO = matrix of inverse coefficients = Leontieff inverse

I = identity matrix

IO = matrix of intermediates of input-output-tables [Mio*EURO 2005] (not used)

ΔFU = change of final use [Mio*EURO 2005]

ΔTCost = change of transport cost

is = index for sectoral inputs in the input-output-table

os = index for sectoral outputs in the input-output-tables

i = index for EU27+2 countries

4.4 Employment model

The employment model simulates the development of national labour markets, estimates sectoral employment trends, distinguishes between full-time and part-time employment and computes unemployment. It provides valuable information for several other modules and models of the MAC module. For example, the data of total hours worked (labour supply) is used as input in the production function, employment and unemployment numbers are needed to calculate social contributions, direct taxes and benefits for unemployed as revenues and expenditures in the government model.

The most important input to the employment model is gross-value added provided by the sectoral interchange model (*MAC_iot*). Relating this to exogenous labour productivity, i.e. reversing the usual calculation of productivity as the ratio between value-added and employment, the number of full-time-equivalent (FTE) employed is calculated:

$$FTE_{i,s}(t) = \frac{GVA_{i,s}(t) * 1000000}{LP_{i,s}(t)}$$ Eq. 23

With: FTE = full-time-equivalent employment [Persons]

GVA = gross-value added [Mio*EURO 2005]

LP = labour productivity [EURO 2005/full-time-equivalent employed person]

s = index for 25 economic sectors

i = index for EU27+2 countries

Labour productivity per sector is derived from statistical numbers for full-time-equivalent employment and gross value-added per sector for the period from 1995 to 2010. For future development, an exogenous trend for labour productivity is assumed. This trend is derived from EC DG ECFIN (2012). Besides the exogenous trend for labour productivity the model considers also an endogenous driver depending on the level of unemployment. If the level of unemployment achieves a rate below 5 %, then the ASTRA-EC model assumes a stronger future increase of labour productivity in order to compensate the probable lack of employees. This reaction could be observed in the past and will be of strong importance when the number of labour force in many EU member states will decline due to ageing societies.

The integration and continuation of statistical trends for part-time and full-time employed per sector allow the estimation of total full-time and part-time employment per sector. Activity rates that are calibrated in the Population module provide the necessary information to determine unemployment rates per country.

The ASTRA-EC model allows in theory to simulate more direct impacts of transport strategies and policies. Therefore gross-value added can be switched from the classical calculation based on input-output tables to a separate calculation for the vehicle production sector and the transport service sectors. GVA of the transport vehicle sector is derived from vehicle investments into all modes, from private consumption of vehicles, from exports of the vehicle sector and sectoral labour productivity of the vehicle sector. Using the assumption that the ratio GVA to production value is the same between output of the vehicle sector that is used as intermediate output and that is produced for final use the ratio taken from the IO-tables can be used to derive GVA of the vehicle sectors from the three categories of final use. A similar approach as for the vehicle sector is chosen for the two transport service sectors transport inland services and transport air maritime services. In this case the three different categories to consider for the calculations of GVA consist of: Firstly, final use in terms of net passenger consumption expenditures; Secondly, expenditures for domestic freight transport services; Thirdly, exports of transport services. Again the ratio GVA to production value from the IO-tables is applied to estimate GVA of the transport service sectors. Finally full-time equivalent employment could be composed out of the three elements: the general sectoral FTE-employment for all sectors besides the transport production and the transport service sectors, FTE-employment in vehicle production and in the two transport service sectors. The general sectoral FTE-employment is calculated by multiplying the sectoral GVA from the input-output model with the sectoral labour productivities. As Eurostat does not provide the relevant data for the calculation of FTE employment, the ASTRA-EC model derives the FTE employment for all sectors from the gross value added calculated in the sectoral interchange model.

The next step in the employment model consists in the calculation of total employment. This means a split of FTE-employment into a share of persons working full-time i.e. having a 5-days job with average weekly working hours between 35 and 45 hours depending on the country of residence and a share of persons working part-time. The latter could be defined opposite to full-time as working not full-time but less than the average weekly working hours. This reflects the large degree of variation that can be found with part-time employment ranging from e.g. half-day a week to four days a week. Base data for developing the part-time employment model is taken from the Eurostat database. That enables either to calculate the share of part-time employed on the FTE-employment and to derive a multiplier on how many part-time employed constitute one FTE-employed. Based on these two inputs total sectoral employment can be calculated in ASTRA-EC by the following equation. Furthermore, a growth trend for the share of part-time employed is considered. This growth trend is one of the exogenous leverages to adapt the economic growth as well as the labour market for the future simulation period from 2014 to 2050.

$$EMP_{i,s}(t) = FTE_{i,s}(t) * \left(1 - \left(shPT_{i,s} * trPT_i(t)\right)\right) + FTE_{i,s}(t) * \left(shPT_{i,s} * trPT_i(t)\right) * PTF_{i,s} \quad \text{Eq. 24}$$

With: EMP = total employment [Persons]

FTE = full-time equivalent employment [Persons]

shPT = sectoral share part-time employment

trPT = trend part-time employment

PTF = part-time factor reflecting the number of part-time employed equivalent to one full-time employed

s = index for 25 economic sectors

i = index for EU27+2 countries

Finally, the employment model derives unemployment based on total employment and active labour force. Active labour force is an indicator computed in the Population model based on the number of labour force per country and the country-specific activity rate extracted from Eurostat. Due to the demographic decline in EU27+2 until 2050 the activity rate, representing the share of labour force people that are active on the labour market, is assumed to increase slightly. This is assumed to be necessary in order to avoid severe labour shortages in EU27+2.

4.5 Government model

The main objective of the government model is to account all revenues and all expenditures of a national state in order to provide significant information to other models. It enables to control the financial impacts of transport policies on national budgets. Furthermore, it provides a few feedbacks to other models e.g. the dampening impact on investments if government debt becomes too large in comparison to GDP. Finally, it offers several leverage points to implement policies though these would not necessarily be transport policies but could be treated as accompanying to transport policies e.g. changes of transfers to households for children or of direct taxes both to increase consumption if a transport policy would alter consumption significantly.

Three main components define the government model of which two are aggregating mechanisms for government revenues respectively expenditures and one is the balancing mechanism for the government budget by increasing or reducing government debt.

The single components of revenue and expenditure of government budget can be distinguished into indicators computed endogenously by ASTRA-EC and into indicators that could be derived as a percentage of GDP. The latter would constitute a rough approximation approach, though being not completely exogenous as GDP is modelled endogenously in ASTRA-EC. Also Eurostat statistics tend to present many of these categories as percentage of GDP.

On revenue side six categories exist of which two have to be considered with the percentage-to-GDP approach: direct taxes and other taxes. Revenues modelled in detail comprise most of the indirect taxes like value-added tax (VAT) on general consumption and on fuel consumption, fuel tax and import tax. They also include any charges on transport like road tolls that could all be calculated based on output from the transport model. Finally, social contributions could be derived since these depend on total employment.

To calculate the social contributions per employee ASTRA-EC has to take into account the different social systems in the EU27+2 countries. In order to avoid a complex calculation of social contribution, the model is based on social contributions per employee. This is required for calculating the total yearly social contributions

The expenditure side of government budget consists of eight elements of which one is completely exogenous and constant, which are subsidies, and two have to be considered with the percentage-to-GDP approach: government investment and government expenditures for materials. Subsidies are aggregated exogenous inputs and not further differentiated by mode. The other elements are linked to specific variables of ASTRA-EC. Government consumption consists of government wage payments and government expenditures for materials where the former depend on employment and wage level for non-market-service sector.

Government investments are composed out of two elements: firstly, transport network investments, and secondly investments for other purposes. The latter are based on the share-to-GDP approach while the former consist of one component describing network investments per mode also with the share-to-GDP approach and a second component that is related to policy implementation.

Transfers to households consist of three elements: firstly, transfers to children respectively their families; secondly, transfers to retired, and thirdly transfers to unemployed. For the calculation of each two inputs are needed: the number of persons concerned and the average rate of transfer per person. The former can be derived either from the population model or from the employment model of ASTRA-EC as explained in previous sections. The latter is taken exogenously from the Eurostat.

To complete the total budget balance the final expenditure item are the interest payments for the debt of government. The level of interest payments depends on the level of debts and on the yearly balance of revenues and expenditures. A positive balance allows reducing debts. Together with the balance of revenues and expenditures explained above generate the final budget balance as shown in the following equation:

$$GBB_i(t) = GR_i(t) - GC_i(t) - GI_i(t) - THH_i(t) - IP_i(t) \quad \text{Eq. 25}$$

With:
- GBB = government budget balance [Mio*EURO 2005]
- GR = government revenues [Mio*EURO 2005]
- GC = government consumption [Mio*EURO 2005]
- GI = government investment [Mio*EURO 2005]
- THH= transfers households [Mio*EURO 2005]
- IP = interest payments of government [Mio*EURO 2005]
- i = index for EU27+2 countries

5 The Trade module

In the period between 1995 and 2008, foreign trade was one of the major drivers of economic growth in most EU27+2 countries. Annual export growth rates are often significantly higher than growth rates of all other important macroeconomic indicators. Improvements in transport systems like efficient logistics or faster connections led to removing trade barriers. Expert expectations confirm that future economic growth will be strongly influenced by foreign trade even if energy prices are continuously increasing which would have a negative impact on trade flows.

The Trade module (FOT) can be differentiated into two parts. The first part represents foreign trade between the EU27+2 countries, the so-called *INTRA-EU trade* model (*FOT_weu*). The second part simulates foreign trade between the EU27+2 countries and countries in the rest-of-the world, the *EU-RoW trade* model (*FOT_row*). Countries in the rest-of-the-world (RoW) are assigned to 15 regions (see Table 5-1).

Table 5-1: Overview rest-of-the-world regions used in the Trade model

ASTRA-EC code	**Rest-of-the-World Region**
ARO	Arabian-African Oil Exporters
ASO	Asian Oil Exporters
AUZ	Oceania
BRA	Brazil
CHI	China
EAS	East Asia
IND	India
JAP	Japan
LAM	Latin America
NAM	North America
RotW	Res-of-the-World countries
RUS	Russian Federation
SAF	South Africa
SOA	South Asia
TUR	Turkey

Source: Fraunhofer-ISI

The structure of the two models is similar as both models are differentiated into bilateral trade flows by country pair for a set of economic sectors. As exports are dominated by the manufacturing sectors, the originally 25 economic sectors are aggregated to 17 sectors in both trade models. The new subscript *TradeSector* consists of all 15 manufacturing sectors and the following two service sectors: *T_Transport_Services*, which is representing all transport services trade flows, and *T_Other_Services*, which is standing for all trade flows in other service sectors.

Regarding the implemented dynamics, the INTRA-EU trade model contains more endogenous drivers than the EU-RoW trade model. Three endogenous and one exogenous factor determine the development of trade between EU27+2 countries:

- different level of sectoral labour productivity of the two trading partners,
- growth of GDP of the importing country,
- world GDP growth,
- generalised time of passenger transport between the two trading partners and
- generalised costs of freight transport between the two trading partners.

Measured historical and estimated future world GDP growth is supposed to be an important driver of foreign trade. A look at historical time series of exports and world GDP growth demonstrates a strong correlation. Hence, world GDP growth is considered to be a valuable exogenous input for the INTRA-EU trade model (Schade/Krail 2004). *[*Projections for GDP growth in world regions abroad Europe are taken from OECD. GDP growth rate of the importing country is the first endogenous influence on trade flows. As consumption and production processes of a country are strongly affecting GDP, this indicator has been chosen as a driver of foreign trade. Competitive advantages compared to trade partners are simulated by an influencing factor representing relative changes of sectoral labour productivities between importing and exporting country. Averaged generalised costs of passenger and freight transport between the trade partners are aggregated from the detailed transport costs and times and reflect the accessibility of a certain trade partner.

In contrast to the INTRA-EU trade model the EU-RoW trade model cannot consider transport costs and times as an impact. The ASTRA-EC Transport module covers only transport activities within EU27+2 countries. Hence, this model is mainly driven by relative productivity between the European countries and the Rest-of-the-World regions. Productivity changes together with GDP growth of the importing Rest-of-the-World-country and world GDP growth drive the export-import relationships between the countries. The growth trend for productivity is estimated based on world GDP growth projections published by the OECD. The aggregation of influences is also similar, with the exception that the two terms representing transport in INTRA-EU model are missing.

$$EX_{i,j,s}(t) = EX(t-dt)_{i,j,ts} * \left(1 + \left(\Delta rPRO_{i,j,ts}(t) + \Delta GDP_{i,j,ts}(t) + \Delta WGDP_{i,j,ts}(t) + \Delta fGC_{i,j,ts}(t) + \Delta pGC_{i,j,ts}(t)\right)\right)$$ Eq. 26

With:

EX	=	sectoral exports between two EU27+2 countries [Mio*EURO 2005]
ΔrPRO	=	influence of sectoral relative productivity changes between period *t* and the previous period *t-dt* [dmnl]
ΔGDP	=	influence of GDP growth between period *t* and the previous period *t-dt* of importing country [dmnl]
ΔWGDP	=	influence of world GDP growth between period *t* and the previous period *t-dt* [dmnl]
ΔfGC	=	influence of changes in accessibility of freight transport between period *t* and the previous period *t-dt* [dmnl]
ΔpGC	=	influence of changes in accessibility of passenger transport between period *t* and the previous period *t-dt* [dmnl]
ts	=	index for 17 trade sectors
i	=	index for exporting EU27+2 country
j	=	index for importing EU27+2 country

The resulting sectoral export-import flows of both trade models are fed back into the Economic module as part of final demand and national final use respectively. Exports are one of the major drivers of investment. Furthermore, the trade model provides the input for international freight generation and distribution within the Transport module.

6 The 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 modelled state-of-the-art in a detailed way, the last step – the assignment stage – is not modelled 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 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.

Geographical dimensions for transport demand

In the transport module of ASTRA-EC, demand is segmented according to the zoning system of the model.

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 between 3 and 50 km);
- **Short distance** (extra NUTS III level or intra NUTS III with travelling distance higher than 50 km);

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 with destination outside the NUTS II zone of origin (at **extra NUTS II level)** is aggregated and represented by NUTS I to NUTS I matrices; nevertheless, since some countries are segmented in one NUTS II zone only (namely Cyprus, Malta, Luxembourg, Estonia, Latvia, Lithuania), the extra NUTS II demand is null and national demand is represented only by intra NUTS II trips. Annex 1 reports the list of NUTS zone by country.

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 with destination outside the NUTS II zone of origin (at extra NUTS II level) is aggregated and represented by NUTS I to NUTS I matrices, with the exception mentioned above for the Countries represented with one NUTS II zones only. In these cases, national demand is represented only at intra NUTS II level.

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

Table 6-1: Segmentation of transport demand

<table>
<tr><td colspan="7">Passenger demand</td></tr>
<tr><td colspan="4">National – intra NUTS II</td><td>National – extra NUTS II</td><td>International European</td><td>Intercontinental</td></tr>
<tr><td colspan="3">Intra NUTS III</td><td rowspan="2">Extra NUTS III</td><td rowspan="2">OD at NUTS I level</td><td rowspan="2">OD at Country level</td><td rowspan="2">Country to world regions</td></tr>
<tr><td>< 3 km</td><td>3 to 50 km</td><td>>50 km</td></tr>
<tr><td>Local</td><td>Very Short</td><td colspan="2">Short</td><td>National</td><td>European</td><td>Intercontinental</td></tr>
<tr><td colspan="7">Freight demand</td></tr>
<tr><td colspan="4">National – intra NUTS II</td><td>National – extra NUTS II</td><td>International European</td><td>Intercontinental</td></tr>
<tr><td colspan="2">Intra NUTS III</td><td colspan="2">Extra NUTS III</td><td>OD at NUTS I level</td><td>OD at Country level</td><td>Country to world regions</td></tr>
<tr><td colspan="2">Local</td><td colspan="2">Short</td><td>National</td><td>European</td><td>Intercontinental</td></tr>
</table>

Source: TRT

The following table summarises 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. Indeed, the ETISplus matrix is a major source for the calibration of the TRA model.

6.1 The passenger transport module

The passenger transport component of the ASTRA-EC model consists of adapted classical 4-stage transport models (*TRA_pass* module).

Namely, passenger trip generation is performed individually for each NUTS II zone, applying trip rates to several population groups based on age structure and income group.

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.

The modal split process is calculated separately for each spatial domain (intra-NUTS II local, intra- NUTS II very short, etc.): direct and cross elasticities to cost variation and time variation (implemented separately) are used, as well as additional elasticity parameters implemented to reflect the contribution of other significant determinants (e.g. car ownership).

The model considers endogenous reactions in all 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.

6.1.1 Passengers demand generation

Passenger trip generation is performed individually for each NUTS II zone, applying trip rates by trip purpose to several population groups based on employment situation, age and income group. In general terms, the following equation is applied:

$$GT_{zgp}(t)= TR_{gp} * Pop_{zg}(t) \qquad \text{Eq. 27}$$

With: $GT_{zgp}(t)$= Generated trips in zone z for purpose p of population group g at time t

TR_{gp} = Trip rate for purpose p of population group

$Pop_{zg}(t)$ = Amount of population group g in zone z at time t

Trip rates by country and groups are estimated from data of national travel surveys and/or derived from the ETIS+ database (see chapter 9.5): since not full information is available for all countries, in some cases data have been estimated assuming an equivalence between similar countries and with the purpose to comply with statistics on trips.

Generated passenger demand evolves over time depending on population size and structure, whereas trips rates are generally kept as fixed[3] even if they can change over time for some countries to reflect changes in the socioeconomic conditions not explicitly modelled. For instance, in new member states car availability is expected to rise in all income groups. Since car availability affect mobility rates, but population is not segmented by car availability in the model, the trip rates can change over time following the motorisation rate.

The model represents all the individuals, including children below 15 years.

As reported in the following table, the population groups implemented for the generation of transport demand consist of 25 combinations (5 income groups out of 5 age groups).

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3 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.

Table 6-2: Population groups: segmentation for transport generation

Population groups	Income	Age
Elements	5 groups (quin-tiles)	P1: Children / young people below 17 P2: Adults 18 to 25 P3: Adults 26 to 59 P4: Adults 60 to 69 P5: Adults above 69

Source: TRT

Trip rates follow the same segmentation, including a differentiation by trip purpose. 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.

As a result of the process, trips generated by income group, age and trip purpose are estimated at NUTS II level.

Right after the generation phase, the amount of trips related to young individuals (P1, below 17) is kept separated from the rest of the process (distribution and mode split): a parallel line of estimation is implemented, in order to take into account the different distribution and mode split of this segment of population. Distribution is limited to the intra-NUTS III destination (local and very short). In particular, it should be underlined that the share of car mode for this segment refers to passenger only (not drivers).

This part of the module include additional options to simulate:

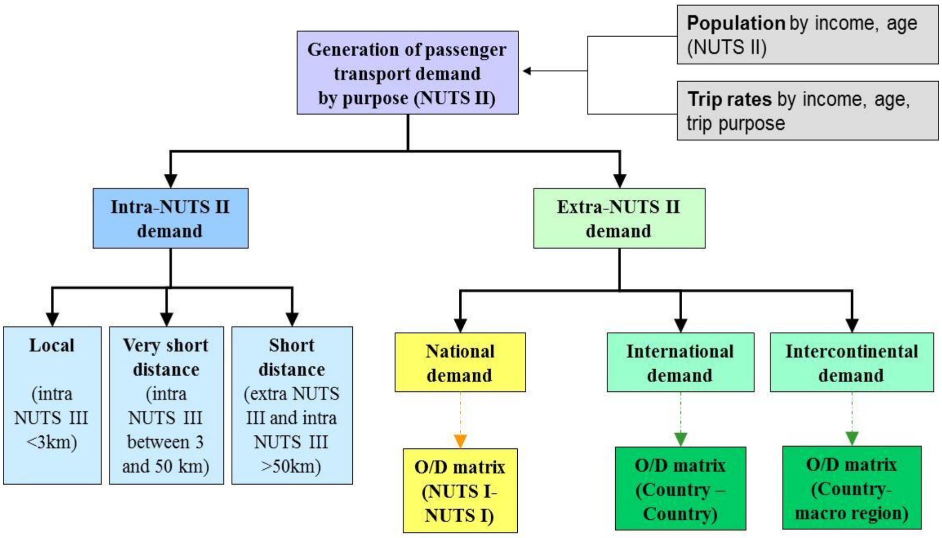
- Reduction of trips caused by crisis,
- Growth trends of trip rates for specific countries (e.g. EU12),
- The effect of teleworking diffusion, resulting from an increase of fuel cost.

All the aspects mentioned above influence the value of the trip rates.

6.1.2 Passengers demand distribution

Trips generated by NUTS II zone are estimated and distributed among all geographical dimensions[4] (from local to intercontinental).

At this level of the estimation process, the segmentation is aggregated with respect to the generation phase: income groups are aggregated (from 5 to 3) and the information on age is not used anymore (except the distinction between young people below 17 and adults). In fact, it is assumed that these aspects are less relevant for the estimation of the following steps of the process. Therefore, the distribution of trips include details on trip purpose and aggregated income group at NUTS II level (9 combinations per each NUTS II zone).



Source: TRT

Figure 6-1: Passenger demand breakdown

4 Local, very short, short, national, international, intercontinental.

Passenger trip distribution is the result of a progressive breakdown of generated demand as shown in Figure 6-1. 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 6.1.1 above).

In general, the allocation depends in each step on the initial value of the specific NUTS II zone, modified over time via elasticities with respect to the variation of generalized cost or other parameters. In general terms, the amount of demand shifted is computed according to equations of the type:

$$\mathrm{D}_{pzg}(t) = \mathrm{BD}_{pzg}(t) \cdot \left(\frac{\mathrm{C}G_{pz}(t)}{\mathrm{C}G_{pz}(t0)} - 1 \right) \cdot \varepsilon_{pzg} \qquad \text{Eq. 28}$$

With: $D_{pzg}(t)$ = Demand for purpose p, in zone z of population group g at time t

$BD_{pzg}(t)$ = Base demand for purpose p, in zone z of population group g at time t

$CG_{pz}(t)$ = generalised cost of trips for purpose p in zone z at time t

ε_{pzg} = Elasticity of demand with respect to changes of the generalised cost of population group g for trips purpose p in zone z

Generalised cost for a specific mode is defined as follows:

$$\mathrm{CG}^m_{pz}(t) = \mathrm{C}^m_{pz}(t) + VOT_{pz}(t) \cdot T^m_{pz}(t) \qquad \text{Eq. 29}$$

With: $C^m_{pz}(t)$ = cost of a trip with mode m for purpose p, in zone z at time t

$T^m_{pz}(t)$ = time spent for a trip with mode m for purpose p, in zone z at time t

$VOT_{pz}(t)$)= value of time for purpose p in zone z at time t

Cost includes only perceived components, namely: fuel and toll cost for car users, tickets prices for public transport and air modes.

In case generalised cost refers to a whole distance band, not related to a specific mode, it results from the weighted average of generalised cost by mode on the basis of trips.

More details on the various steps are reported in the following paragraphs.

Reference shares are mainly derived from the ETISplus database. In principle, reference shares are estimated by trip purpose, 'aggregated income group' and NUTS II zone at each stage of the breakdown process of the trips generated by zone; nevertheless, at national and international level it is assumed that the income group is not relevant for the choice of destination in terms of OD.

Different elasticities are applied depending on the step of breakdown: the variation of distribution at local level is more sensitive than at national or international level. The segmentation of elasticities is reported in the following table.

Table 6-3: Elasticities: segmentation by breakdown step

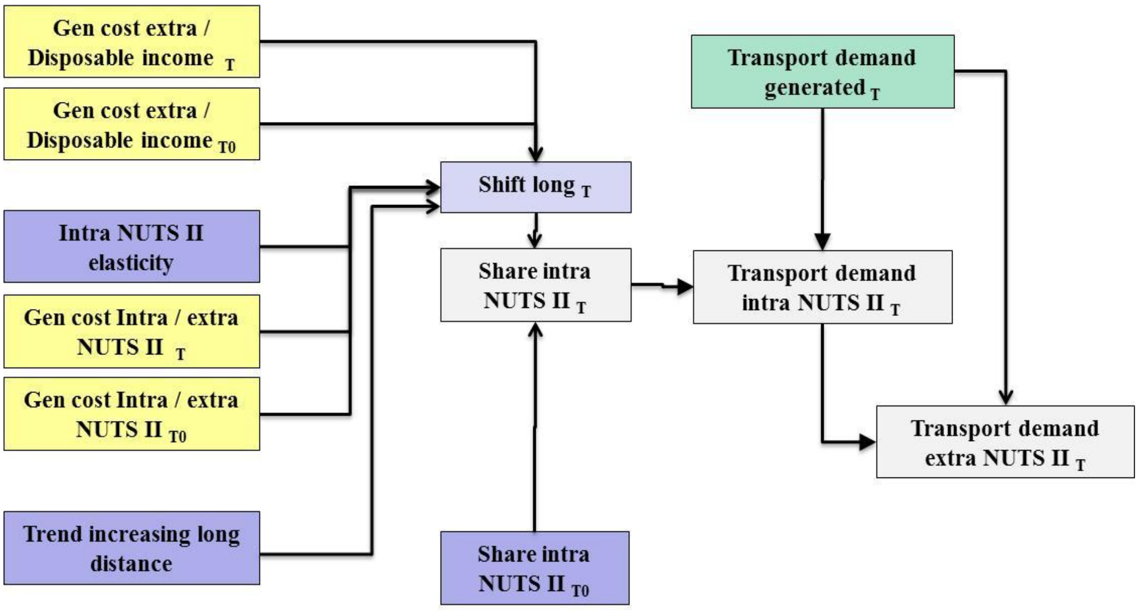
Breakdown Step	NUTS II	Country	Trip purpose	Income
Intra / extra NUTS II	X		X	X
Short / local (intra NUTS II)	X		X	X
Very short / local (intra NUTS II)	X		X	X
OD national		X	X	
OD international		X	X	

Source: TRT

Intra/extra NUTS II segmentation

At the first stage of the process (defining the share of intra/extra NUTS II trips) it is assumed that if long distance travels become cheaper a larger share of total demand is long-distance, but this effect will be smoothed in case the short distance travels become cheaper as well. Thus, an index of the (generalised) cost of extra-NUTS II trips compared to an index of (generalised) cost of intra-NUTS II trips is used in the equation term. Furthermore, in order to avoid an increase of long distance trips in case of an overall increase of cost (both in short and long distance trips), an additional term is added to compare the generalised cost of extra NUTS II trips and the disposable income by adults. In case the generalised cost increase more than the disposable income, the shift toward long distance is unlikely – even if cost of longer distance trips increases less than shorter distance trips' – and therefore prevented.

This phase also includes a parameter changing over time to simulate the trend of increasing long distance trip (reducing the share of intra NUTS II) which has been observed over the years and that is not entirely due to reduction of generalised travel cost but rather on growing social and economic relationships between people and activities located in different regions. This additional parameter captures this trend (and can be used for calibration purposes as well).



Source: TRT

Figure 6-2: Intra/extra NUTS II segmentation

In terms of equations:

$$\mathrm{iNT}_{zpi}(t) = \mathrm{GT}_{zpi}(t) \cdot \mathrm{Sh\_iNT}_{zpi}(t)$$ Eq. 30

With: $\mathrm{iNT}_{zpi}(t)$ = intra NUTS II trips generated by the zone z for the purpose p and the (aggregated) income group i at the time period t

$\mathrm{GT}_{zpi}(t)$ = trips generated by the zone z for the purpose p and the (aggregated) income group i at the time period t

$\mathrm{Sh\_iNT}_{zpi}(t)$ = share of intra NUTS II trips of the zone z for the purpose p and the (aggregated) income group i at the time period t

This latter term is computed as:

$$\mathrm{Sh\_iNT}_{zpi}(t) = \mathrm{Sh\_iNT}_{zpi}(t_0) \cdot \mathrm{LgSh}_{zpi}(t) \cdot \mathrm{LgTr(t)} \qquad \text{Eq. 31}$$

With: $\mathrm{Sh\_iNT}_{zpi}(t)$ = share of intra NUTS II trips of the zone z for the purpose p and the (aggregated) income group i at the initial time period t0 (year 1995)

$\mathrm{LgTr(t)}$ = exogenous trend towards long distance trips, reducing the share of intra NUTS II trips at the time period t

$\mathrm{LgSh}_{zpi}(t)$ = shift towards long distance trips for the zone z for the purpose p and the (aggregated) income group i at the time period t.

As mentioned above, $\mathrm{LgSh}_{zpi}(t)$ depends on two elements, as reported in the following formula:

- the relative change of average generalised cost at extra NUTS II level in comparison to relative change of average generalised cost at intra NUTS II level,
- the relative change of average generalised cost at extra NUTS II level in comparison to relative change of disposable income.

$$\mathrm{LgSh\_}_{zpi}(t) = if\ \frac{\mathrm{GCInc_{zp}}(t)}{\mathrm{GCInc_{zp}}(t0)} \geq 1 \quad \text{then} \quad 1 \quad \text{else} \quad \delta_{zpi} \cdot \left(\frac{\mathrm{GCexin_{zp}}(t)}{\mathrm{GCexin_{zp}}(t0)} - 1 \right) \qquad \text{Eq. 32}$$

With: $GCInc_{zp}(t)$ = ratio between generalised cost of extra NUTS II trips of the zone *z* for the purpose *p* and the private income per person in the zone *z* at time period *t*

$GCexin_{zp}(t)$ = ratio between generalised cost of extra and intra NUTS II trips of the zone *z* for the purpose *p* at time period *t*

δ_{zpi} = elasticity with respect to changes of generalised cost to shift towards long distance trips for the zone *z* for the purpose *p* and the (aggregated) income group *i*

The amount of extra NUTS II trips is computed by difference:

$$\mathrm{eNT}_{zpi}(t) = \mathrm{GT}_{zpi}(t) - i\mathrm{NT}_{zpi}(t) \qquad \text{Eq. 33}$$

With: $\mathrm{eNT}_{zpi}(t)$ = extra NUTS II trips generated by the zone z for the purpose p and the (aggregated) income group I at the time period t

In order to avoid an excessive shift towards extra NUTS II destinations, the equations above include a minimum share of intra NUTS II trips which have to be satisfied. On the other hand (except for the countries represented with only one NUTS II zone), a minimum share of extra NUTS II trips is also defined in the equation.

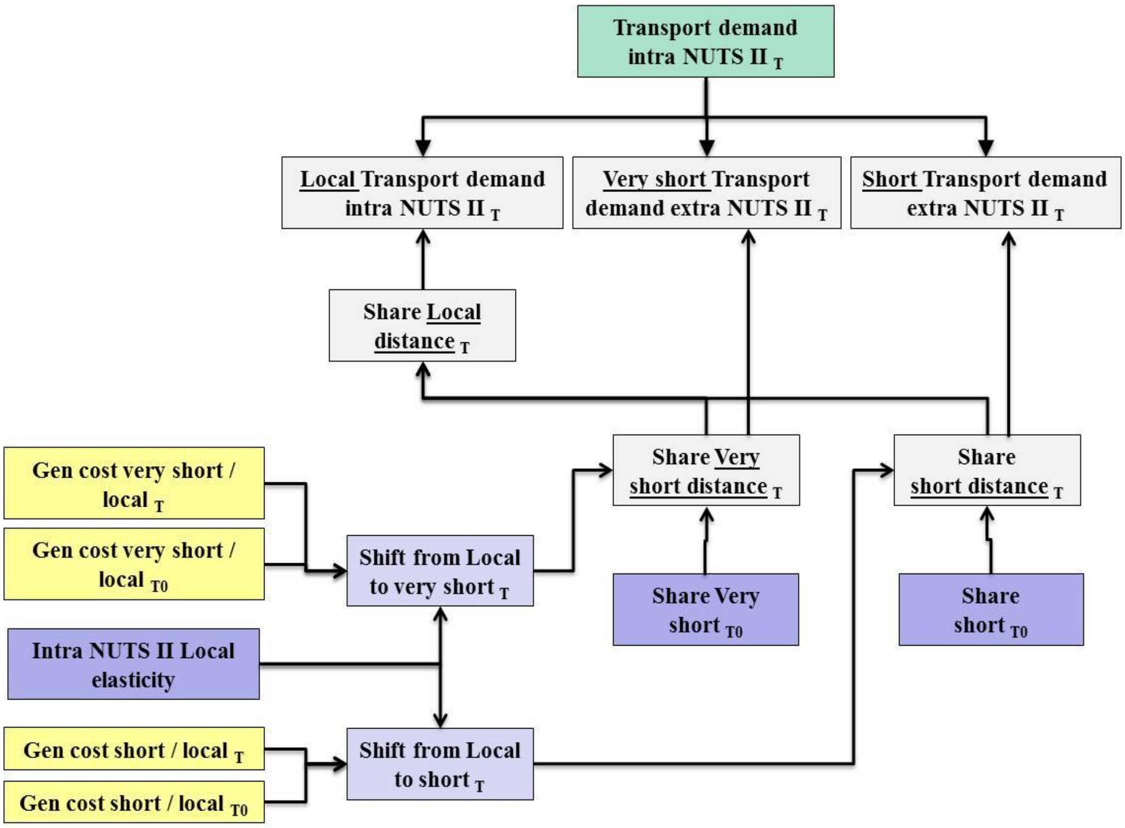
It can be noted that the shift applies only in one direction with respect to the configuration at the time period t_0: from intra to the extra NUTS II (not vice-versa). This means that it is assumed that over time demand moves from shorter to longer distances with respect to the configuration at the time period t_0, or remain within the same distance band. Nevertheless, it allows the model to simulate increase and decrease of the shift over the simulation period (but never below the level observed at the time period t_0).

Intra NUTS II segmentation (local/ very short/ short)

The principle is the same of the first step of segmentation: it is assumed that if long distance travels become cheaper a larger share of total demand is expected to be long-distance, but this effect will be smoothed in case the short distance travels become cheaper as well. The comparison of generalised cost trends is made between the three distance bands at local level in two steps:

- Shift from 'Local' to 'Very short'
- Shift from 'Local' to 'Short'

Both shifts are estimated with respect to local band for sake of simplicity. This way the calculation of local trips can be made in terms of residual.



Source: TRT

Figure 6-3: Intra NUTS II segmentation (local/ very short/ short)

In terms of equations:

$$\mathrm{iNlcT}_{zpi}(t) = \mathrm{iNT}_{zpi}(t) \cdot \mathrm{Sh\_iNlcT}_{zpi}(t) \quad \text{Eq. 34}$$

$$\mathrm{iNvsT}_{zpi}(t) = \mathrm{iNT}_{zpi}(t) \cdot \mathrm{Sh\_iNvsT}_{zpi}(t) \quad \text{Eq. 35}$$

$$\mathrm{iNstT}_{zpi}(t) = \mathrm{iNT}_{zpi}(t) \cdot \mathrm{Sh\_iNstT}_{zpi}(t) \quad \text{Eq. 36}$$

With: $\mathrm{iNxxT}_{zpi}(t)$ = intra NUTS II trips of the distance band xx (xx = lc for local, vs for very short, st for short) generated by the zone *z* for the purpose *p* and the (aggregated) income group *i* at the time period *t*

$\mathrm{Sh\_iNxxT}_{zpi}(t)$ = share of intra NUTS II trips of the distance band xx of the zone *z* for the purpose *p* and the (aggregated) income group *i* at the time period *t*

Shares for distance bands short and very short are computed as follows:

$$\mathrm{Sh\_iNvsT}_{zpi}(t) = \mathrm{Sh\_iNvsT}_{zpi}(t_0) \cdot \mathrm{vsSh}_{zpi}(t) \quad \text{Eq. 37}$$

$$\mathrm{Sh\_iNstT}_{zpi}(t) = \mathrm{Sh\_iNstT}_{zpi}(t_0) \cdot \mathrm{stSh}_{zpi}(t) \quad \text{Eq. 38}$$

With: $\mathrm{xxSh}_{zpi}(t)$ = number of trips shifted from distance band LC towards distance band xx for zone *z* for the purpose *p* and the (aggregated) income group *i* at the time period *t*.

The values of variables $vsSh_{zpi}(t)$ and $stSh_{zpi}(t)$ depends on the relative change of average generalised cost at *xx* level with respect to the local (lc) level according to the general Eq. 28.

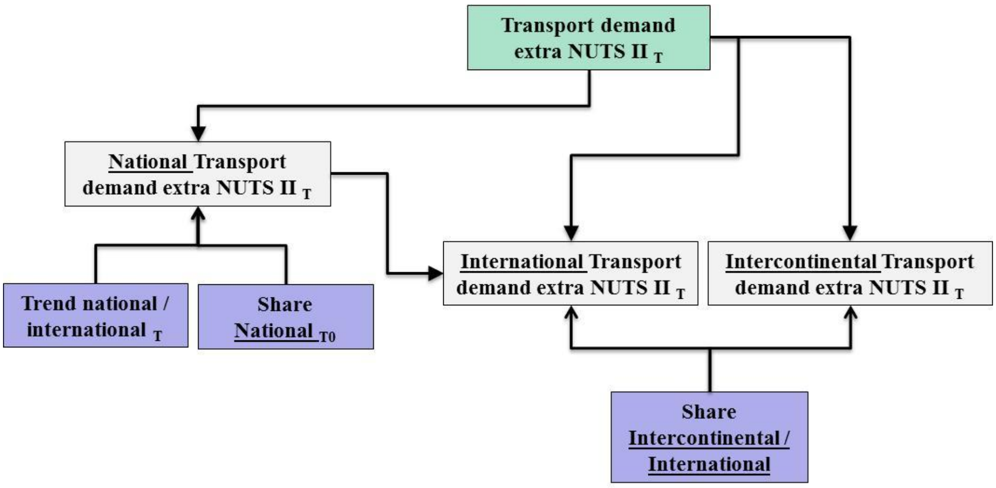
It can be noted that the shift applies only in one direction with respect to the configuration at the time period t_0: from local to the other distance bands (not vice-versa). This means that it is assumed that over time demand moves from shorter to longer distances with respect to the configuration at the time period t_0, or remain within the same distance band. Nevertheless, it allows the model to simulate increase and decrease of the shift over the simulation period (but never below the level observed at the time period t_0).

As mentioned above, the share of local trips is computed as a residual:

$$\mathrm{Sh\_iNlcT}_{zpi}(t) = \left(1 - \mathrm{Sh\_iNvsT}_{zpi}(t) - \mathrm{Sh\_iNstT}_{zpi}(t)\right) \cdot \qquad \text{Eq. 39}$$

Extra NUTS II segmentation (national/ international / intercontinental)

The share of national trips by purpose, income and NUTS II zone is driven by initial shares modified over time with a parameter differentiated by country and purpose. It is assumed that all commuting trips at extra NUTS II level are national (not international).



Source: TRT

Figure 6-4: Extra NUTS II segmentation (national / international / intercontinental)

In terms of equations, the amount of national trips is:

$$\mathrm{eNnT}_{zpi}(t) = \mathrm{eNT}_{zpi}(t) \cdot \mathrm{Sh\_eNnT}_{zpi}(t_0) \cdot \mathrm{eNnTr}_{zp}(t) \qquad \text{Eq. 40}$$

With: $\mathrm{eNnT}_{zpi}(t)$ = domestic extra NUTS II trips generated by the zone *z* for the purpose *p* and the (aggregated) income group *i* at the time period *t*

$\mathrm{eNT}_{zpi}(t)$ = extra NUTS II trips generated by the zone *z* for the purpose *p* and the (aggregated) income group *i* at the time period *t* (result of Eq. 33)

$\mathrm{Sh\_eNnT}_{zpi}(t_0)$ = share of domestic extra NUTS II trips generated by the zone *z* for the purpose *p* and the (aggregated) income group *i* at the time period t_0 (year 1995)

$\mathrm{eNnTr}_{zp}(t)$ = exogenous trend towards international trips, reducing the share of national trips at the time period *t*, by zone *z* and purpose *p*

The term $\mathrm{eNnT}_{zpi}(t)$ has the same meaning of the term $\mathrm{LgSh}_{zpi}(t)$ used in Eq. 31, i.e. account for the trend towards an internalisation due to elements diverse from the trend of transport costs.

The amount of international intercontinental trips is computed as:

$$\mathrm{eNicT}_{zpi}(t) = \left(\mathrm{eNT}_{zpi}(t) - \mathrm{eNnT}_{zpi}(t)\right) \cdot \left(\mathrm{Sh\_eNicT}_{zpi}\right) \qquad \text{Eq. 41}$$

With: $\mathrm{eNicT}_{zpi}(t)$ = international intercontinental extra NUTS II trips generated by the zone *z* for the purpose *p* and the (aggregated) income group *i* at the time period *t*

$\left(\mathrm{Sh\_eNicT}_{zpi}\right)$ = share of international intercontinental extra NUTS II trips generated by the zone *z* for the purpose *p* and the (aggregated) income group *i*

The share of international intercontinental extra NUTS II trips $\left(\mathrm{Sh\_eNicT}_{zpi}\right)$ is constant over time.

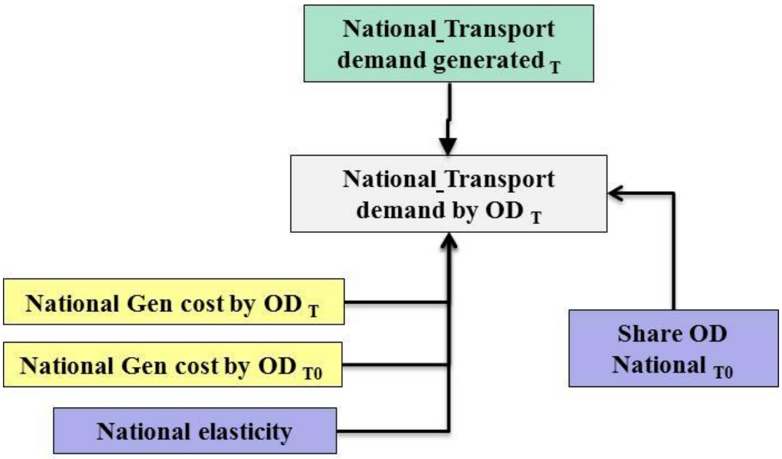
Finally, the amount of international European trips is computed as:

$$\mathrm{eNinT}_{zpi}(t) = \left(\mathrm{eNT}_{zpi}(t) - \mathrm{eNnT}_{zpi}(t)\right)\cdot\left(1-\left(\mathrm{Sh\_eNicT}_{zpi}\right)\right) \quad \text{Eq. 42}$$

With: $\mathrm{eNinT}_{zpi}(t) =$ international European extra NUTS II trips generated by the zone *z* for the purpose *p* and the (aggregated) income group *i* at the time period *t*

National OD distribution

In the previous step, the number of Extra NUTS II national trips generated in each NUTS II zone is estimated. In this step such trips are distributed. Initially trips are aggregated at NUTSI[5] level (see paragraph 6.1.1 above). In 12 countries out of 28 only one zone is defined at NUTS I level, corresponding to the country level. Then trips generated in each NUTS I are distributed among all domestic NUTS I (including intra NUTS I trips, i.e. with destination in the same NUTS I but extra NUTS II).). Distribution is based on reference shares modified through elasticity to generalised cost per OD.



Source: TRT

Figure 6-5: National OD distribution

5 At national level, in order to generate NUTS I to NUTS I matrices, specific subscripts for each country have to be defined in order to avoid a huge increase of model size. As an example, for Italy the 'ITAnat' subscript includes 5 elements: ITCn, ITDn, ITEn, ITFn, ITGn. Within the subscript 'Nuts1' (of 95 elements), the elements related to Italy (5 elements) are: ITC, ITD, ITE, ITF, ITG (the NUTS I codes). In this way each variable representing the national matrix includes e.g. 5 x 5 OD, instead of 95 x 95 of which only 5 x 5 not null.

In terms of equations:

$$\mathrm{eNnT}_{ODpi}(t) = \mathrm{eNnT}_{zpi}(t) \cdot \mathrm{Sh\_eNnT}_{ODpi}(t_0) \cdot \left(1 + \mathrm{eNnEl}_{zp} \cdot \left(\frac{\mathrm{eNnCg}_{ODp}(t)}{\mathrm{eNnCg}_{ODp}(t_0)} - 1\right)\right) \qquad \text{Eq. 43}$$

With: $\mathrm{eNnT}_{ODpi}(t)$ = national trips from origin zone *O* (NUTS I region) to destination zone *D* (NUTS I region) for the purpose *p* and the (aggregated) income group *i* at the time period *t*

$\mathrm{eNnT}_{zpi}(t)$ = domestic extra NUTS II trips generated by the zone *z* for the purpose *p* and the (aggregated) income group *i* at the time period *t* (result of Eq. 40)

$\mathrm{Sh\_eNnT}_{ODpi}(t_0) \cdot$ = base share of national trips from origin zone *O* to destination zone *D* for the purpose *p* and the (aggregated) income group *i* at the time period t_0 (year 1995)

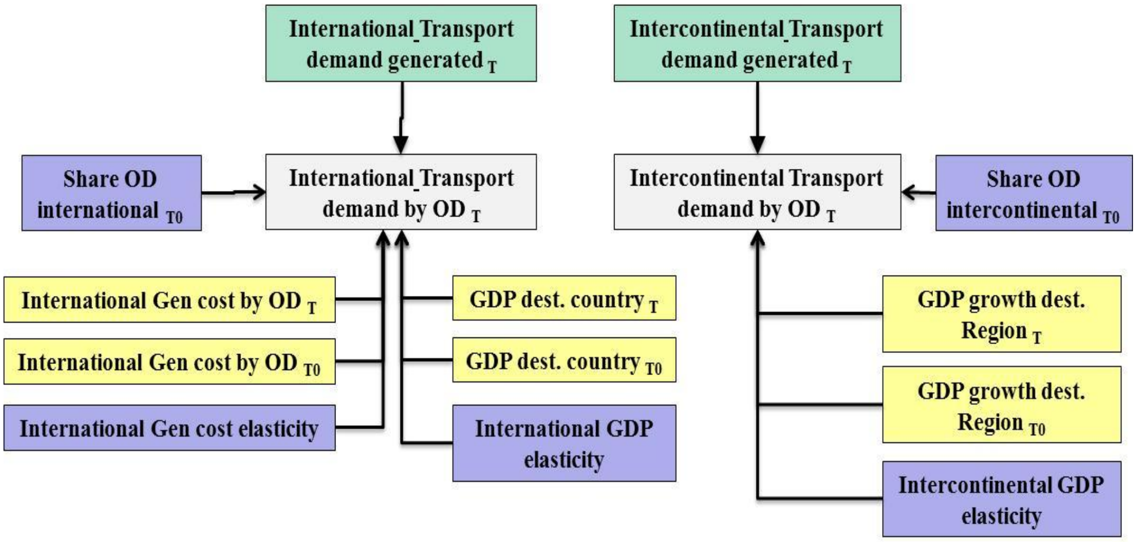
$\mathrm{eNnCg}_{ODp}(t)$ = average generalised cost of national trips from origin zone *O* to destination zone *D* for the purpose *p* at the time period *t*

eNnEl_{zp} = elasticity to changes of average generalised cost of national trips by zone *z* and purpose *p*.

International and intercontinental OD distribution

In the previous step, the number of Extra NUTS II international (intra-Europe and intercontinental) trips generated in each NUTS II zone is estimated. In this step such trips are distributed. Initially trips are aggregated at country level. In fact, matrices at international level are estimated respectively at Country level and intercontinental trips from country to macro-region (see paragraph 6.1.1 above).

In case of the OD distribution at international level the drivers are the reference shares, modified through elasticity to generalised cost per OD and also elasticity to an attractor (i.e. GDP). Elasticity is differentiated by purpose (business or personal/holiday). It is assumed that trips for commuting purpose are not made at international and intercontinental level.



Source: TRT

Figure 6-6: International and intercontinental OD distribution

In terms of equation at international level:

$$\mathrm{eNinT}_{ODpi}(t) = \mathrm{eNinT}_{zpi}(t) \cdot \mathrm{Sh\_eNinT}_{ODp}(t)$$ Eq. 44

$$\mathrm{Sh\_eNinT}_{ODp}(t) = \mathrm{Sh\_eNinT}_{ODp}(t_0) \cdot \left(1 + e\mathrm{NinEl}_p \cdot \left(\frac{\mathrm{eNinCg}_{ODp}(t)}{\mathrm{eNinCg}_{ODp}(t0)} - 1\right)\right) \cdot \left(1 + e\mathrm{NinElG}_p \cdot \left(\frac{\mathrm{GDP}_D(t)}{\mathrm{GDP}_D(t0)} - 1\right)\right)$$ Eq. 45

With: $\mathrm{eNinT}_{ODpi}(t)$ = international European trips from origin Country *O* to destination country *D* for the purpose *p* and the (aggregated) income group *i* at the time period *t*

$\mathrm{eNinT}_{zpi}(t)$ = International European extra NUTS II trips generated by the zone *z* for the purpose *p* and the (aggregated) income group *i* at the time period *t* (result of Eq. 42)

$\text{Sh\_eNinT}_{ODp}(t)$ = share of international trips from origin Country *O* to destination country *D* for the purpose *p* at the time period *t*

$\text{eNinCg}_{ODp}(t)$ = average generalised cost of international trips by OD (at Country level) for the purpose *p* at the time period *t*

eNinEl_{p} = international elasticity to changes of average generalised cost of international trips by purpose *p*

$\text{GDP}_{D}(t)$ = GDP of destination country *D* at the time period *t*

eNinElG_{p} = international elasticity to changes of GDP by purpose *p*

It should be noted that after the application of elasticities, the new shares are re-scaled to ensure that they sum up to 1. Therefore, if e.g. GDP increases in all destination countries, only countries where the increase is above the average will increase their share of trips

The distribution at intercontinental level follows the same principle but just GDP variation is used to change the base shares:

$$\text{eNicT}_{ODR}(t) = \left(\sum_{pi} \text{eNicT}_{zpi}(t)\right) \cdot \text{Sh\_eNicT}_{ODR}(t) \qquad \text{Eq. 46}$$

$$\text{Sh\_eNicT}_{ODR}(t) = \text{Sh\_eNicT}_{ODR}(t_0) \cdot \left(1 + \text{eNicElG} \cdot \Delta\left(\text{GDP gr}_{DR}\right)\right) \qquad \text{Eq. 47}$$

With: $\text{eNicT}_{ODR}(t)$ = international extra-European trips from origin Country *O* to destination region *DR* at the time period *t*

$\text{eNicT}_{zpi}(t)$ = extra NUTS II trips generated by the zone *z* with destination at intercontinental level for the purpose *p* and the (aggregated) income group *i* at the time period *t*

$\text{Sh\_eNicT}_{ODR}(t_0) \cdot$ = share of intercontinental trips from origin Country *O* to destination region *DR* at the time period t_0 (year 1995)

$\text{GDP gr}_{DR}(t)$ = yearly GDP growth of destination region *DR* at the time period *t*

eNicElG = intercontinental elasticity to changes of GDP growth

Output indicators

At the end of the process, for the production of output indicators, a correspondence is defined between the geographical dimension at intra-NUTS II level and a distinction of urban / non-urban context.

This process is carried out under assumptions based on the characteristics of each NUTS II zone. The share of trips in urban context by zone and distance band is based on the classification by 'Urban-rural typology' of EUROSTAT provided at NUTS III level[6]. This data applies the following assumption, classifying region as:

- predominantly urban (PU), if the share of population living in rural LAU2 is below 15 %;
- intermediate (IN), if the share of population living in rural LAU2 is between 15 % and 50 %;
- predominantly rural (PR), if the share of population living in rural LAU2 is higher than 50 %.

For the purpose of the model the data has been processed and aggregated estimating an average value at NUTS II level.

In addition, it should be underlined that, within the model, the distinction between the urban and non-urban context does not refer exclusively to individuals living in a zone, but also to people travelling there.

6.1.3 Passengers mode split

In terms of transport mode availability, ASTRA-EC models different options for passenger:

- Slow modes (pedestrian and cycling),
- Car (including also 2-wheelers and passenger LDV),
- Bus/Coach,
- Train and
- Air.

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

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6 European Commission (DG REGIO and DG AGRI): Urban-rural typology.

Table 6-4: 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[1]	X	X	X	
Air				X	X	X

Note: 1 Tram and metro only at Local level, including also Tram and metro at Very short level

Source: TRT

The following assumptions are considered in ASTRA-EC:

- Tram and metro are not explicitly modelled 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.
- Ferries are part of road mode (car).

The modal split process is calculated separately for each spatial domain (intra-NUTS II local, intra- NUTS II very short, etc.). The mode shares of young people are estimated separately, and added at the end of the process in the correspondent spatial domain (local or very short). As mentioned above, in this case the individuals travelling by car are only passengers (not drivers).

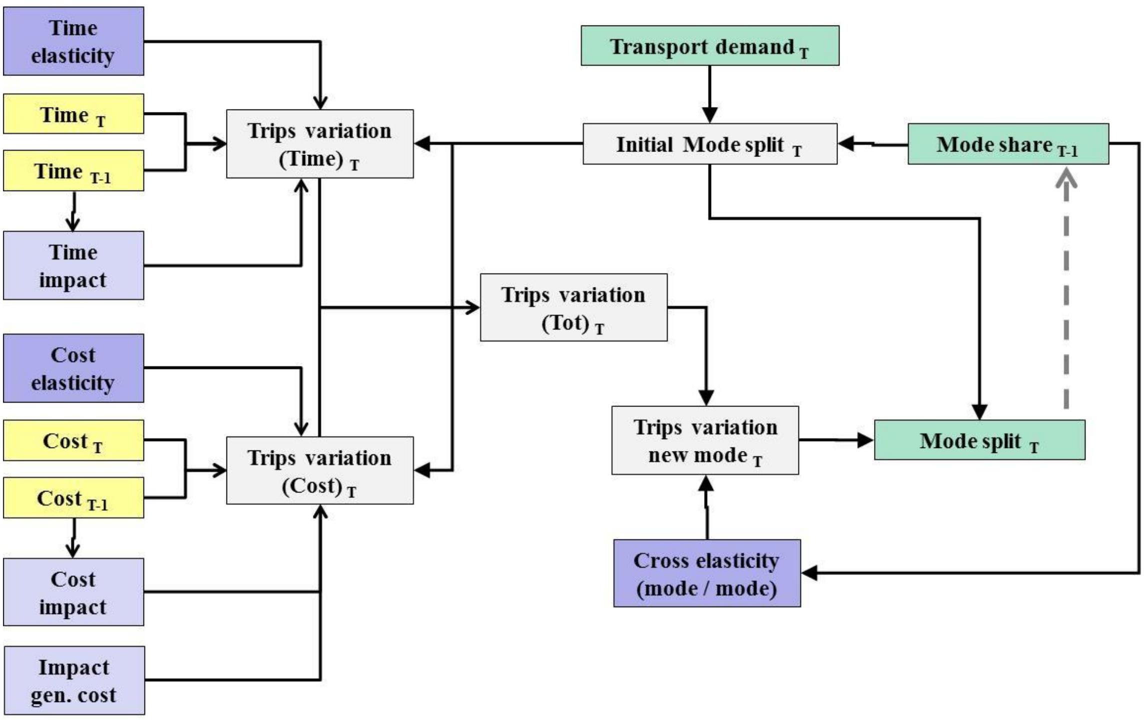
Despite logit is the most widely used algorithm for mode choice, in ASTRA-EC a different solution is chosen. Direct and cross elasticities to cost variation and time variation (implemented separately) are used. Additional elasticity parameters can be implemented to reflect the contribution of other significant determinants of modal split. In particular, a specific parameter related to the increase of car ownership is used to take into account the increase of the motorization rate, considering different reactions depending on the country.

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.

In the end, mode split depends on the following elements:

- Initial mode shares at the base year (and then mode shares at previous time period),
- Elasticity to cost variation over time,
- Elasticity to time variation over time,
- Elasticity to car ownership variation over time (for selected cases, only when a significant increase is observed starting from a low value at the base year),
- Cross elasticity to re-distribute the shares from one mode to the others (which depend directly on mode split at previous time period).

The following figure gives an overview of the mode split process for passenger demand.



Source: TRT

Figure 6-7: Overview of the mode split process

First, passenger demand is provisionally split according to mode shares at previous time period t-1.

$$\mathrm{prov\_T}_{zpi}^{m}(t) = \mathrm{T}_{zpi}(t) \cdot \mathrm{Sh\_T}_{zpi}^{m}(t-1)$$ Eq. 48

With: $\mathrm{prov\_T}_{zpi}^{m}(t)$ = provisional estimation of passenger trips generated by the zone *z*[7] for purpose *p* and the (aggregated) income group *i* at the time period *t* by mode *m*

$\mathrm{T}_{zpi}(t)$ = passenger trips generated by the zone *z*[8] for purpose *p* and the (aggregated) income group *i* at the time period *t*

$\mathrm{Sh\_T}_{zpi}^{m}(t-1)$ = shares by mode *m* of passenger trips generated by the zone *z*[9] for purpose *p* and the (aggregated) income group *i* at the time period *t-1*

As a second step, the variations in terms of trips by mode with respect to time and cost variations are estimated separately through elasticity parameters.

The equation applied for time variations is the following:

$$\Delta\mathrm{tT}_{zpi}^{m}(t) = \mathrm{prov\_T}_{zpi}^{\mathrm{m}}(t) \cdot \mathrm{tEl}_{zpi}^{\mathrm{m}}(t) \cdot \left(\frac{\mathrm{T}_{z}^{m}(t) - \mathrm{T}_{z}^{m}(t-1)}{\mathrm{T}_{z}^{m}(t-1)} \right)$$ Eq. 49

With: $\Delta\mathrm{tT}_{zpi}^{m}(t)$ = provisional variation of trips by mode *m*, zone *z*, purpose *p* and income group *i* with respect to time variations at the time period *t*

$\mathrm{tEl}_{zpi}^{\mathrm{m}}(t)$ = elasticity with respect to time variations by mode *m*, zone *z*, purpose *p* and income group *i* at the time period *t*

$\mathrm{T}_{z}^{\mathrm{m}}(t)$ = travel time by mode *m* and zone *z* at the time period *t*

Elasticity is not just a fixed value. It changes as effect of two elements.

One is due to the change of the value of travel time (which depends on personal income, although not directly, since it evolves over time with a growth rate depending on GDP growth rate). As far as the value of travel time increases, the elasticity to time variation is slightly increased.

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7 By OD in case of matrices.

8 By OD in case of matrices.

9 By OD in case of matrices.

The other is the change of the absolute value of travel time (the larger the absolute value the larger the impact of a given relative change). More details on this function are reported below in Box 1.

Then, the elasticity parameter is computed as:

$$\mathrm{tEl}^{\mathrm{m}}_{zpi}(t) = \mathrm{tEl}^{\mathrm{m}}_{zpi} \cdot \mathrm{Vtr}_{zp}(t) \cdot \mathrm{Ttr}^{m}_{z}(t)$$ Eq. 50

With: $\mathrm{tEl}^{\mathrm{m}}_{zpi}$ = base value of elasticity with respect to time variation by mode *m*, zone *z*, purpose *p* and income group *i*

$\mathrm{Vtr}_{zp}(t)$ = trend of elasticity depending on Value of Time variation by zone *z* and purpose *p* at the time period *t*

$\mathrm{Ttr}^{m}_{z}(t)$ = trend[10] of elasticity depending on the absolute value of travel time of mode *m* from zone *z* at the time period *t*

The equation applied for cost variations follows the same approach, taking into account a correction factor related to the mode share instead of the value of time (details are reported below in Box 1). Cost variations refers only to perceived cost, including fuel cost and tolls for car users and ticket prices for public transport and air mode.

In a second step, the variations of demand by mode due to time change and cost change which have been estimated separately are aggregated together.

In general terms, the following equation applies:

$$pr\Delta\mathrm{T}^{m}_{zpi}(t) = \Delta\mathrm{tT}^{m}_{zpi}(t) + \Delta\mathrm{cT}^{m}_{zpi}(t)$$ Eq. 51

With: $pr\Delta\mathrm{T}^{m}_{zpi}(t)$ = provisional total variation at the time period *t* of trips by mode *m*, zone *z*, purpose *p* and income group *i*

At this stage, in order to avoid excessive changes in a short time, the model is set to allow a maximum overall reduction in one mode equal to 75 % of the value at previous time period or a maximum increase equal to a percentage (15 % to 75 %, depending on the mode shares) of the sum of the demand of the other modes.

10 See box 1 below.

At this point, also the impact of an increase of car ownership is included in the estimation for car mode.

The following step is based on the application of cross-elasticities, in order to simulate the shift from one mode to another. Indeed the parameters used are not pure elasticities but rather the share of demand gained (lost) by one mode as result of a reduction (increment) of demand for another mode. Such parameters are computed on the mode shares at the previous time period, differentiated by country, mode, trip purpose and income group.

The following table gives an example. The mode split at the first time period is 20 % by bus, 70 % by car and 10 % by train. The cross-elasticities used to distribute e.g. bus demand changes (the same parameters are applied irrespective to the direction of variation: i.e. for a reduction or an increment of demand) are calculated as follows:

Cross elasticity of car demand is 70 / (70+10) = 0.875, i.e. the ratio between the mode share of car and the sum of modes shares of car and train

Cross elasticity of train demand is 10 / (70+10) = 0.125, i.e. the ratio between the mode share of train and the sum of modes shares of car and train.

The same for the other parameters.

Table 6-5: Example of cross-elasticities

Cross-elasticity	**bus**	**car**	**train**	**Total**
bus	0	0.875	0.125	1.0
car	0.667	0	0.333	1.0
train	0.222	0.778	0	1.0
Mode share	20 %	70 %	10 %	100 %

Source: TRT

In general terms, the following equation applies:

$$\mathrm{T}_{zpi}^{m}(t) = \mathrm{prov\_T}_{zpi}^{m}(t) + \sum_{M}\left(pr\_\Delta\mathrm{T}_{zpi}^{M}\right)(t)\cdot\left(\mathrm{mElT}_{zi}^{mM}\right) - \sum_{M}\left(pr\_\Delta\mathrm{T}_{zpi}^{M}\right)(t)\cdot\left(\mathrm{mElT}_{zi}^{Mm}\right) \qquad \text{Eq. 52}$$

With: $\mathrm{T}_{zpi}^{m}(t)$ = passenger trips generated by the zone *z*[11] for purpose *p* and the (aggregated) income group *i* at the time period *t* by mode *m*

$\left(\mathrm{mElT}_{zi}^{Mm}\right)$ = cross-elasticity from mode *M* to 'new' mode *m*, zone *z* and income group *i*

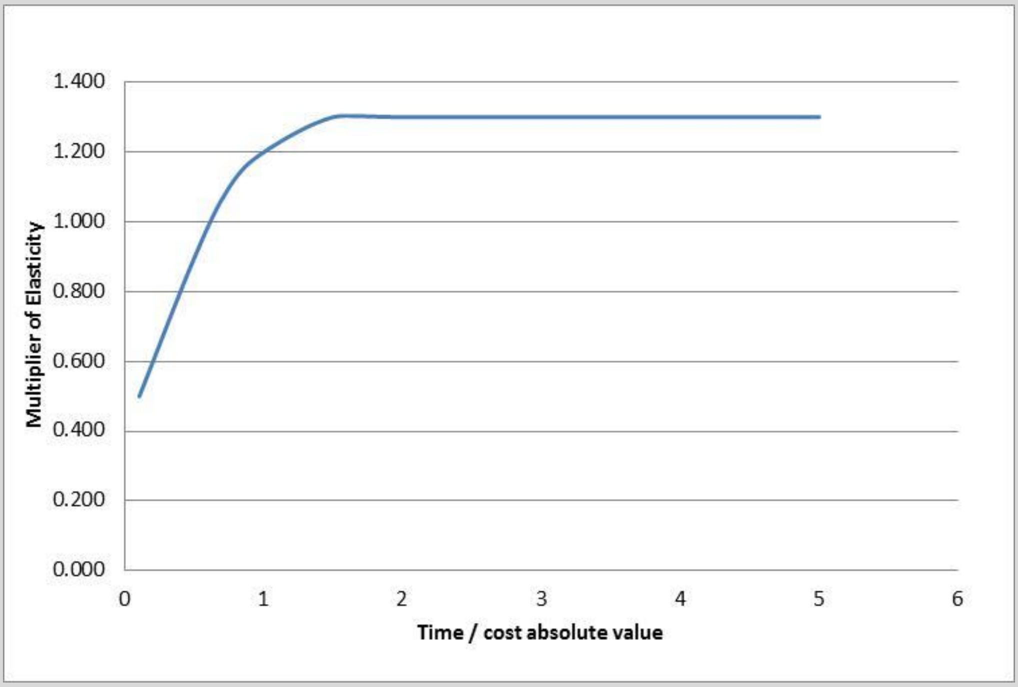
It can be noticed that the variations have to be added to the new mode m and deducted from the original mode M.

The new allocation to the transport modes results from the variations of each mode, occurring simultaneously (e.g. both car and bus trips might increase while train trips decrease).

BOX 1

Elasticities to cost/time variation are differentiated by country, mode, trip purpose and income group. The elasticity value changes over time depending on the absolute value of time/cost <u>per trip</u> at previous time period. The rationale is that small absolute changes are not perceived as significant variations despite in relative terms they are. The following figure shows the principle applied in the model.

11 By OD in case of matrices.



Source: TRT

Figure 6-8: Example of change of elasticity depending on the absolute value of time/cost

The following equations interpret the form of the curves applied for time elasticity for intra NUTS II and respectively extra NUTS II trips.

$$\begin{aligned} \mathrm{TtrIn}_z^{\mathrm{m}}(t) &= if\ T_z^{\mathrm{m}}(t-1) \le 2 \\ &\quad \mathrm{then} -0.286 \cdot \left(T_z^{\mathrm{m}}(t-1)\right)^2 + 0.971 \cdot \left(T_z^{\mathrm{m}}(t-1)\right) + 0.497 \\ &\quad \mathrm{else}\ 1.3 \end{aligned}$$ Eq. 53

$$\begin{aligned} \mathrm{TtrEx}_z^{\mathrm{m}}(t) &= if\ T_z^{\mathrm{m}}(t-1) \le 24 \\ &\quad \mathrm{then} -0.001 \cdot \left(T_z^{\mathrm{m}}(t-1)\right)^2 + 0.045 \cdot \left(T_z^{\mathrm{m}}(t-1)\right) + 0.78 \\ &\quad \mathrm{else}\ 1.3 \end{aligned}$$ Eq. 54

With: $\mathrm{TtrIn}_z^{\mathrm{m}}(t)$ = trend of elasticity at intra NUTS II level depending on the absolute value of travel time of mode *m* from zone *z* at the time period *t*

$\mathrm{TtrEx}_z^{\mathrm{m}}(t)$ = trend of elasticity at intra NUTS II level depending on the absolute value of travel time of mode m from zone *z* at the time period *t*

$\mathrm{T}_{z}^{\mathrm{m}}(t-1)=$ travel time of trips by mode *m*, zone *z*, at time period *t -1*

The following equations interpret the form of the curves applied for cost elasticity for intra NUTS II and respectively extra NUTS II trips.

$$\begin{aligned}\mathrm{CtrIn}_{z}^{\mathrm{m}}(t) = if\ & C_{z}^{\mathrm{m}}(t-1) \le 10 \\ & \text{then} -0.013\cdot\left(C_{z}^{\mathrm{m}}(t-1)\right)^{2}+0.199\cdot\left(C_{z}^{\mathrm{m}}(t-1)\right)+0.498 \\ & \text{else } 1.2\end{aligned}$$ Eq. 55

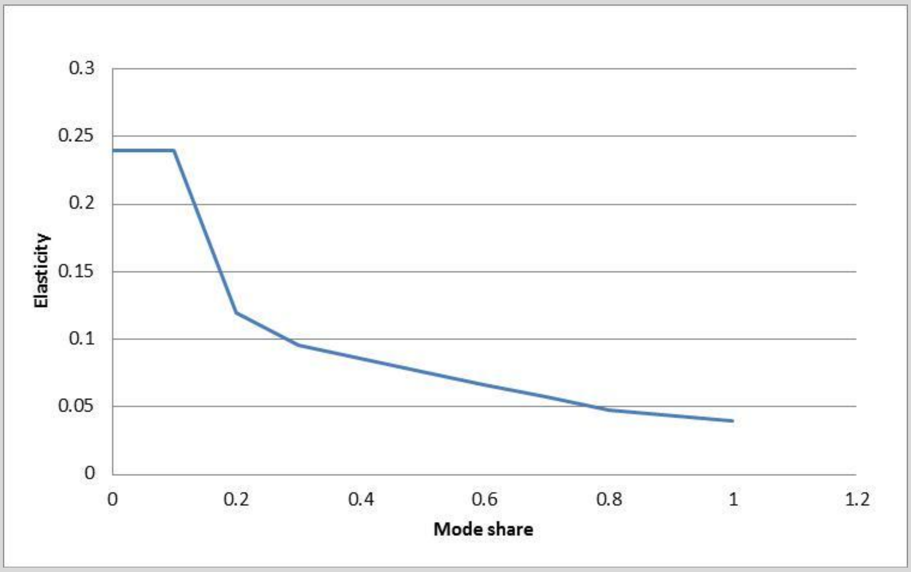
$$\begin{aligned}\mathrm{CtrEx}_{z}^{\mathrm{m}}(t) = if\ & C_{z}^{\mathrm{m}}(t-1) \le 200 \\ & \text{then} -0.00001\cdot\left(C_{z}^{\mathrm{m}}(t-1)\right)^{2}+0.004\cdot\left(C_{z}^{\mathrm{m}}(t-1)\right)+0.85 \\ & \text{else } 1.25\end{aligned}$$ Eq. 56

With: $\mathrm{CtrIn}_{z}^{\mathrm{m}}(t)=$ trend of elasticity at intra NUTS II level depending on the absolute value of travel cost of mode *m* from zone *z* at the time period *t*

$\mathrm{CtrEx}_{z}^{\mathrm{m}}(t)=$ trend of elasticity at intra NUTS II level depending on the absolute value of travel cost of mode *m* from zone *z* at the time period *t*

$\mathrm{C}_{z}^{\mathrm{m}}(t-1)=$ travel cost of trips by mode *m*, zone *z*, at time period *t -1*

In addition, the elasticity value with respect to cost variation changes over time also depending on the mode share. The rationale is that a mode with a dominant share is probably hard to replace and so demand is probably less sensitive to cost or time changes. A the same time, when a mode has a very small share this probably represents some very specific demand segments whose travel choice are not very motivated by cost and time.



Source: TRT

Figure 6-9: Change of cost elasticity depending on mode share

The following equations interpret the form of the curves applied for all distance band.

$$CtrMs_z^m(t) = +3.804 \cdot \left(Ms_z^m(t-1)\right)^2 - 6.197 \cdot \left(Ms_z^m(t-1)\right) + 3.041 \quad \text{Eq. 57}$$

With: $CtrMs_z^m(t)$ = trend of elasticity based on the mode share of mode *m* from zone *z* at the time period *t*

$Ms_z^m(t-1)$ = mode share of mode *m*, zone *z*, at time period *t-1*

6.1.4 Transport performances and occupancy factors

Transport performances

Passenger transport performances are estimated in terms of passenger-km, resulting by multiplying passenger trips by mode of each distance band by the related average distance.

Average distances by mode are implemented in the model: at NUTS II level for intra NUTS II trips, at NUTS I level for national trips, from country to country (or World Region) at international (intercontinental) level. An exogenous trend drives the increase of distances over time.

In general terms, the following equation applies:

$$TP_z^{\mathrm{DB,m}}(t) = d_z^{\mathrm{DB,m}}(t) \cdot \sum_{p,i} T_{zpi}^{\mathrm{DB,m}}(t) \qquad \text{Eq. 58}$$

With: $TP_z^{\mathrm{DB,m}}(t)$ = passenger transport performance (pkm) generated by the zone z[12] of distance band DB at the time period t by mode m

$d_z^{\mathrm{DB,m}}(t)$ = average distance travelled of trips generated by the zone z[13] of distance band DB at the time period t by mode m

$\mathrm{T}_{zpi}^{DB,m}(t)$ = passenger trips generated by the zone z[14] for purpose p and the (aggregated) income group i of distance band DB at the time period t by mode m

Nevertheless, in case of OD trips the estimation is made taking into account the variables differentiated by OD.

Occupancy factors

Average occupancy factors are estimated in the model to calculate performance in terms of vehicles.

For **cars**, occupancy factor is influenced at local level (distance band LC and VS) by the share of young passengers mentioned above: trips by car of young individuals (resulting from the mode split process of the corresponding modelling line) have to be considered in terms of passengers (not drivers). Therefore, the car occupancy factor has to satisfy (at least) the constraint related to this amount of car passengers. Otherwise, in general, car occupancy factor evolves over time according to a dedicated parameter (see figure below).

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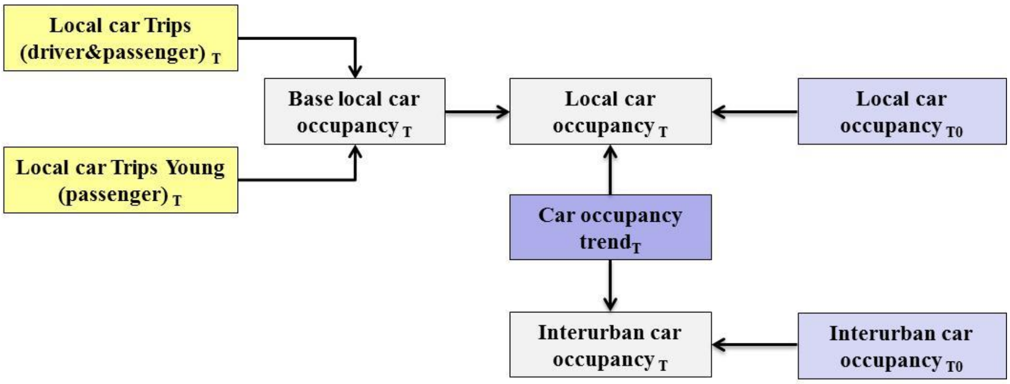
12 By OD in case of matrices.

13 By OD in case of matrices.

14 By OD in case of matrices.



Source: *TRT*

Figure 6-10: Overview of the process to estimate car average occupancy factor

For local car occupancy, the following equation applies:

$$\mathrm{OFcar}_{cpD}^{\mathrm{loc}}(t) = \min\left(2, \max\begin{pmatrix}\mathrm{OFcar}_{cpD}^{\mathrm{loc}}(t0)\cdot \mathrm{OFcarT}_{cp}(t), \\ \mathrm{OFcarM}_{cpD}^{\mathrm{loc}}(t-1)\cdot 1.05\end{pmatrix}\right) \quad \text{Eq. 59}$$

$$\mathrm{OFcarM}_{cpD}^{\mathrm{loc}}(t-1) = \frac{\sum_i T_{cpiD}^{car}(t-1)}{\sum_i T_{cpiD}^{car}(t-1) - \sum_i TY_{cpiD}^{car}(t-1)} \quad \text{Eq. 60}$$

With: $\mathrm{OFcar}_{cpD}^{\mathrm{loc}}(t)$ = local occupancy factor of car trips generated by country *c* for purpose *p* and distance band *D* at the time period *t*

$\mathrm{OFcarT}_{cp}(t)$ = trend of occupancy factor of car trips generated by country *c* for purpose *p* at the time period *t*

$\mathrm{OFcarM}_{cpD}^{\mathrm{loc}}(t-1)$ = minimum local occupancy factor of car trips generated by country *c* for purpose *p* and distance band *D* at the time period *t-1*, derived from the amount of car trips of young individuals

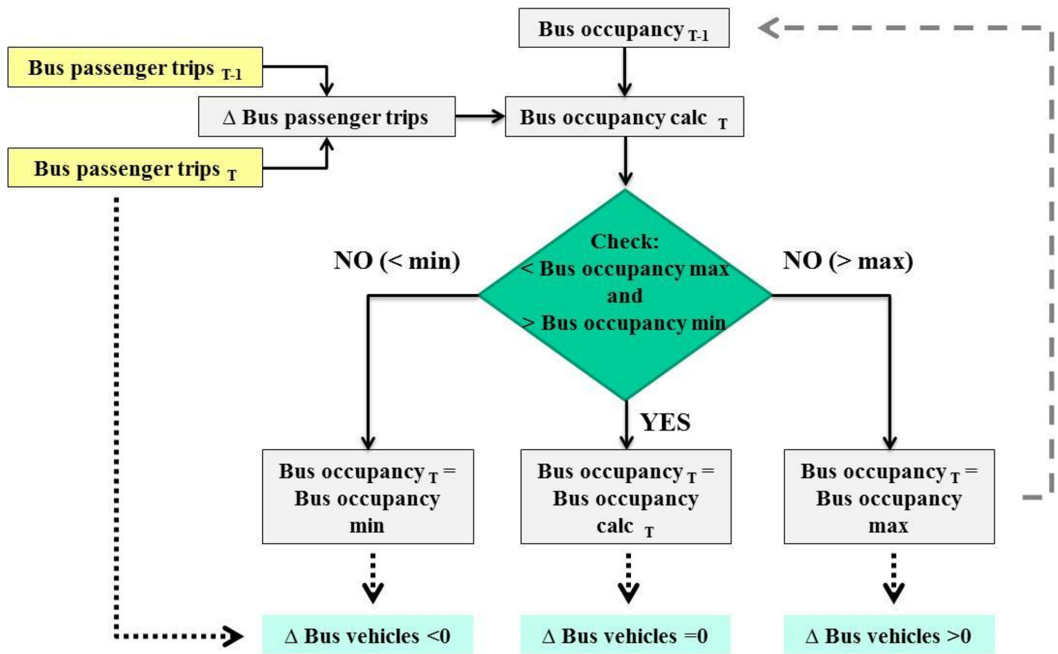
$\mathrm{T}_{cpiD}^{car}(t-1)$ = total car passenger trips generated by country *c* for purpose *p*, the (aggregated) income group *i* and distance band D at the time period *t -1* (including all individuals)

$\mathrm{TY}_{cpiD}^{car}(t-1)$ = car passenger trips generated by young individuals by country *c* for purpose *p*, the (aggregated) income group *i* and distance band *D* at the time period *t -1*

For interurban car occupancy, the estimation results from the application of a predefined trend to the initial value (at 1995) of occupancy factor differentiated by purpose and country.

The approach for simulating the occupancy factor of **public transport modes** takes into account that occupancy of public transport vehicles is the first variable that changes when demand increases or falls. For instance, if the number of passenger of the public transport service in one city increases of 5 %, this does not mean that more buses will circulate, rather than the average number of people riding on a bus is increased. Only when occupancy factor increases over a certain limit, public transport companies will increase the number of buses. In order to simulate this approach, minimum and maximum values of occupancy factor have to be defined, as follows:

- maximum accepted level of occupancy, i.e. the highest average number of passengers per vehicle before bus companies decide to add new trips (p/v),
- minimum accepted level of occupancy, i.e. the lowest average number of users per vehicle before bus companies decide to cut some trips (p/v).



Source: *TRT*

Figure 6-11: Example of estimation of occupancy factor of public transport: bus mode

For buses, four levels of service (and therefore occupancy factor and vkm) are estimated:

- Urban (LC+VS)
- Non urban (ST)
- National (NAT)
- International (INT)

For train, two levels of services (occupancy factor) are estimated:

- Short distance (VS+ST)
- Long distance (NAT+INT)

For air mode, two levels of services (occupancy factor) are estimated:

- National (NAT)
- International (INT)

The average base values of occupancy factors as well as minimum and maximum thresholds are reported in paragraph 9.6.

6.1.5 Accessibility indicators

In general terms, accessibility is made of two components. One component represents the attractiveness of potential destinations, the other one represents the “distance” of such destinations:

$$A_i = \sum_j \mathrm{g}(W_j)\,\mathrm{f}\,(c_{ij})$$

where A_i is the accessibility of area *i*, W_j is the attractiveness to be reached in area *j*, and *cij* is the distance between area *i* and area *j*. The functions $g(W_{ij})$ and $f(c_{ij})$ are called activity functions and impedance functions, respectively. According to the specification made for these two functions, different types of accessibility indicators can be generated, e.g.:

- *Travel cost*. If only destinations of a certain kind, e.g. cities beyond a certain size, are considered the accessibility indicator is total or average travel cost to a predefined set of destinations.
- *Daily accessibility*. If only destinations within a certain travel time are considered the accessibility indicator measures the number of potential destinations (customers, business contacts, tourist attractions, etc.) that can be reached in a given time, e.g. a day.

- *Potential accessibility*. If the impedance function takes travel behaviour into account, i.e. the diminishing inclination to travel long distances (the impedance function is nonlinear, e.g. exponential), the accessibility indicator is a potential indicator. The activity function may take account of agglomeration effects or economies of scale (i.e. may be nonlinear, e.g. a power function).

Within the ASTRA-EC model potential accessibility indicators are computed for passengers demand:

- Potential accessibility at national level (including local and national context) by mode,
- Potential accessibility at national level (including local and national context) by income group,
- Potential accessibility at international level by mode,
- Potential accessibility at international level by income group,

In the above indicators the activity function is measured in terms of population of the destination zone, while the impedance function is represented by the generalised cost between zones for the potential accessibility differentiated by mode and by the average travel time (based on demand by mode) for the potential accessibility differentiated by income group.

The role of these indicators is to quantify the impact of simulated policy measures on the connectivity of different areas. It is important to note that:

a) The indicators make reference to the potential destinations rather than to actual destinations. In other words, for the indicator it is not relevant whether there is some demand between two zones or not, only the attractiveness of the destinations and their distance matter.

b) Given the spatial detail of the model, the indicators are sensitive to relatively large changes of attractiveness and/or distance between zones. Local differences cannot be captured by the indicators. This is also the reason why it is not so significant using the indicators to compare accessibility of different regions in a given year and in a given scenario. The appropriate use of the indicators is to assess whether accessibility of zones change when a policy measure is applied.

6.2 The freight transport module

The freight transport component of the ASTRA-EC model consists of adapted classical 4-stage transport models (*TRA_fre*).

Freight transport demand is generated and distributed on the basis of international trade (in monetary terms) and of the value of production at national level for different goods categories (provided by the economic and trade modules). Freight demand distribution at national level is the result of a progressive breakdown of generated demand, with the same approach of passenger demand. Freight demand distribution at international level depends directly on the trend of country to country trade computed in the trade module.

The simulation of freight modal split is based on the application of direct and cross elasticities to cost variation and time variation (likewise passengers), calculated separately for each spatial domain.

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.

6.2.1 Freight demand generation

For freight transport, the demand is generated and distributed separately at international and national level: on one hand it is estimated on the basis of international trade (in monetary terms), on the other hand with reference to the value of production at national level for different goods categories. The inputs are provided respectively by the economic and trade modules: therefore, the zoning system implemented is at country level.

These variables are used to drive the evolution over time of the volume of tons, starting from an initial value at the year 1995 estimated from the ETISplus matrices. The assumption is that the variation of transport volumes follows from the change of the value of production and trade, but in an indirect way. The element linking the monetary values and the physical volumes is the unitary value of the goods produced or exported. In principle this element can be modelled by means of value-to-volume ratios, distinguished by sector and related to country (national production) or OD pair of country (international trade). As the link is only indirect, however, value-to-volume ratios need to be continuously adjusted in order to follow the transport trend given the economic trend. This adjustment is quite complex in terms of model calibration when observed data is available and, above all, makes the use of value-to-volume ratios not very reliable for forecasting purposes as the continuous adjustment of ratios in the future is basically unpredictable because it depends on relative prices, market conditions and other elements outside the domain of ASTRA.

Therefore, in order to give the overall model a stable structure the variations of production and export are used to estimate the variation of generated freight demand. The following equations apply.

At domestic level:

$$\mathrm{DT}_{cf}(t) = \mathrm{DT}_{cf}(t0) \cdot \left(1 + \cdot \alpha_{cf} \cdot \frac{PV_{cv}(t)}{PV_{cv}(t-1)}\right) \qquad \text{Eq. 61}$$

With: DT_{cf} (t) = domestic tons in country *c* for flow group *f* at time *t*

α_{cf} = coefficient to scale the variation of domestic production into variation of tons in country *c* for flow group *f*

PV_{cv} (t) = value of domestic production by sector *v* in country *c* at time *t*

At international level:

$$\mathrm{DT}_{ODf}(t) = \mathrm{DT}_{ODf}(t0) \cdot \left(1 + \cdot \alpha_{Of} \cdot \frac{Tr_{ODv}(t)}{Tr_{ODv}(t-1)}\right) \qquad \text{Eq. 62}$$

With: DT_{ODf}(t) = international volumes between country *O* and country *D* for flow group *f* at time *t*

α_{Of} = coefficient to scale the variation of international trade into variation of tons from origin country *O* for flow group *f*

Tr_{ODv} (t) = value of international trade between country *O* and country *D* by sector *v* at time *t*

A minimum and maximum threshold is set to avoid excessive variation of freight volumes.

Volumes are segmented by aggregated commodity type: bulk, general cargo and unitised cargo. Such groups are defined as aggregation of the more detailed groups defined within ETISplus and based on NST/R chapters (see table below).

Table 6-6: Conversion between ETIS commodity groups and ASTRA flow groups

ETIS Commodity group	ASTRA flow group	Shares
Agricultural products	General cargo	100 %
Foodstuffs	Unitised	100 %
Solid mineral fuels	Bulk	100 %
Crude oil	Bulk	100 %
Ores, metal waste	Bulk	100 %
Metal products	General cargo	100 %
Building minerals & material	Bulk	77 %
	Unitised	23 %
Fertilisers	General cargo	100 %
Chemicals	Bulk	100 %
Machinery & other manufacturing	Unitised	83 %
	General cargo	17 %
Petroleum products	Bulk	100 %

Source: TRT

In a similar way, also the intercontinental demand is estimated, based on trade from Europe to the rest of the world. The following equation applies:

$$\mathrm{DT}_{ORf}(t) = \mathrm{DT}_{ORf}(t0) \cdot \left(1 + \cdot \sigma_{Of} \cdot \frac{Tr_{ORv}(t)}{Tr_{ORv}(t-1)}\right) \quad \text{Eq. 63}$$

With: $\mathrm{DT}_{ORf}(t)$ = intercontinental volumes between country *O* and world region *R* for flow group *f* at time *t*

σ_{Of} = coefficient to scale the variation of intercontinental trade into variation of tons from origin country *O* for flow group *f*

$Tr_{ORv}(t)$ = value of intercontinental trade between country *O* and world region *R* by sector *v* at time *t*

After the estimation of domestic volumes, freight demand at national level is assigned to the NUTS II zone of origin. The estimation is made on the basis of reference shares modified over time via elasticities with respect to the variation of an attractor indicator, namely the active population by zone. Fixed reference shares are based on the ETIS-plus matrices (since GDP or employment are not computed at NUTS II level in the macroeconomic module and cannot work as attractors).

$$\mathrm{DT}_{zf}(t) = \mathrm{DT}_{cf}(t) \cdot shDT_{zf}(t0) \cdot \left(1 + \varepsilon \cdot \frac{AP_z(t)}{AP_z(t-1)}\right)$$ Eq. 64

With: DTzf (t) = domestic tons originated by NUTS II zone *z* for flow group *f* at time *t*

DTcf (t) = domestic tons in country *c* for flow group *f* at time *t*

$shDT_{zf}$ (t0) = share of domestic tons originated by NUTS II zone z for flow group f at time t0

AP_z (t)= active population in zone z at time t

ε = parameter to rescale the impact of change of active population on distribution by zone z

After the application of the distribution related to changes of active population, the new shares (namely the terms $shDT_{zf}(t0) \cdot \left(1 + \varepsilon \cdot \frac{AP_z(t)}{AP_z(t-1)}\right)$) are re-scaled to ensure that they sum up to 1.

6.2.2 Freight demand distribution

Freight demand distribution at national level is the result of a progressive breakdown of generated demand, with the same approach of passenger demand (see paragraph 6.1.2).

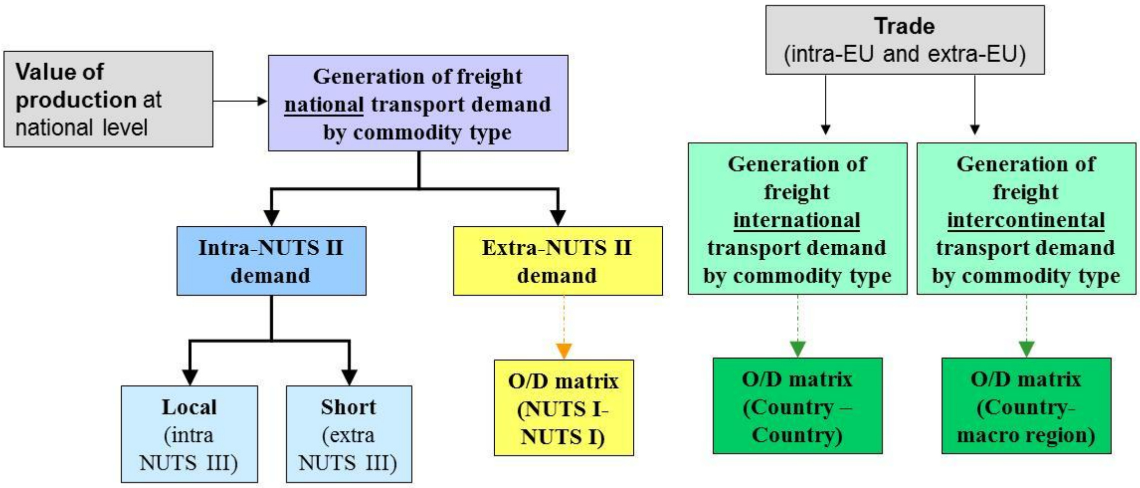
As mentioned above, domestic freight transport is generated at the national level on the basis of the value of production and allocated to the NUTS II zone of origin; then domestic demand is segmented between intra and extra NUTS II destination.

At **intra NUTS II level** the distribution phase is split 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[15] to NUTS I matrices.

International European freight demand is derived from intra-EU trade data and represented by country to country matrices; intercontinental freight demand derives from extra-EU trade and is represented by country to world macro-region matrices.



Source: TRT

Figure 6-12: Freight demand breakdown

In general, the allocation depends in each step on the initial value of the specific NUTS II zone, modified over time via elasticities with respect to the variation of generalised cost or other parameters. In general terms, the amount of demand shifted is computed according to equations of the type:

15 At national level, in order to generate NUTS I to NUTS I matrices, specific subscripts for each country have to be defined in order to avoid a huge increase of model size. As an example, for Italy the 'ITAnat' subscript includes 5 elements: ITCn, ITDn, ITEn, ITFn, ITGn. Within the subscript 'Nuts1' (of 95 elements), the elements related to Italy (5 elements) are: ITC, ITD, ITE, ITF, ITG (the NUTS I codes). In this way each variable representing the national matrix includes e.g. 5 x 5 OD, instead of 95 x 95 of which only 5 x 5 not null.

$$\mathrm{D}_{fz}(t) = \mathrm{BD}_{fz}(t) \cdot \left(\frac{\mathrm{C}G_{fz}(t)}{\mathrm{C}G_{fz}(t0)} - 1 \right) \cdot \varepsilon_{fz}$$ Eq. 65

With: D_{fz} (t) = demand for flow f with origin in zone *z* at time *t*

BD_{fz} (t) = base demand for flow *f* with origin in zone *z* at time *t*

CG_{fz} (t) = generalised cost of volumes for flow *f* with origin in zone *z* at time *t*

ε_{fz} = Elasticity of freight demand with respect to changes of the generalised cost of volumes for flow *f* with origin in zone *z*

Generalised cost for a specific freight mode is defined as follows:

$$\mathrm{CG}^{m}_{fz}(t) = \mathrm{C}^{m}_{fz}(t) + VOT_{fz}(t) \cdot T^{m}_{fz}(t)$$ Eq. 66

With: $C^{m}_{fz}(t)$ = cost of a shipment with mode *m* for flow *f*, in zone z at time *t*

$T^{m}_{fz}(t)$ = time spent for a trip with mode *m* for flow *f*, in zone *z* at time *t*

$VOT_{fz}(t)$)= value of time for flow *f* in zone *z* at time *t*

Freight cost per mode includes all type of costs: for labour, maintenance, investments, fuels, tolls, etc.

In case generalised cost refers to a whole distance band, not related to a specific mode, it results from the weighted average of generalised cost by mode on the basis of volumes.

More details on the various steps are reported in the following paragraphs.

Distribution by geographical dimension[16] is made on the basis of reference shares, modified over time via elasticities with respect to the relative variation generalised cost. Reference shares are mainly derived from the ETISplus database.

Elasticities are differentiated by country and commodity flow at each step of the process.

16 Local, short or national.

Intra/extra NUTS II segmentation

At the first stage of the process (defining the share of intra/extra NUTS II volumes) it is assumed that if long distance travels become cheaper a larger share of total demand can be satisfied from long-distance suppliers, but this effect will be smoothed in case the short distance travels become cheaper as well. Thus, an index of the (generalised) cost of extra-NUTS II volumes compared to an index of (generalised) cost of intra-NUTS II volumes is used in the equation term.

This phase also includes a parameter changing over time to simulate the trend of increasing long distance shipments (reducing the share of intra NUTS II) which has been observed over the years and that is not entirely due to reduction of generalised travel cost but rather on growing social and economic relationships between production and distribution activities located in different regions. This additional parameter captures this trend (and can be used for calibration purposes as well).

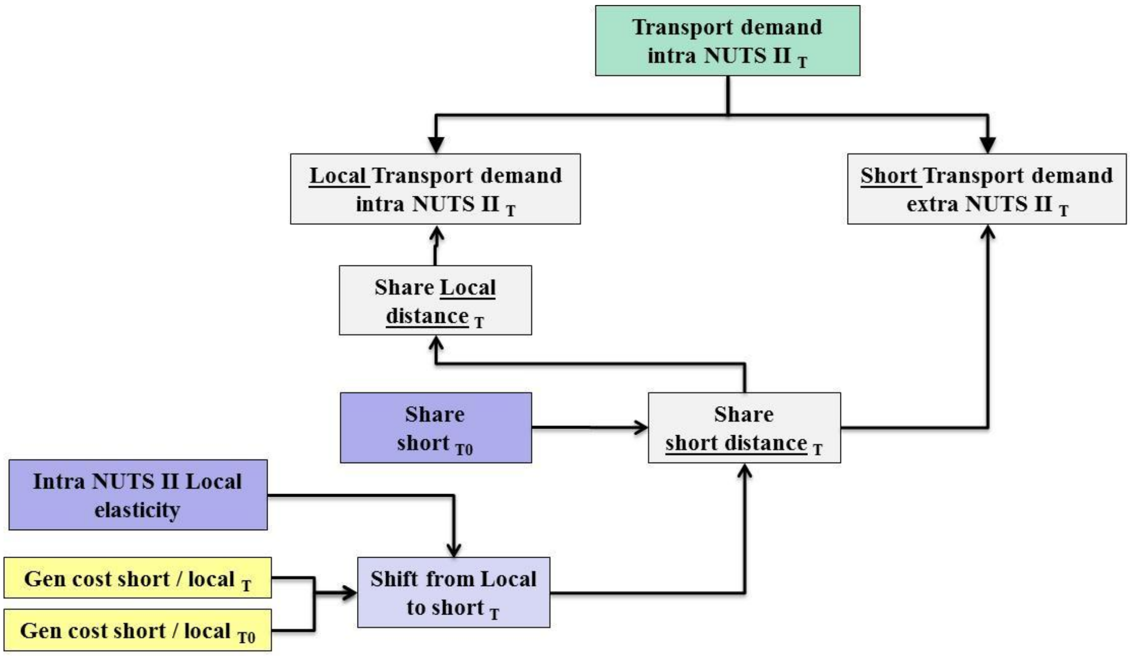
The approach and the equations are the same as for passenger demand, written by commodity flow *f* and zone *z* (see Figure 6-2 and Eq. 30 to Eq. 33).

Again, in order to avoid an excessive shift towards extra NUTS II destinations, the equations include a minimum share of intra NUTS II volumes which have to be satisfied.

It can be noted that the shift applies only in one direction with respect to the configuration at the time period t_0 (namely the year 1995): from intra to the extra NUTS II (not vice-versa). This means that it is assumed that over time demand moves from shorter to longer distances with respect to the configuration at the time period t0, or remain within the same distance band. Nevertheless, it allows the model to simulate increase and decrease of the shift over the simulation period (but never below the level observed at the time period t_0).

Intra NUTS II segmentation (local/ short)

The basic principle is the same mentioned above: it is assumed that if long distance shipments become cheaper a larger share of volume is long-distance, but this effect is smoothed in case the short distance shipments become cheaper as well. The comparison of generalised cost trends is made between the two distance bands at local level, considering the shift from ‘Local’ to ‘Short’. The approach is the same implemented for passenger demand.



Source: TRT

Figure 6-13: Intra NUTS II segmentation (local/ short)

In terms of equations, the approach is the same as for passenger (see Eq. 34 to Eq. 39), distinguished by NUTS II zone and commodity flow.

As already mentioned for the step before, the shift is implemented in order to apply only in one direction with respect to the configuration at the time period t_0: from local to the other distance bands (not vice-versa).

National OD distribution

In the previous step, the number of Extra NUTS II national volume with origin in each NUTS II zone is estimated. In this step such volumes are distributed among destinations. Initially volumes are aggregated at NUTS I[17] level (see paragraph 6.2.1 above). In 12 countries out of 28 only one zone is defined at NUTS I level, corresponding to the country level. Then freight volumes generated in each NUTS I are distributed among all domestic NUTS I (including intra NUTS I, i.e. with destination in the same NUTS I but

17 At national level, in order to generate NUTS I to NUTS I matrices, specific subscripts for each country have to be defined in order to avoid a huge increase of model size. As an example, for Italy the 'ITAnat' subscript includes 5 elements: ITCn, ITDn, ITEn, ITFn, ITGn. Within the subscript 'Nuts1' (of 95 elements), the elements related to Italy (5 elements) are: ITC, ITD, ITE, ITF, ITG. In this way each variable representing the national matrix includes e.g. 5 x 5 OD, instead of 95 x 95 of which only 5 x 5 not null.

extra NUTS II). As implemented for passenger demand, distribution is based on reference shares modified through elasticity to generalised cost per OD, distinguished by commodity flow (see Figure 6-5 and Eq. 43).

International and intercontinental OD distribution

At international level the zoning system refers to a country basis (country to country for the European matrix and Country to destination region for the international extra-European matrix), as derived from the trade data.

Volumes evolve over time according to trade data, as explained in paragraph 6.2.1.

Output indicators

At the end of the process, for the production of output indicators, a correspondence is defined in order to estimate indicators by origin country with the required classification by distance band (<300km, <1000km and above). This process is carried out based on the information related to the average distance between zones in each spatial dimension.

6.2.3 Freight mode split

Freight transport modes in ASTRA-EC are:

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

Table 6-7: Modes available for freight demand by spatial dimension

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

Source: TRT

- Inland waterway is modelled in a simplified way. For countries where this mode is relevant, its share is computed as part of the generated inland demand (see paragraph below for more details).
- For intermodal freight volumes, the concept of “main mode” is used. For instance, a shipment made by rail, maritime and truck is considered part of the mode “Maritime”. A shipment made by road and rail is considered part of mode “Rail”.
- Ferries are part of road mode, not of maritime.

The modal split process is calculated separately for each spatial domain: short, national extra NUTS II and international. At intra NUTS III level (local) freight volumes are supposed to travel by truck only and at intercontinental level by maritime only. The simulation is based on the application of direct and cross elasticities to cost variation and time variation likewise passengers (see Figure 6-7 and Eq. 48 to Eq. 52).

Direct elasticities to cost / time variation are differentiated by country, mode and commodity flow. As for passenger, the elasticity value:

- changes over time depending on the absolute value of time / cost per ton at previous time period;
- for time elasticity, depends on the trend of Value of Time;
- for cost elasticity, changes over time depending on the mode share, in order to differentiate the impact of elasticity taking into account whether a specific mode is more or less relevant in the mode split.

Finally, cross-elasticities are applied in order to simulate the shift from one mode to another, representing the share of demand gained (lost) by one mode as result of a reduction (increment) of demand for another mode. Such parameters are differentiated by country, mode and commodity flow and change over time depending directly on mode split at previous time period.

Inland waterways

As mentioned above, the freight volumes by inland waterways are estimated with a simplified approach.

In each spatial dimension of the countries where this mode is used, the trend of volumes by commodity type is estimated on the basis of a base value at 1995 and a reference trend. In addition, the trend is influenced by the variation of generalised cost of inland waterways over time. The estimated volumes are then subtracted from the volumes of the other inland modes (road and rail). A minimum threshold is implemented in order to avoid that the inland modes volumes are reduced to unbelievable low values due to the increase of inland waterways volumes.

The list of countries where inland waterways is available includes:

- Austria
- Belgium
- Luxembourg
- Finland
- France
- United Kingdom
- Germany
- Italy
- The Netherlands
- Bulgaria
- Switzerland
- Czech republic
- Hungary
- Latvia
- Poland
- Romania
- Slovakia.

6.2.4 Transport performances and load factors

Transport performances

Freight transport performances are estimated in terms of tonnes-km, resulting by multiplying volumes by mode of each distance band by the related average distance.

Average distances by mode are implemented in the model: at NUTS II level for intra NUTS II shipments, at NUTS I level for national trips, from country to country (or World Region) at international (intercontinental) level.

In general terms, the following equation applies:

$$TF_z^{\mathrm{DB,m}}(t) = d_z^{\mathrm{DB,m}}(t) \cdot \sum_f T_{zf}^{\mathrm{DB,m}}(t) \qquad \text{Eq. 67}$$

With: $TF_z^{\mathrm{DB,m}}(t)$ = freight transport performance (tkm) generated by the zone z[18] of distance band DB at the time period *t* by mode *m*

$d_z^{\mathrm{DB,m}}(t)$ = average distance travelled of volumes transported from the zone z[19] of distance band DB at the time period *t* by mode *m*

$\mathrm{T}_{zf}^{DB,m}(t)$ = freight volumes transported from the zone z[20] by flow group *f* of distance band DB at the time period *t* by mode *m*

Nevertheless, in case of OD trips the estimation is made taking into account the variables differentiated by OD.

Load factors

Average load factors are estimated in the model to calculate performance in terms of vehicles.

For **trucks**, average load factors are influenced by both the dimension of the vehicle and the share of empty trips. The latest can be estimated from EUROSTAT data on road freight transport vehicle movements, loaded and empty. As various vehicles could be used for travelling within each geographical dimension, the average load factor per

18 By OD in case of matrices.

19 By OD in case of matrices.

20 By OD in case of matrices.

context is also influenced by the assumptions on the composition of vehicle fleet used in each case (e.g. at local level, vans and LDV are used). The following table gives an example of the assumptions which might be implemented in this sense.

Table 6-8: Example of composition of truck vehicle fleet by spatial dimension

	Local	Short	National	International
LDV	100 %	27 %		
HDV below 12 t		73 %	30 %	
HDV above 12 t			70 %	100 %
Total	100 %	100 %	100 %	100 %

Source: TRT

For all countries, it is assumed that volumes at local level are moved always with LDV and at international level always with HDV above 12 tons.

For the remaining distance bands (short and national), the split of transport activity between truck types is estimated and differentiated by country, taking into account the vehicle fleet, the average annual mileage travelled, the average distance by distance band and the data on tkm travelled by LDV and HDV.

As a result, the output indicators related to road freight transport activity (i.e. tkm and vkm) can be differentiated taking into account the type of truck vehicle. This information is one of the input driving the evolution of the LDV and HDV vehicle fleet (see chapter 7).

For **freight train** the model takes into account that load factor is the first variable that changes when demand increases or falls. Therefore, minimum and maximum values of load factor have been defined, as follows:

- maximum accepted load factor, i.e. the highest average amount of ton per train before companies decide to add new services (t/v)
- minimum accepted load factor, i.e. the lowest average amount of ton per train before companies decide to cut some services (t/v).

The approach is therefore the same as for passenger, as reported in Figure 6-11.

The same approach is applied to **maritime ship**, while load factor for **inland waterways ship** is basically constant (except in case some policy is applied).

The average base values of load factors as well as minimum and maximum thresholds are reported in paragraph 9.6.

6.2.5 Accessibility indicators

As for passengers, in ASTRA-EC potential accessibility indicators are computed for freight demand at international level.

The same approach applies, estimating the indicator of potential accessibility by mode.

In this case the activity function is measured in terms of GDP of the destination zone, while the impedance function is represented by the average generalised cost between countries by mode.

The same remarks made for the case of passengers apply here, in particular that the appropriate use of the indicators is to assess whether accessibility of zones change when a policy measure is applied rather than comparing zones to each other.

6.3 The infrastructure module

The infrastructure networks (influencing **travel time**) are represented in the ASTRA-EC model in a simplified way (*INF*). In fact, in case of road (and rail) network the effect of speed-flow functions is included in the model indirectly: in other words, the increase of traffic flow has an impact on transport time but the functions and capacity values are not implemented directly in the tool.

In general terms, the following equation applies for travel time on road network:

$$
\begin{aligned}
\mathrm{T}_z^{\mathrm{m}}(t) = \text{if } & \left(\frac{F_z\,(t)}{\mathrm{C}_z(t)}\right) \leq 1 \\
& \text{then } \mathrm{BT}_z^{\mathrm{m}} \cdot \left(1 + \alpha \cdot \frac{F_z\,(t)}{\mathrm{C}_z(t)}\right)^{\beta} \\
& \text{else } \mathrm{BT}_z^{\mathrm{m}} \cdot \left(1 + \alpha + \chi \cdot \left(1 - \frac{1}{\left(\frac{F_z\,(t)}{\mathrm{C}_z(t)}\right)^{\delta}}\right)\right)
\end{aligned}
\qquad \text{Eq. 68}
$$

With: T^m_z (t) = travel time for mode *m* in transit through zone *z* (at NUTS I level) at time *t*

BT^m_z = base travel time for mode *m* in transit through zone *z* (at NUTS I level)

$\left(\frac{F_z\,(t)}{\mathrm{C}_z(t)}\right)$ = ratio between traffic flow *F* and capacity *C* in transit through zone *z* at time *t*

A similar equation applies to rail network.

In general, in case of trips between different origin and destination zones (i.e. national and international demand), the concept of transit matrix is applied, in order to estimate the travel time related to the NUTS I zone where the traffic is travelling.

The road network is differentiated into three “categories”:

- ‘Urban’
- ‘Non-Urban, short’
- ‘Non-Urban, long distance’

The following table reports the assumption on the percentage of transport demand contributing to road traffic on each network.

Table 6-9: Composition of traffic on road network “categories”

	DB	Road network		
		Local	**Non-urban short distance**	**Non-urban Long distance**
Passenger (car, bus)	LC	100 %		
	VS	100 %		
	ST	10 %	90 %	
	National		10 %	90 %
	International		10 %	90 %
Freight (truck)	LOC	100 %		
	SRT	10 %	90 %	
	National		10 %	90 %
	International		10 %	90 %

Source: TRT

For air mode and shipping travel time is constant over the simulation period.

For the purpose of the transport modules, estimating mode split and generalised cost, access time and fixed terminal times are implemented where relevant. Different base travel times are applied for different demand segments, at least for freight (e.g. travel time for the mode “maritime” is expected to be larger for the segment “bulk” than for the segment “unitised”).

The following table summarises the time components (travel, access, etc.) implemented for each mode.

Table 6-10: Time components by mode

	Time components			
	Mode	**Travel time**	**Access and waiting time**	**Load / unload time**
Passenger	**Car**	Depending on traffic flow and on investments		
	Bus	Depending on traffic flow and on investments		
	Train	Depending on traffic flow and on investments	Constant	
	Air	Constant	Depending on share of low cost flights and on investments	
	Slow	Constant		
Freight	**Truck**	Depending on traffic flow and on investments		Constant
	Train	Depending on traffic flow and on investments	Constant	Constant
	Ship	Constant	Constant	Depending on investments
	Inland waterways	Constant	Constant	Constant

Source: TRT

The investments in transport networks by mode are used in the module as input to drive the (slight) change of the variables related to

- “capacity” (and therefore travel time) for road and rail mode,
- access and waiting time for air mode,
- load / unload time for maritime.

For road and rail network, travel time can change over time also as a result of investments under the TEN-T programme: specific investments allocated over the years for building / improving infrastructures are implemented in the model taking into account the NUTS I zones where each project is developed and the OD trips which benefit from each project.

The amount of investments is converted under exogenous assumptions into variation (reduction) of travel time applied to the trips using routes passing through the NUTS I zones involved by the projects. For the selection of the OD trips in transit through the zones where TEN-T projects are realised, the concept of transit matrix is applied: based on the outputs of a European transport network model (TRUST network model[21]), for each OD trip the share of distance travelled in transit through a specific Nuts I zone is estimated.

The amount of investments evolves over time and the variation of travel time develops accordingly.

In the reference scenario, it is assumed that the core network will be (gradually) completed by 2030 and the comprehensive network by 2050.

A specific policy measures introduces the potential accelerated implementation of TEN-T projects (see chapter 11).

21 TRUST (TRansport eUropean Simulation Tool), is a transport network model developed by TRT in the MEPLAN software environment. The model builds on the transport network of TRANS-TOOLS and ETISplus and allows for the assignment of Origin-Destination matrices at the NUTS3 level. The TRUST model was used to support the assessment of the Eurovignette directive on behalf of DG MOVE.

7 The Vehicle fleet module

7.1 Car vehicle fleet

Modelling the technological diffusion of vehicle fleets is crucial for a holistic assessment of climate and environmental policies impacts on the economy, transport and environmental systems. System Dynamics suits perfectly as methodology for this purpose. There are several feedbacks that can be modelled best in a System Dynamics model which will be described in this chapter. Furthermore, the chapter explains the chosen approach to simulate the diffusion of alternative and conventional drives in passenger cars.

The Vehicle Fleet module in ASTRA-EC can be differentiated into three sub-models which simulate:

- the ageing of the car stock,
- the new cars registered and
- the choice of fuel technology.

The core of the model is a classical stock–flow model. New cars registered per time period constitute the inflow into the car stock which is differentiated by age cohorts. Cars are ageing within the stock. The outflow from the stock represents both, scrapping of cars and export of cars outside the EU. With increasing age, the model supposes growing probability of scrapping or exporting. The flow variables and the car stock variable are differentiated by age cohorts, emission standards (pre-Euro to Euro 6) and fuel technology. Several drivers determine in a linear way with varying significance the number of new registered cars per time period. The most important driver is the development of average disposable income per adult. Based on the principles of the national accounting system, ASTRA-EC computes the disposable income of private households in real terms top down from gross domestic product (GDP) for each EU27 country. Bol (2004) and Krail (2009) describe this approach in detail. Other drivers with lower significance are the number of cars scrapped per year, the evolution of average car prices, of average fuel prices and the number of persons above 18 years. The level of motorization plays a significant role as it closes a negative feedback loop dampening the number of new cars registered. It represents a saturation factor in the market. Another feedback is closed via the interrelation between new car registrations, investment and consumption, GDP and disposable income.

Based on the time of the new car registrations, the total new cars registered are then allocated with a certain probability to emission standards. The second differentiation in this top-down process is the allocation to the available fuel technologies. This allocation is modelled in the fuel technology choice sub-model. Today, the major alternatives to the conventional gasoline and diesel cars are: compressed natural gas (CNG) vehicles, liquefied petroleum gas (LPG) vehicles, hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), extended range electric vehicles (E-REV), battery electric vehicles (BEV), bioethanol (or flexi-fuel) vehicles and fuel cell electric vehicles (FCEV). Some alternative drives are available and offered to consumers at least by some OEM since years like CNG cars, LPG, HEV and flexi-fuel cars. Other alternative drives like PHEV and BEV had their first market entry in the EU only shortly. FCEV are currently not available but some OEM announced to bring the first FCEV in 2015 to the market (e.g. Daimler). ASTRA-EC distinguishes between six main alternative fuel technologies and the conventional technologies gasoline and diesel. For reasons of simplification, PHEV and E-REV are assigned to the group of HEV. Full HEV are diffusing in the period 2020 to 2030 to the conventional categories gasoline and diesel such that after 2030 only PHEV and E-REV are accounted to this car category.

In EU27 conventional gasoline and diesel cars will still dominate the vehicle fleet at least of the next decade according to experts, but the share of alternative drives is slowly increasing. According to the theory of diffusion, innovations diffuse with different speed into the market. Common to all diffusion processes is an S-shaped pathway of diffusion over time.

Rogers (2003) differentiates between five stages of innovation on an S-shaped diffusion curve. According to his categories current purchasers of alternative drives still belong to the first category “Innovators”. In the theory of diffusion several approaches for diffusion models have been developed since the 1960s. The research made by Mansfield (1968) provided the baseline for development of epidemic diffusion models. The basic idea behind this type of models is that new technologies diffuse via spreading information and learning processes into the market. Bass (1969) developed a similar approach explaining the process how new technologies diffuse into the market due to the interaction of innovation and imitation. Common to both approaches is the logistic function leading to an S-shaped curve of diffusion.

Another possibility to model the diffusion of alternative drives is given by the theory for analyzing discrete choice for which McFadden (2001) won the Nobel price the in the year 2000. Originally, McFadden applied the discrete choice theory to forecast the modal choice and transport demand in the context of planning the BART system in San Francisco. The choice for a transport mode out of a set of alternatives is similar to the choice of a suitable fuel technology in the car purchasing process. Each alternative has its consumer utilities which can be expressed by negative costs. Accessibility and availability of alternatives play a significant role for both. The accessibility of public transport is an example for a driver of modal choice, the density of the filling station infrastructure one for fuel technology choice. The possibility to integrate also non-quantitative impacts like individual preferences is very important as well.

Several US studies and a study from ARAL (2005) elaborated via costumer surveys potential factors influencing the decision of a car purchaser for a certain fuel technology. According to this study the costumers set a high value on economic efficiency for new cars. Price in combination with the provided performance of a car is the most significant factor with 55 % followed by the mileage of the car. Compared with older surveys the factor safety lost significance but, nevertheless, safety still plays an important role for 47 % of all interviewed customers. Besides economic and technical factors influencing the car purchase decision the study included also soft factors like design, image and prestige. The so-called residual disutility in logit functions can represent these soft factors influencing the acceptance of a fuel technology.

Similar to the application of logit-functions in the modal-split stage this model does not compute benefits but costs derived from the concept of Total Cost of Ownership (TCO) that can be put into the logit function as negative benefits according to the following equation:

$$P_{cc,i} = \frac{\exp(-\lambda_i * C_{cc,i} + LC_{cc,i})}{\sum_{cc} \exp(-\lambda_i * C_{cc,i} + LC_{cc,i})} \qquad \text{Eq. 69}$$

With:

With:	P =	share of purchased cars per car category cc and country i
	C =	costs per vehicle-km per car category cc and country i
	λ =	multiplier lambda per country i
	LC =	logit const per car category cc and country i representing the residual disutility
	cc =	index for car categories/fuel technologies
	i =	index for EU27+2 countries

The car fleet model calculates the required average costs per vehicle-km for each fuel technology in a bottom-up approach. First, the model computes variable costs per vehicle-km based on average fuel consumption factors for each technology and country-specific fuel prices provided by the POLES model described in Krail et al. (2007). The linkage to the world energy model POLES closes an important feedback loop. ASTRA-EC calculates transport demand in terms of yearly fuel consumption which is used as an input to simulate the fuel and energy price development. Finally, fuel prices are fed back and change the transport demand, influence the economy and the technology choice.

Fuel consumption factors for fossil fuel cars are derived from HBEFA (2010). Available sales figures for specific car categories for each alternative fuel category and general information from Original Equipment Manufacturers (OEM) are used to generate average fuel consumption factors for the alternative fuel categories.

Besides variable costs the model also considers fixed costs for each car category. Fixed costs per car category and country are determined by car-ownership taxation, registration fees and purchase costs per country and car category as well as country-specific average maintenance costs. All elements of fixed costs are transformed into costs per vehicle-km by the division of average yearly mileages per car category and country. As the conversion of purchase costs into costs per vehicle-km requires information on average lifetime per car category, this is derived from the car stock model via a feedback loop.

Assuming completely rational purchase decision behaviour based on all variable and fixed costs would disregard other important drivers like the distribution grid of filling or charging stations selling the requested type of fuel. For conventional fuel types like gasoline and diesel the distribution grid is characterised by a good quality in all EU27 countries. At present, owners or prospective customers of alternative fuel cars have to cope with the burden that the procurement of alternative fuels requires significantly longer additional trips or is even not feasible due to lacking filling stations. Janssen et al. (2004) concluded in their paper on CNG market penetration that successful diffusion of new car technologies depend on a uniform development of technology and filling station infrastructure. Taking into account these significant impacts due to fuel supply differences, the model has to consider the quality of filing station grids as well. Hence, the four mentioned cost categories have to be completed by so-called fuel procurement costs. In order to generate these costs per vehicle-km for each car category and country the model requires input in terms of approximated development of filling station numbers for each fuel types. An optimal distribution of filling stations offering alternative fuels is assumed.

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

$$C_{cc,i} = \alpha_{cc,i} * pC_{cc,i} + taxC_{cc,i} + mC_i + vC_{cc,i} + procC_{cc,i} \quad \text{Eq. 70}$$

With:
C = perceived car cost per vehicle-km per car category cc and country i
pC = purchase cost per vehicle-km per car category cc and country i
taxC = taxation/registration cost per vehicle-km per car category cc and country i
mC = maintenance cost per vehicle-km per country i
vC = variable/fuel cost per vehicle-km per car category cc and country i
procC =fuel procurement cost per vehicle-km per car category cc and country i
α = weighting factor representing the significance of purchasing costs
cc = index for car categories/technologies
i = index for EU27+2 countries

Finally, the logit function simulates the probability of the choice of a fuel technology based on the simulated perceived car costs.

7.2 Truck (LDV and HDV) vehicle fleet

The systematisation of the truck vehicle fleet module is very similar to the described car module above. In general, it is divided by total vehicle weight into two different parts: Vehicles above 3.5 t total weight (HDV) and the ones below (LDV). The reason therefore is that light duty vehicles (LDV) are from a technical point of view only slightly different to private cars. The technical characteristics (powertrain technologies) of heavy duty vehicles (HDV) however differ quite a lot. ASTRA-EC considers no alternatives for powertrains of HDV besides conventional Diesel and Biodiesel. LNG is not considered in ASTRA-EC.

The LDV-module can be divided into two sub-modules:

- LDV fleet growth and aging and
- LDV technology choice.

The calculation of the number of LDVs needed is based on the generated transport demand for vehicles with a total weight of less than 3,5t coming from the transport module (TRA). The differentiation of vehicle-km into the truck categories is based on assumed split factors for each distance band (e.g. 85% of all vehicle-km in the short distance band are assumed to be done with LDV). The number of existing vehicles multiplied with an annual vehicle mileage leads to the status quo transport supply. In case of the supply not meeting the demand the results could be on the one hand a growing or on the other hand a shrinking fleet of LDV. Based on this general framework the scrapping ratio as well as the annual mileage can be calibrated within statistic deviation by comparing the existing fleet data with the calculated figures. The new LDVs are assigned to emission standards similar to approach used in the car module. The probability that a new truck is allocated to a certain emission standard depends on the year of registration. E.g. trucks registered in 2011 are assumed to have by 30% Euro 5 standard and by 70% Euro 4 standard. In 2012, the model assumes that 100% of all new registered trucks fulfil Euro 5 standard.

As the diffusion of alternative powertrain technologies within the LDV-market seems to be quite likely, the second sub-module ("technology choice") considers battery-electric driven vehicles besides diesel and gasoline engines. The used discrete choice model is based on a logit function comparing total cost of ownership of the different technologies in a simplified way. As opposed to the car fleet approach, fuel procurement costs are not considered in order to simplify the approach. Due to the assumption of a more rational decision process within the duty vehicle operators, the total costs of ownership consist of two components: purchase and fuel costs. Thereby the importance of purchase cost is taken into account by a specific weight. The following equation describes the TCO calculation.

$$C_{ldvc,i} = \alpha_{ldvc,i} * pC_{ldvc,i} + vC_{ldvc,i} \qquad \text{Eq. 71}$$

With:
- C = perceived vehicle cost per vehicle-km per ldv category ldvc and country i
- pC = purchase cost per vehicle-km per ldv category ldvc and country i
- vC = variable/fuel cost per vehicle-km per ldv category ldvc and country i
- α = weighting factor representing the significance of purchasing costs
- ldvc = index for three ldv categories/technologies
- i = index for EU27+2 countries

The fuel consumption values for conventional as well as for the alternative powertrains are based on figures from Original Equipment Manufacturers (OEM). According to the car module, the fuel prices are provided by POLES. Assumptions for cost development of powertrain technologies are taken from LBST (2012). The perceived total LDV costs per vehicle-km as a composition of fuel and purchase costs are the input for the following logit-function:

$$P_{ldvc,i} = \frac{\exp(-\lambda_i * C_{ldvc,i} + LC_{ldvc,i})}{\sum_{cc} \exp(-\lambda_i * C_{ldvc,i} + LC_{ldvc,i})} \qquad \text{Eq. 72}$$

With:
- P = share of purchased ldv per vehicle category ldvc and country i
- C = costs per vehicle-km per ldv category ldvc and country i
- λ = multiplier lambda per country i
- LC = logit const per ldv category ldvc and country i representing the residual disutility
- ldvc = index for three ldv categories/fuel technologies
- i = index for EU27+2 countries

The result of the simulation is the probability of the choice of a fuel technology based on the simulated perceived LDV costs.

The HDV fleet module divides the fleet into vehicles with a total weight above and below 12t. Reasons therefore are the differences within heavy duty vehicles. The demand for each vehicle class depends on the segmented traffic demand in vhc-km coming from the transport module (TRA). The calculation as well as the calibration process is very similar to the one of the LDV module and hence not described in detail. At the first stage the annual mileage is chosen from statistics to be calibrated in the second stage. The demand for new HDVs as well as the replaced vehicles is associated with emission standards depending on the year of registration.

7.3 Bus vehicle fleet

The Bus fleet module calculates the number of buses used in EU depending on the traffic demand. The traffic demand as a major output of the transport module (TRA) leads to a number of buses needed to satisfy the demand. The major assumption is that rationality of bus operators will lead to an optimal number of buses to satisfy the demand. Therefore the transport supply which can be offered by the buses in the current fleet is calculated in the following way:

$$S_{bus,i} = N_{bus,i} * m_{bus,i}$$ Eq. 73

With:

S =	Transport supply by buses per country i
N =	number of buses per country i
m =	average mileage per country i
i =	index for EU27+2 countries

If the supply is not equal to the demand, the fleet size will change depending on the algebraic sign of the gap. Each new bus will be classified to an emission standard according to the year of registration. The bus fleet represented by a stock is feed by new purchased busses and diminished by scrapped buses. The scrapping ratio per vehicle age as well as the average annual mileage of the vehicles is calibrated to fit the fleet size to historical data.

8 The Environmental module

The environment module (*ENV*) uses input from the transport module (in terms of vehicle-kilometres-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, greenhouse gas emissions and pollutant emissions from transport, accidents and the related externality value.

8.1 Pollutant emissions

ASTRA-EC simulates annual emissions for NOx, CO, VOC and $PM_{2.5}$ for all transport modes.

In order to represent the whole life-cycle of transport related emissions, hot emissions, cold start emissions, vehicle production emissions and fuel production emissions are considered: hot emissions occur during the driving activity, cold start emissions are emitted during the warm-up phase of vehicles starting with cold engines, fuel production emissions escape during filling and production processes of consumed fuel, and vehicle production emissions occur during the manufacturing process of new vehicles.

Hot and cold start emissions are simulated on the basis of emission factors per vehicle category, emission standard and, only for hot emissions, different traffic situations depending on distance band. The model is able to generate hot emissions for each pollutant via mode-specific transport performance in vehicle-kilometres-travelled provided by the transport module.

In general terms, for each transport mode the following equation applies for the estimation of hot emissions:

$$hEM_{z,db}^{cc}(t) = hEF_{db}^{cc}(t) \cdot shVft_{z}^{cc}(t) \cdot Vkm_{z,db}(t) \qquad \text{Eq. 74}$$

With: $hEM^{cc}_{z,db}$ =hot emissions for vehicle technology/emission standard *cc* and distance band *db* in zone *z* [t/year]

$hEF^{cc}_{db,}$ = hot emission factor for vehicle technology /emission standard *cc* and distance band *db* [g/km]

$shVft^{cc}_{z}$ =vehicle fleet composition (by vehicle technology /emission standard *cc*) in zone *z* (the same in all zones of a country) [%]

$vkm_{z,db}$ =vehicle-km travelled in zone *z* and distance band *db* [Mio*vkm/year]

z = NUTS I zone

The number of originating trips per mode is the input for the computation of cold start emissions.

$$cEM_z^{cc}(t) = cEF^{cc}(t) \cdot shVft_z^{cc}(t) \cdot oT_z(t)$$ Eq. 75

With: $cEM^{cc}_{z,}$ =cold start emissions for vehicle category/emission standard *cc* in zone *z* [t/year]

cEF^{cc} = cold emission factor for vehicle category/emission standard *cc* [g/start]

$shVft^{cc}_z$ =vehicle fleet composition (vehicle category/emission standard *cc*) in zone *z* [%]

oT_z = originating trips in zone *z* [Mio*trips/year]

z = NUTS I zone

The amount of new vehicle produced is used to estimate vehicle production emissions.

$$vEM_z(t) = vEF(t) \cdot nVft_z(t)$$ Eq. 76

With: $vEM_{z,}$ = emissions for vehicle production in zone *z* [t/year]

cEF^{cc} = emission factor for vehicle production [kg/v]

$nVFT_z$ = purchase of new vehicles in zone *z* [v/year]

z = country

Fuel production emission factors representing NOx, CO and VOC emissions caused by the extraction of crude oil from the ground, the transport of crude oil to refineries, the refining process and the transportation of fuel to the end-user are considered and applied to fuel consumption indicators.

$$fEM_z^f(t) = fEF^f(t) \cdot fC^f{}_z(t)$$ Eq. 77

With: $fEM^f_{z,}$ = emissions for fuel production of fuel *f* in zone *z* [t/year]

fEF^f = emission factor for fuel *f* production [g/l or g/kg fuel]

fC^f_z = total fuel consumption of fuel *f* in zone *z* [Mio l/year or t/year]

z = country

Currently, emission factors are derived from HBEFA 3.1[22] for road transport and from other sources for rail, ship and air transport. Emission factors from HBEFA 3.1 are in line with those factors from COPERT IV. The following table reports the data sources used by mode.

Table 8-1: Data sources for emission factors by mode

Emissions	Mode	Sources
Cold start	Car	HBEFA 3.1
Hot	Car	HBEFA 3.1
	Bus	HBEFA 3.1
	Trucks	HBEFA 3.1
	Train (passenger and freight)	TREMOVE, INFRAS-IWW
	Air	MEET D18 / D4
	Inland waterways	GEERTS at al.[23]
	Maritime	MEET D22, Cooper[24]
Fuel production	All	MEET D20
Vehicle production	Car	German federal statistical agency (Schade 1997)
	Bus	German federal statistical agency (Schade 1997)
	Trucks	German federal statistical agency (Schade 1997)

Source: TRT

The HBEFA 3.1 database provides emission factors for all EURO emission standards of road vehicle categories. Within the ASTRA-EC model, a selection of vehicle categories is used (representing fuel engine and EURO standard, see paragraph 7.1); nevertheless, for each vehicle category three different hot emission factors are needed to represent the ASTRA-EC distance bands (urban, non-urban, long distance). The esti-

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

23 GEERTS et al. (2010), Improving the efficiency of small inland vessels.

24 Cooper D. (2002), Representative emission factors for use in “Quantification of emissions from ships associated with ship movements between port in the European Community”.

mation of hot emission factors by distance band is based on assumptions on average speed in each case.

A similar approach applies to the other modes: e.g. rail transport performance is split into diesel and electrical traction on the basis of the share of total train-km with diesel traction, evolving over time. This share is estimated on UIC data (e.g. Halder and Lochter, 2005). Based on emission factors of power stations representing the national electricity mix, the emissions of NOx, CO and VOC are computed. The electricity mix has been estimated on the basis of EUROSTAT data on Gross electricity production. Since the national electricity mix might change over time and especially in the future, the related emission factors evolve over time according to a specific parameter.

Air transport emissions is estimated by considering average emissions of short and long distance flights of a representative aircraft type.

8.2 Fuel consumption

Fuel consumption factors are also taken from HBEFA 3.1. They are composed similarly as the emission factors to reflect the different traffic situations in the ASTRA-EC distance bands. Fuel consumption factors evolve over time due to different aspects: increased use of air conditioning, speed influence, etc.

Total fuel consumption is estimated applying fuel consumption factors to transport performances expressed in terms of vehicle-km by distance band, differentiated by vehicle category (and therefore mode of transport) based on the estimation of average mileage.

$$Fc_{z,db}^{cc}(t) = FcF_{db}^{cc}(t) \cdot shVft_{z}^{cc}(t) \cdot Vkm_{z,db}(t) \qquad \text{Eq. 78}$$

With: $Fc^{cc}_{z,db}$ =fuel consumption for vehicle technology/emission standard *cc* and distance band *db* in zone *z* [t/year]

$FcF^{cc}_{db,}$ = fuel consumption factor for vehicle technology /emission standard *cc* and distance band *db* [g/km]

$shVft^{cc}_{z}$ = vehicle fleet composition (by vehicle technology / emission standard *cc*) in zone *z* (the same in all zones of a country) [%]

$vkm_{z,db}$ = vehicle-km travelled in zone *z* and distance band *db* [Mio*vkm/year]

z = NUTS I zone

For air and maritime mode the amount of vehicle-km refers to the origin zone (or country), since the concept of transit would not be meaningful for the estimation of fuel consumption. In addition, it should be highlighted that for these modes (air and maritime) fuel consumption and therefore CO_2 emissions is not fully comprehensive, since only domestic and intra-European transport demand is taken into account.

Nevertheless, a comparison with observed data to check the status of calibration on this aspect has been made by fuel and mode.

The following fuels are taken into account in the model:

- Electricity
- Diesel
- Gasoline
- Biodiesel
- Bioethanol
- Kerosene
- LPG
- CNG
- Hydrogen.

In particular, it should be mentioned that biofuels are mainly related at current stage to road and rail modes; nevertheless, the model include the possibility to reflect the uptake of these fuels for aviation, inland waterways and maritime in the long run.

8.3 CO_2 emissions

Tank-to-wheel CO_2 emissions depend directly on fuel consumption. Conversion factors for the estimation of CO_2 emissions resulting from burning transport fuels are used as follows:

$$hCO_2EM^{f}_{z,m}(t) = cF^{f} \cdot FC^{f}_{z,m}(t) \cdot 1000$$ Eq. 79

With: $hCO_2EM^{f}_{z,m}$ = tank-to-wheel CO_2 emissions for fuel *f* by mode *m* in zone *z* [t/year]

cF^{f} = conversion factor for fuel *f* (CO_2 emissions per litre of fuel burned) [kg CO_2/l]

$Fc^{f}_{z,m}$ = fuel consumption for fuel *f* by mode *m* in zone *z* [Mio*l/year]

z = country

ASTRA-EC also estimates the upstream CO_2 emissions (well-to-tank) due to fuel production and vehicles production. The same equations described for pollutant emissions apply (see paragraph 8.1).

$$vEM_z^{CO2}(t) = vEF^{CO2}(t) \cdot nVft_z(t) \qquad \text{Eq. 80}$$

With: $vEM_{z,}^{CO2}$ = emissions of CO_2 for vehicle production in zone z [t/year]

vEF^{CO2} = CO_2 emission factor for vehicle production [kg/v]

$nVFT_z$ = purchase of new vehicles in zone z [v/year]

z = country

$$fEM_z^{f\,CO2}(t) = fEF^{f\,CO2}(t) \cdot fC^f{}_z(t) \qquad \text{Eq. 81}$$

With: $fEM^f_{z,}{}^{CO2}$ = CO_2 emissions for fuel production of fuel f in zone z [t/year]

$fEF^{f\,CO2}$ = CO_2 emission factor for fuel f production [g/l or g/kg fuel]

fC^f_z = total fuel consumption of fuel f in zone z [Mio l/year or t/year]

z = country

Therefore, considering all contributions, well-to-wheel CO_2 emissions can be provided.

Nevertheless, as mentioned above, it should be highlighted that for air and maritime modes fuel consumption and therefore CO_2 emissions is not fully comprehensive, since only domestic and intra-European transport demand is taken into account.

8.4 Accidents

Accidents are estimated in ASTRA-EC on the basis of accident rates by mode, implemented with reference to transport demand performances. Accidents are differentiated in categories (fatality, serious, light, material) according to their severity.

For car mode, accident rates are distinguished by urban and non-urban context, in order to take into account different traffic conditions; blood alcohol limit and speed limits affect the risk represented by the accident rate and might be varied according to specific policies. Accident rates for car (passenger and driver) are expressed in terms of cases per billion of vehicle*km, applied to the amount of vehicle*km travelling within a zone in urban or non-urban context.

$$cAcc^{f}_{z,u}(t) = cAccR^{f}_{z,u}(t) \cdot cVkm_{z,u}(t) \qquad \text{Eq. 82}$$

With: $cAcc^{f}_{z,u}$ = car accident of category f in zone z and context u [cases/year]

$cAccR^{f}_{z,u}$ = car accident rate of category f in zone z and context u [cases/Bio*vkm]

$cVkm_{z,u}$ = car vkm travelling within zone z and context u [Bio*vkm/year]

z = NUTS I zone

For slow modes, the accident rates refer to passenger*km travelling within a zone in urban context. For both road and slow modes, the main sources of data is the IRTAD database[25].

For all other modes the accident rates could not be differentiated by zone or country; therefore, average values from different sources have been taken into account and applied to the amount of transport demand expressed in vehicle*km: namely, the IRTAD database, the INFRAS\IWW study on external cost[26], UIC database , CE Delft – Infras - Fraunhofer ISI[27], Aviation Safety - Boeing Commercial Airplanes[28] data.

For shipping mode (and inland waterways) only material damages are estimated in an approximated way (i.e. with reference to oil tanker accidents). In any case, the equation applied follows the same structure reported above for car mode.

The accident rates evolve over time by a mode specific trend, taking into account technical development as well as other circumstances (speed limits, infrastructure quality, etc.). In particular, for road modes in non-urban context, road quality has an impact on the accident rates in case that roads are deteriorated over time because of an insufficient investment in road maintenance. Within the model, actual maintenance investments are calculated as a share of total road investments: comparing the necessary investments for a stable road quality with the actual investments the safety level is increased or decreased over time.

25 International Traffic Safety Data and Analysis Group.

26 INFRAS-IWW, External cost of transport - Final report, Zurich/Karlsruhe 2004.

27 CE Delft, Infras, Fraunhofer ISI (2011), External Costs of Transport in Europe: Update Study for 2008, Delft.

28 Boeing Commercial Airplanes (2012), Statistical Summary of Commercial Jet Airplane Accidents - Worldwide Operations 1959 – 2011, Seattle (USA).

8.5 Externalities

The ASTRA-EC model include the estimation of the value of externalities related to pollutant emissions, CO_2 and accidents.

The estimation of externalities for CO_2 and pollutant emissions (NOx, VOC, PM) depends on the correspondent quantitative environmental indicator (e.g. CO_2 yearly emissions) and an externality cost value, expressed as EURO per ton emitted. The externality cost values are taken from the deliverable D1 of the IMPACT project[29].

The following equation is applied in general terms.

$$ExC_z^p(t) = tEM_z^p(t) \cdot ec_z^p(t) \qquad \text{Eq. 83}$$

With: $ExC^p{}_z$ = total externality Cost of pollutant *p* in zone *z* [EURO/year]

$tEM^p{}_z$ = total emissions (hot, cold, etc.) of pollutant *p* in zone *z* [t/year]

$ec^p{}_z$ =externality cost value of pollutant *p* in zone *z* [EURO/t]

z = country

The model calculates also externalities related to accidents, taking into account value of safety as well as direct and indirect economic costs. The estimation depends on one hand on the number of accidents causing fatalities, injuries and /or material damages, and on the other hand on the monetary value of material and human damages. The externality cost values are taken from the IMPACT study mentioned above, distinguishing between fatalities and injuries. In particular, the average Value of Statistical Life (VSL) of € 1.6 million is applied, from which values for severe injuries (13 % of VSL) and slight injuries (1 % of VSL) are derived.

The following equation is implemented:

$$ExC_z^{Ai}(t) = A_z^{Ai}(t) \cdot ec_z^{Ai}(t) \qquad \text{Eq. 84}$$

With: $ExC^{Ai}{}_z$ = total externality Cost of accident by type *Ai* in zone *z* [EURO/year]

$A^{Ai}{}_z$ = total accidents by type *Ai* (fatalities, injuries) in zone *z* [cases/year]

$ec^{Ai}{}_z$ =externality cost value of accident by type *Ai* in zone *z* [EURO/case]

z = country

29 "Handbook on estimation of external costs in the transport sector - Internalisation Measures and Policies for All external Cost of Transport", IMPACT project D1, CE Delft, 2008.

In any cases (CO_2, pollutant, accidents) the externality cost value might change over time.

Finally it has to be reminded that the considered externalities do not represent the complete range of externalities of transport. Further effects (i.e. noise and impacts on nature and landscape) should be considered to get a complete picture of transport externalities.

9 The database

9.1 Transport cost

9.1.1 Passenger mode

Transport cost variables related to passenger transport demand are always expressed in terms of €/pkm and refer to each transport mode available in the demand module:

- Car
- Train (regional and long distance)
- Bus (urban and medium-long distance)
- Air

Car

Passenger car average cost per passenger-km is differentiated by country, purpose and distance band.

The main driver of this variable is the weighted average of car variable cost per vehicle on the basis of car vehicle fleet composition by country. Road passenger user cost includes only fuel cost, taking into account fuel consumption factors related to each distance band and vehicle type. In other words, only car perceived costs are implemented in the transport module.

For those countries where this policy is applied, also the network toll cost (for motorway or other roads) is taken into consideration (in terms of €/vkm): in the reference (current) situation the same value is applied to all type of car vehicles. The toll cost is applied only to the share of traffic using the tolled network, differentiated by distance band and country on domestic network. The share of traffic is mainly estimated on the basis of the share of tolled network with respect to the total length of main road network in each NUTS I zone of a country. In addition, with reference to the distance band, it is expected that the tolled network is used less in the short distance band.

The value of road tolls have been estimated on the basis of the information available from various reports and internet sites on car tariffs, differentiating the value by country. Where an annual vignette is applied, the distance-related toll has been estimated under the hypothesis of an yearly average mileage travelled on tolled network. Where distance related tolls per km were not directly available, they have been estimated using a sample of paths for which total toll and total distance travelled on the network have been extracted from dedicated websites. When tolls are different among sections of the road network (or among zones of the same Country), an average value has been estimated.

Finally, car occupancy factors differentiated by distance band, purpose and country allow to estimate the average car passenger cost per passenger-km.

For trips within short distance band (where the tolled network might be used), the average car cost is estimated with the following equation:

$$\mathrm{C}_{zpD}^{\mathrm{car}} = \left(\frac{\mathrm{vC}_{cD}^{\mathrm{car}} + \mathrm{M}_{c}^{\mathrm{car}} \cdot Sm_{z}^{\mathrm{car}}}{\mathrm{OF}_{cpD}^{\mathrm{car}}} \right) \qquad \text{Eq. 85}$$

With: $C^{car}{}_{cpD}$ = average car cost per passenger-km in country c for purpose p within distance band D [euro/pkm]

$vC^{car}{}_{cD}$ = car average variable cost per vehicle-km in country c within distance band D [euro/vkm]

$M^{car}{}_{c}$ = car toll cost per vehicle-km in country c at time T [euro/vkm]

$Sm^{car}{}_{z}$ = share of traffic using tolled network in zone z of country c [%]

$OF^{car}{}_{cpD}$ = car occupancy factor in country c for purpose p within distance band D [person/v]

c = country

For trips at national and international level, the car toll cost is estimated as an average taking into account the zone (or countries) of transit and the characteristic of their tolled network. As an example, at national level the average car toll cost between zone z and zone y is estimated as follows:

$$\mathrm{M}_{zy}^{\mathrm{car}} = \sum_{x} \mathrm{M}_{c}^{\mathrm{car}} \cdot Sm_{x}^{\mathrm{car}} \cdot T_{zyx}^{\mathrm{car}} \qquad \text{Eq. 86}$$

With: $M^{car}{}_{c}$ = car toll cost per vehicle-km in country c [euro/vkm]

$Sm^{car}{}_{x}$ = share of traffic using tolled network in zone x of country c [%]

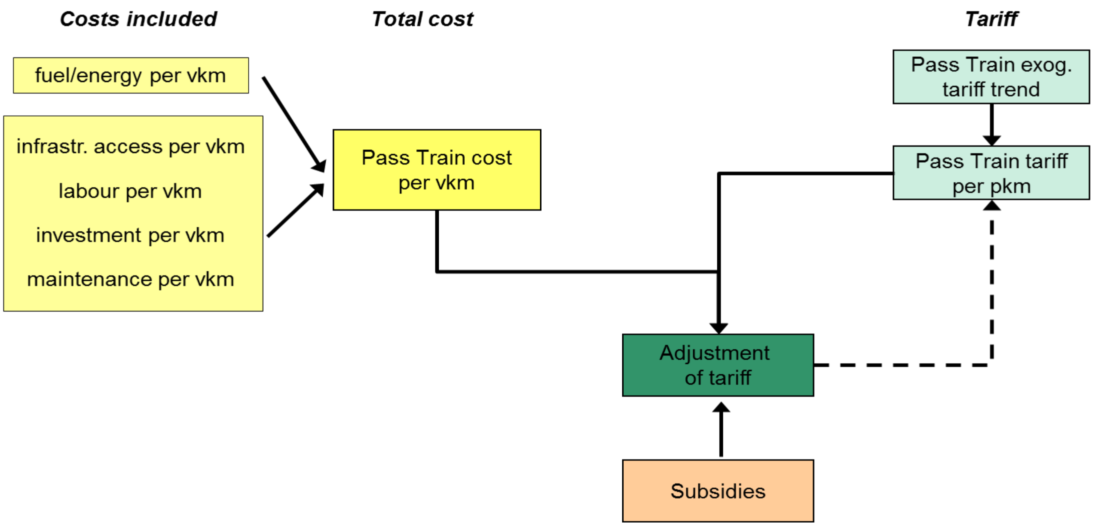
$T^{car}{}_{zyx}$ = share of distance travelled in transit within zone x in a car trip from zone z to zone y [%]

x,y,z = NUTS I zone in country c

Train

For train mode, a disconnection occurs between unitary production cost and customer tariff; nevertheless, in the model an approximated procedure is applied in order to estimate the tariff per passenger-km taking into account the impact of different cost components, in particular differentiating energy costs and other cost (labour costs, investments, infrastructure access and maintenance). More in details, total cost for providing the passenger train services are estimated: the trend of total cost affects indirectly the current tariff. In addition, changes of subsidies are taken into account and might produce a further adjustment of the tariff. Anyway, an exogenous base trend is applied to the tariff to drive the evolution over time. The estimation is made by distance band, differentiating regional and national / international services.

The following figure represents the structure of cost for passenger train services.



Source: TRT

Figure 9-1: Estimation of train passenger tariff

For estimating cost components the following sources have been used:

- for Italy an official document is available (Cicini et al, 2005) detailing costs splitting for single voices and for different services (local, intercity, high speed, freight),
- a complete survey of average costs of rail companies in Europe can be derived from UIC data.

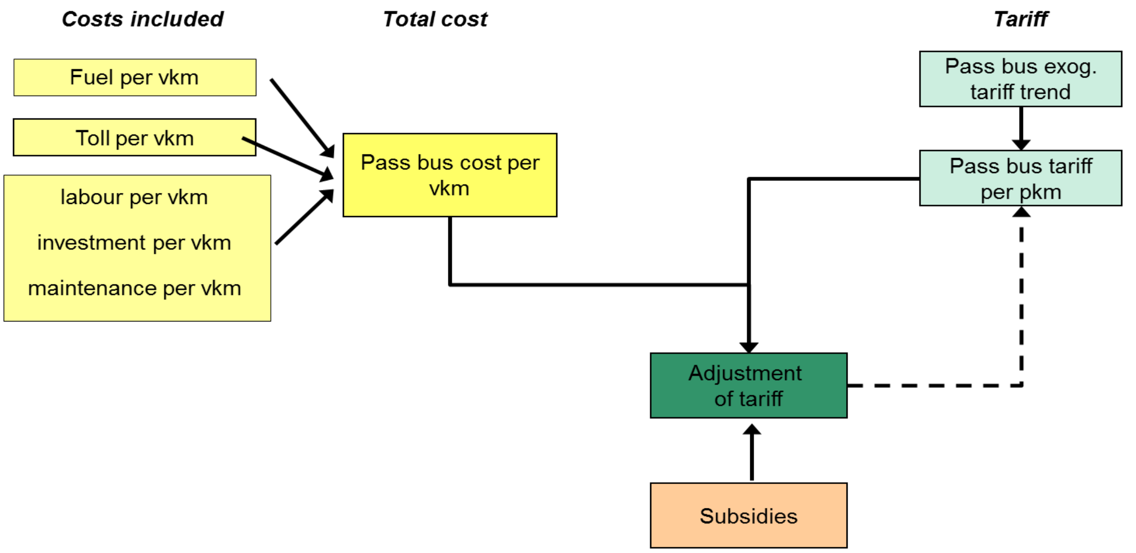
Passenger tariff has been estimated in terms of €/pkm on the basis of the information available from various internet sites related to train transport service. Where distance related tariff per km was not directly available, it has been estimated using a sample of paths for which total tariff and total distance travelled have been extracted from dedicated websites.

Tariff is differentiated by purpose: it has been assumed that commuters using train mode benefit of special discounts for frequent use (season tickets, weekly or monthly rate, etc.), setting the train tariff equal to 50 % of the "normal" rate.

Bus (urban) and medium-long distance

The public transport sector (urban and non-urban) is characterised by a disconnection between unitary production cost and customer tariff. Firstly, due to relevant subsidies of the sector (included explicitly in the module) and secondly, due to the fact that the tariff in most of the cases is unique (time tariff, season tickets, etc.), with no link to distance travelled. Therefore, for the purpose of the model an approximated procedure is applied in order to estimate the tariff per passenger-km taking into account detailed production costs. In particular, fuel cost, other cost (labour costs, investments and maintenance) and road network toll cost (for long distance services only) are considered. The structure of the model is similar to the train tariff: total cost for providing the passenger bus services are estimated and the trend is used to adjust the current tariff; changes of subsidies might influence the tariff a well. Anyway, an exogenous base trend is applied to the tariff to drive the evolution over time. The estimation is made by distance band, differentiating urban, non-urban and long distance services.

The scheme of the estimation procedure is presented in the following figure.



Source: TRT

Figure 9-2: Estimation of bus passenger tariff

For the estimation of cost components, data is available for a selection of Western European countries (Earchimede, 2005). The data collected has been expanded to the whole Europe.

Passenger tariff has been estimated in terms of €/pkm on the basis of the information available from various internet sites related to bus transport service at local or long distance level. Where distance related tariff per km was not directly available, it has been estimated using a sample of paths for which total tariff and total distance travelled have been extracted from dedicated websites. In general, at local level data related to the urban service of the capital city has been used.

Tariff is differentiated by purpose at local level: it has been assumed that commuters using train mode benefit of special discounts for frequent use (season tickets, weekly or monthly rate, etc.), setting the train tariff equal to 65 % of the “normal” rate.

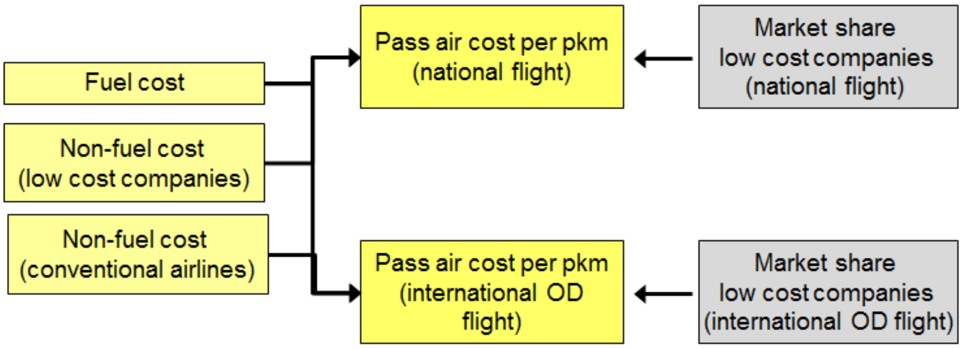
Air (continental and intercontinental)

The model is structured to work with air passenger tariff, evolving over time depending on the trend of air passenger costs.

The structure for the calculation of air passenger costs distinguishes explicitly fuel and non-fuel costs, which are further detailed to introduce the differences between conventional airlines and budget (low cost) companies. The structure is implemented in a simplified way: the non-fuel cost is calculated as weighted average between the conventional airlines cost and the budget companies cost, on the basis of the assumed market shares. The market share of the low cost companies has been distinguished between national and international flights (by OD pair) and evolves over time in order to reflect the growth observed during the last years.

Non-fuel costs include all the elements not related to fuel: labour cost, airport fees, maintenance, sales and distribution, as well as ETS price.

The resulting air passenger tariff has been checked on the basis of data available from internet web-sites, selecting a sample of journeys and estimating the value in terms of €/pkm as ratio between cost and distance travelled.



Source: TRT

Figure 9-3: Estimation of air passenger tariff

9.1.2 Freight mode

Transport cost variables related to freight transport demand are always expressed in terms of €/tkm and refer to each transport mode available in the demand module:

- Truck
- Rail
- Short sea shipping
- Inland waterways

Truck

The model estimates the average truck cost per tkm by distance band, under specific assumptions on the type of vehicles (weight) used in each context:

- light duty vehicle (<3.5 tons),
- heavy duty vehicle (3.5-12 t),
- heavy duty vehicle (above 12 t).

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

The cost component related to fuel cost takes into account also the different fuel efficiency depending on vehicle fleet composition (i.e. in terms of fuel type and euro emission standard).

The same applies for estimating road toll per vehicle-km: first of all, in many countries the toll is applied on the basis of the number of axis: therefore, the weighted average has been calculated applying the share drawn from the AlpCrossing database for the year 2004. The same shares have been applied for all countries. Where an annual vignette is applied, a distance-related toll has been estimated under the hypothesis of the yearly average mileage travelled on tolled network. Where distance related tolls per km were not directly available, they have been estimated using a sample of paths for which total toll and total distance travelled on the network have been extracted from dedicated websites. When tolls are different among sections of the tolled network (or among zones of the same Country), an average value has been estimated. Where tolls are differentiated by EURO emission standard, the model estimate an average weighted value on the basis of vehicle fleet composition.

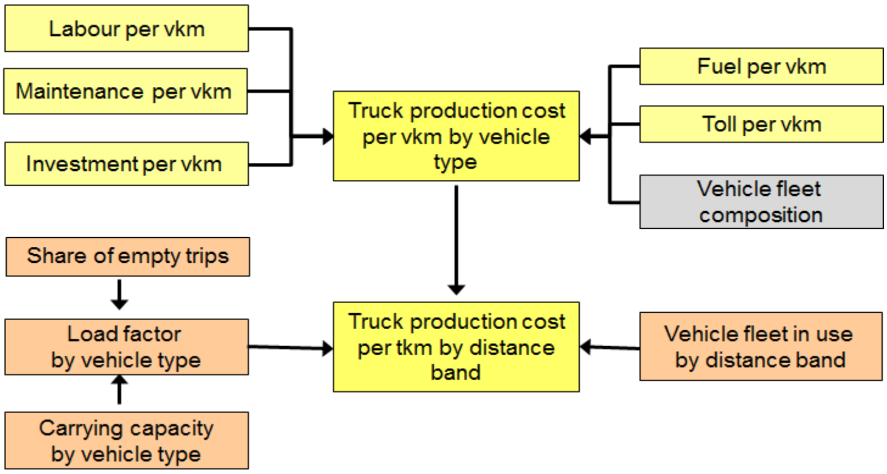
Labour, maintenance and investments cost are estimated on the basis of a document produced for Italian Ministry and the syndicate of truck operators[30], which contains comparative numerical materials about costs of truck transport. The data refers to nine countries only (Italy, Austria, France, Germany, Poland, Slovenia, Spain, Hungary, Ukraine): several assumptions have been applied to extend the analysis to all countries.

In order to estimate production cost per tkm, the load factor by vehicle type is applied, taking into account not only the carrying capacity but also the share of empty trips. The value of this parameter has been estimated from EUROSTAT data on road freight transport vehicle movements, related to loaded and empty vehicles.

Finally, in order to estimate the average cost by distance band, assumptions on the type of vehicle fleet used in each distance band are made: namely, it is expected that at local level mainly light duty vehicles are used, while heavy duty vehicles above 12t mainly travel for long distance movements.

The following figure represents the structure for the estimation of truck production cost.

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

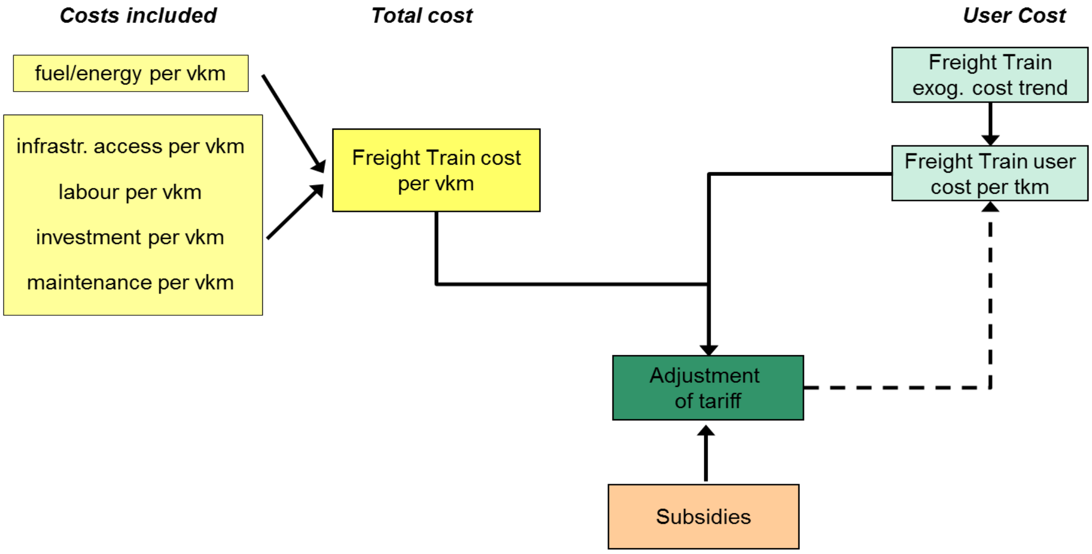


Source: TRT

Figure 9-4: Estimation of truck freight production cost

Rail

The structure of the train costs for freight is the same described above for passenger, as reported in the following figure.



Source: TRT

Figure 9-5: Estimation of freight train user cost per tkm

The data available to estimate cost per vkm are the same described for passenger train cost. In addition, a differentiation is introduced depending on commodity type based on data taken from the Transtools model.

The train user cost (in terms of €/tkm) has been estimated on the basis of the information available from the TRANSTOOLS model by commodity type.

Short sea shipping

The structure for the calculation of short sea costs distinguishes explicitly fuel and non-fuel costs. The evolution of the fuel costs over time depends on the growth rate of the diesel fuel price, taking into account the technical progress in terms of fuel efficiency of ships. Non-fuel costs evolve over time according to the combination of a base exogenous trend and the indirect impact of energy cost trend on non-fuel components. Non fuel costs include all the elements not related to fuel: labour cost, port fees, maintenance, etc.

For maritime cost the reference data for comparison has been derived from the survey on international transport costs (made by TRT for the Italian Bureau of Exchange[31]) considering movements at continental level. Data are available for unitised, bulk and general cargo transport in terms of import and export between Italy and European macro-regions. Cost includes rent as well as handling activities.

Inland waterways

The estimation of cost per tkm for inland waterways applies a simplified approach: a base value evolves over time based on exogenous trend. The base value is derived from existing literature and compared with TRANSTOOLS data.

9.2 Transport time

9.2.1 Transport time by mode and network

The base values of transport (travelling) time parameters have been estimated in terms of hour per km for all passenger and freight modes.

The value of the parameter depends mainly on the type of infrastructure (or distance band of the trip / shipment) and may assume significantly different values depending on the geographical location.

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31 Banca d'Italia, Indagine campionaria sui trasporti internazionali dell'Italia, 1999 – 2011.

For road and rail network the evolution of this parameter varies over time in the model depending on the traffic flow (and therefore the level of congestion) travelling on the infrastructure.

For **road transport**, the estimation of parameter has been set on the basis of professional judgment applied to speed limit and general traffic conditions: at urban level an average speed of 20 km/h for car, 14 km/h for bus and 18 km/h for truck has been used as base reference for all zones, taking into account indirectly also fixed times related to e.g. stop at crossroads and parking. For long distance (motorway or main road network) an average speed of 100 km/h for car, 75 km/h for bus and 65 km/h for truck (for truck this speed includes resting times) have been estimated whereas for non-urban network the average speeds considered were the following: 53 km/h for car, 42 km/h for bus and 47 km/h for truck. The base reference values have been subsequently modulated between the different countries, taking into account the specific context.

For **bus** the parameter refers to running time (including stops) as well as access and waiting time. The estimation has been carried out combining assumptions on time for stops and running time based on speed limits and timetables.

The same approach has been applied for the other modes of transport and corresponding type of infrastructure.

For **passenger train** and **air mode** the parameter refers to travelling time only, while access time to the station / airport and waiting time are explicitly estimated in a dedicated parameter (see paragraph below). The estimation has been carried out based on passenger train and flight timetable information on various websites, differentiating the services: local, regional and long distance for train, national and international for air.

For **freight train, inland waterways** and **maritime** modes the value refers to travelling time only, while access, handling, loading and unloading times are treated separately (see paragraph below). For maritime, the parameter is differentiate for national (short sea) and international (intra EU) services.

The base reference values of transport time parameter for road and non-road infrastructure are reported in the tables below.

Table 9-1: Representative values of transport time parameters by mode for non-road infrastructures

Time per km – Base reference values – Non Road Infrastructures		
Transport Mode	**Distance Range**	**Time per km [h/km]**
Pass Train	Very Short	0.025
	Short	0.017
	Long Distance	0.010
Freight Train	Long Distance	0.013
Ship	National	0.033
	International	0.033
Air	National	0.002
	International	0.002
Inland Water Ways	National	0.067
	International	0.067

Source: TRT

Table 9-2: Representative values of transport time parameters by mode and network for road infrastructures

Time per km – Base reference values – Road Infrastructures		
Type of Road	**Transport Mode**	**Time per km [h/km]**
Local Road	Car	0.050
	Bus	0.069
	Truck	0.056
Non Urban	Car	0.019
	Bus	0.024
	Truck	0.021
Long Distance	Car	0.010
	Bus	0.013
	Truck	0.015

Source: TRT

9.2.2 Access and loading / unloading times

For rail and air passenger transport modes the access and waiting time has been estimated, in order to take into account the time spent to reach the rail station / the airport (with any mode of transport) and the waiting time. The parameter is estimated in terms of hours or fraction of hours.

For **rail passenger mode** the access time has been estimated considering an average representative value of 0.6 hour (about 36 minutes). This value was then differentiated among zones according to the variance of a statistical indicator representative of the use (and therefore the accessibility to rail network) at Nuts I level: the rail trips per habitants ratio (rail trips / population).

For **air passenger mode** the average time of access to the airport has been estimated from the analysis of technical literature[32].

The estimation is mainly based on a sample of UK airports, distinguishing between low cost and conventional services; no differentiation by country has been done. The estimation of the average time to access / exit the airport has been made considering:

- Average access time from home to airport
- Average lag time and lead time from terminal to the mode used to reach the airport and vice versa
- Average time to archive all the land-side procedures from the terminal entrance to flight departure (and vice versa from flight arrival to terminal exit).

For **maritime mode** the estimation of access, handling, loading and unloading time has been carried out starting from available technical literature[33]. The durations of in-port activities data per vessel category has been differentiated by type of freight flow (bulk, general cargo and unitised) and then modulated between zones according to a parameter taking into account the geographical location of the port and its accessibility with reference to the related transport network.

For **freight train** the estimation of loading and unloading time has been carried out starting from data used in TRANS-TOOLS model.

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32 "Airport Rail Services: Forecasting Hourly Demand" - Kate Kenny - Sinclair Knight Merz (Europe) Limited - Association for European Transport and contributors 2007.

33 "Service Contract on Ship Emissions Assignment, Abatement and Market-based Instruments" – European Commission Directorate General Environment - August 2005 - Entec UK Limited.

For **inland waterways** the estimation of loading and unloading time was based on the maritime mode loading and unloading time by applying a reduction factor of 0.5.

In addition, the variables representing access time of air passenger and maritime are influenced by the investments in transport network, reducing the base value estimated above and therefore increasing accessibility.

9.2.3 Infrastructures capacity and congestion

As mentioned above the value of transport time on **road network** is affected by the level of demand, in order to capture the impact of congestion, although in an aggregated way. Yet, congestion is a local effect and a network model is required to simulate it properly, but the ASTRA-EC model can represent that if road demand is growing more than road supply, then average travel time tends to deteriorate and the attractiveness of the road modes is reduced.

This impact of congestion is considered by means of a multiplier, estimated making reference to speed-flow functions of the classical BPR[34] form (see paragraph 6.3).

The driver of the impact is therefore the ratio between demand and capacity; nevertheless, within the model, the value of road "capacity" does not represent the real size of the infrastructures: "capacity" by zone and type of network is expressed in terms of Mio*vkm/day.

In order to set a correct initial level of congestion on road infrastructures, the appropriate road "capacity" value has been estimated with reference to different types of infrastructures (and therefore distance band) at NUTS1 level.

The estimation of "capacity" for "non-urban" and "long distance" road infrastructures has been based on data provided by the TRUST network model, used in the TRACC Project. With the TRUST model, data on road transport time delays due to congestion where estimated on a network basis: therefore, applying an appropriate BPR function (with representative parameters for long distance and non-urban infrastructures), the flow / capacity ratio has been estimated, aggregating results at NUTS I level.

Finally, road "capacity" for "non-urban" and "long distance" road infrastructures has been estimated applying the flow / capacity ratio obtained above to the traffic volume estimated with ASTRA-EC model at the year 2005.

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34 BPR stays for the US Bureau of Public Roads, where this function was initially proposed.

For local road infrastructures, the same methodology has been applied, using as reference the travel time delay data for the main European urban areas contained in the "2012 TomTom European Congestion Index Report". The use of appropriate BPR function allowed to estimate the flow / capacity ratio and therefore the road "capacity" in this context.

For **rail modes**, capacity limits have a different meaning. While on roads the rise of demand brings about a progressive decrease of travel time, for other modes speed is maintained more or less constant until the infrastructure (i.e. the rail track) is saturated. Close to saturation, rather than increasing uniformly for all users, travel time becomes more erratic due to the high probability of interferences between different trains. Therefore, even though the structure in the model looks the same, the conceptual approach for the estimation is slightly different. Nevertheless, also in this case the estimation of rail infrastructures "capacity" has been made using as reference the synthesis data for rail level of service. Data contained in the report of COMPETE Project[35] have been used to estimate rail "capacity" at local and long stance level on the basis of traffic volume estimated with ASTRA-EC model at the year 2005.

In addition, the variable representing "capacity" of road and rail modes is influenced by the investments in transport network, increasing the base value estimated above and therefore reducing the possible impact of congestion.

35 COMPETE Project: Analysis of the contribution of transport policies to the competitiveness of the EU economy and comparison with the United States – 2006 Final Report.

9.3 Value of Time

Parameters representing value of time (VOT) are implemented in ASTRA-EC in order to calculate generalised cost, driving the process of estimation of transport demand.

Value of time parameters has been estimated on the basis of the values reported in the deliverable 5 of the HEATCO project[36], taking into account the segmentation reported in the following table. In order to apply the same VOT to different modes of transport, the values of HEATCO D5 have been weighted on the basis of mode shares by geographical context, trip purpose (or commodity type) and country, available from the ETISplus database at the year 2005.

Table 9-3: Segmentation of Values of Time parameters available in ASTRA-EC

	Value of Time (VOT)		
Passenger	Local (LC, VS, ST distance band)	Commuting	Country
		Business	Country
		private	Country
	Long distance (NAT and INT distance band)	Commuting	Country
		Business	Country
		private	Country
Freight	National (LOC, SRT, NAT distance band)	Bulk	Country
		General cargo	Country
		Unitised	Country
	International (INT distance band)	Bulk	Country
		General cargo	Country
		Unitised	Country

Source: TRT

For freight transport the differentiation by commodity type has been based on the same source (HEADCO D5), combined with data by goods category resulting from elabora-

36 HEATCO Developing Harmonised European Approaches for Transport Costing and Project Assessment: Deliverable 5 - 2006.

tion of results of the SCENES model[37]. Currently, national and international VOT variables are set with the same value, since there is no solid information for a differentiation.

Parameters are expressed in Euro 2005; specific values are reported in the Annex.

9.4 Elasticity parameters

As mentioned previously, in ASTRA-EC direct and cross elasticities to cost variation and time variation (implemented separately) have been used.

The estimated elasticity parameters implemented in the model are the following:

- Elasticity for passenger modes to cost variation over time,
- Elasticity for passenger modes to time variation over time,
- Elasticity for freight modes to cost variation over time,
- Elasticity for freight modes to time variation over time,
- Cross elasticity to re-distribute the shares from one mode to the others,
- Elasticity to car ownership variation over time (to take into account the increase of the motorization rate, considering different reactions depending on the country.).

The estimation was based mainly on the analysis of technical literature on the subject, i.e. the following document:

- "Transportation Elasticities - How Prices and Other Factors Affect Travel Behaviour" - 24 November 2011 - Todd Litman - Victoria Transport Policy Institute
- "A Survey of Recent Estimates of Price Elasticities of Demand for Transport" – January 1990 – Tae H. Oum, W.g.Waters II and Jong Say Yong – Infrastructure and Urban Development Department of The World Bank
- "Price sensitivity of European road freight transport – towards a better understanding of existing results" - June 2010 - Gerard de Jong, Arno Schroten, Huib Van Essen, Matthijs Otten and Pietro Bucci – Significance/Ce Delft

Data from the above sources were compared and standardised in order to obtain homogeneous parameters in line with the requirements of the model structure.

37 Fiorello D., Pasti G., (2003), Il valore del tempo di viaggio, guida teorica ed applicativa,. Ricerchetrasporti quaderno 5.

In particular, for passenger demand the elasticity parameters (with respect to both cost and time) have been estimated for each mode of transport (car, bus, rail, air) and differentiated by distance range (urban and non-urban / long distance) and by travel purpose (commuting, business and personal). The following tables show the initial value of passenger elasticity parameters.

It should be highlighted that the elasticity parameters driving the mode split process result from the application of specific functions (see Box 1 in paragraph 6.1.3) to the reference values reported below.

Table 9-4: Reference Passengers Elasticity Parameters with respect to cost variation and time variation

Passenger transport elasticities – WRT transport cost					
		car	**bus**	**rail**	**air**
urban	Commuting	-0.21	-0.39	-0.54	-
	Business	-0.15	-0.39	-0.51	-
	Personal	-0.24	-0.47	-0.61	-
Non-urban	Commuting	-0.25	-0.53	-0.59	-
	Business	-0.19	-0.45	-0.58	-0.39
	Personal	-0.30	-0.61	-0.70	-0.60
Passenger transport elasticities – WRT transport time					
		car	**bus**	**rail**	**air**
urban	Commuting	-0.18	-0.49	-0.42	-
	Business	-0.08	-0.21	-0.18	-
	Personal	-0.18	-0.48	-0.41	-
Non-urban	Commuting	-0.03	-0.72	-0.54	-
	Business	-0.03	-0.67	-0.50	-0.46
	Personal	-0.03	-0.76	-0.57	-0.48

Source: TRT

For freight demand the elasticity parameters (with respect to both cost and time) have been estimated for each mode of transport (truck, rail and ship) and differentiated by type of flow (general cargo, unitised, bulk) and distance range (local / national / international). The following tables show the initial value of freight elasticity parameters.

Table 9-5: Reference Freight Elasticity Parameters with respect to cost variation and time variation

Freight transport elasticities – WRT transport cost				
		Truck	**Rail**	**Maritime**
Commodity	Bulk	-0.42	-0.40	-0.17
	General cargo	-0.22	-0.42	-0.21
	Unitised	-0.28	-0.66	-0.18
Freight transport elasticities – WRT transport time				
		Truck	**Rail**	**Maritime**
Commodity	Bulk	-0.37	-0.53	-0.18
	General cargo	-0.17	-0.55	-0.19
	Unitised	-0.25	-0.88	-0.16

Source: TRT

Making reference to existing technical literature[38], the initial values were further differentiated in order to take into account additional segmentation:

Passenger Elasticity:

- Income groups (High, Medium and Low)
- Country groups (EU12, EU15 North Europe[39] and EU15 South Europe[40])

In order to differentiate elasticity by income group, assumptions based on professional judgment has been made; more in details:

- medium income groups are represented by average elasticity values;
- low income groups are supposed to be less sensitive to changes of cost and time for public transport modes (bus and train), while the elasticity to air cost is increased and elasticity to car cost is more or less on average;
- high income groups are supposed to be less sensitive to changes of cost for car and air mode and more sensitive to changes of time, while the elasticity for public transport cost (bus and train) is slightly increased.

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38 In particular to “Income’s Effect on Car and Vehicle Ownership, Worldwide: 1960-2015” - February 1997 - Joyce Dargay & Dermot Gately.

39 Austria, Belgium, Germany, Denmark, Finland, Ireland, Luxembourg, The Netherlands, Sweden, United Kingdom, Switzerland, Norway.

40 Spain, Greece, France, Italy, Portugal.

In order to differentiate elasticity by country group, assumptions based on professional judgement have been made; more in details:

- Northern EU15 countries are supposed to be slightly less sensitive to changes of cost and time for buses at urban level;
- In EU12 countries elasticity to cost is slightly reduced for some modes.

Freight Elasticity:

- Distance bands (Short, National and International)
- Country groups (EU12, EU15 North Europe and EU15 South Europe)

In order to differentiate elasticity by distance band, it has been assumed that road transport have cost and time elasticity values increasing with the distance, while rail and maritime have lower values for long distance shipment.

In order to differentiate elasticity by country group, assumptions based on professional judgement have been made.

During the calibration process the elasticity parameters have been slightly adjusted where necessary in order to reproduce the observed trend of transport performances.

As mentioned above (chapter 6.1.3) , cross-elasticities are not exogenous parameters, their value evolves over time together with the mode shares. Therefore, the cross elasticity parameters are distinguished by distance band, purpose and income for passenger and by distance band and commodity type for freight.

9.5 Trip rates

For the estimation of trip rates by country, purpose, age and income group the list of national surveys / statistics reported in the following table have been taken into account.

Table 9-6: Data availability from national travel surveys / statistics

Country	Survey	Purpose	Age	Income
AT	Statistics	Only tourism	No	No
DK	National Travel Survey	Yes	Yes	Yes
ES	National Travel Survey	Yes	Yes	No
FI	National Travel Survey	Yes	No	No
FR	National Travel Survey	Yes	Yes	Yes
UK	National Travel Survey	Yes	Yes	Yes
DE	National Travel Survey	Yes	Yes	Yes
IT	ISFORT survey	Yes	Yes	No
NL	National Travel Survey	Yes	Yes	Yes
SE	National Travel Survey	Yes	No	No
CH	National Travel Survey	Yes	Yes	Yes
NO	National Travel Survey	Yes	No	No

Source: TRT

Not all sources provide the same level of details and for several countries data is not available: therefore, the information has been processed in order to comply with statistics related to the amount of trips per country by purpose, derived from the ETISplus database. In terms of time series, some surveys (i.e. UK national travel survey, ISFORT survey, CH national travel survey, etc.) provide data for various years: this information has been used to adjust, where necessary, the value of trip rates over time.

As already mentioned in chapter 6.1.1, based on the information available in the various travel surveys, the following segmentation has been defined for the application of differentiated trip rates:

- 5 age population groups (children / young people below 17, adults 18 to 25, adults 26 to 59, adults 60 to 69, adults above 69),

- 5 income groups (low income, low to medium income, medium income, medium to high income, persons with high income),
- 3 trip purposes (commuting, business, private / tourism)

Of course, trip rates are also differentiated by country.

The following tables reports aggregated values of trip rates implemented in the model.

Table 9-7: Average value of trip rates by age and purpose (trips/day*1000pers)

		Age 0 to 17	**Age 18 to 25**	**Age 26 to 60**	**Age 60 to 69**	**Age over 70**
EU15	business	2	76	191	84	10
	personal	1,788	1,740	2,251	2,407	2,052
	commuting	1,020	1,277	956	464	49
EU12	business	2	37	99	43	7
	personal	1,386	1,354	1,728	1,851	1,603
	commuting	995	1,412	932	342	20

Source: TRT

Table 9-8: Average value of trip rates by age and income (trips/day*1000pers)

		Age 0 to 17	**Age 18 to 25**	**Age 26 to 60**	**Age 60 to 69**	**Age over 70**
EU15	low	2,444	2,691	2,955	2,571	1,837
	low to medium	2,627	2,892	3,176	2,763	1,974
	medium	2,838	3,124	3,431	2,984	2,133
	medium to high	3,034	3,340	3,669	3,191	2,281
	high	3,118	3,433	3,771	3,280	2,344
EU12	low	2,073	2,438	2,400	1,945	1,418
	low to medium	2,228	2,620	2,580	2,090	1,524
	medium	2,407	2,831	2,787	2,258	1,646
	medium to high	2,574	3,027	2,980	2,415	1,760
	high	2,645	3,111	3,062	2,482	1,809

Source: TRT

9.6 Occupancy factor and load factors

The base value of occupancy factor for **cars** is differentiated by country, purpose and context (urban or inter-urban). Data from UK travel survey, as well as from other National Travel Surveys, has been used, together with parameters implemented for the previous version of the ASTRA model. Some sources provide data differentiated by purpose; while the previous version of the ASTRA model already included a differentiation for urban or inter-urban trips.

Based on this information, a mathematical function depending on car ownership has been interpolated: the higher the car ownership the lower the average occupancy factor (not differentiated). Then, the information on purpose and context differentiation have been used to estimate occupancy factor for cars by zone, purpose and context (urban or inter-urban). The following table reports the average values implemented at the base year.

Table 9-9: Average car occupancy factor (person / vehicle)

		Urban	**Inter-urban**
EU15	business	1.1	1.2
	personal	1.7	2.2
	commuting	1.2	1.5
EU12	business	1.3	1.4
	personal	2.0	2.5
	commuting	1.4	1.7

Source: TRT

The base value of occupancy factors of bus for urban / inter-urban context have been estimated on the basis of data implemented for the MOMO model[41], (provided by macro-regions). It must be underlined that values represent the average daily occupancy factor, not the specific occupancy factor related to e.g. peak hours. Therefore, the estimated values are consistently lower than the capacity of the vehicle. In addition, in order to simulate the adaptation of supply in the short terms (see paragraph 6.1.4), minimum and maximum occupancy factors have been estimated. As already explained,

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41 IEA, Transport and $C0_2$: moving towards sustainability, 2009.

these values represent average parameters for setting the level of public transport service, as reported in the following table.

Base occupancy factor of train have been estimated after a review of the overall capacity of train vehicles in different countries: an average value has been assumed and a percentage has been taken as representative for the daily average occupancy factor (again, not the specific occupancy factor related to e.g. peak hours). Minimum and maximum thresholds are reported in the following table.

Finally, the same approach has been used for occupancy factors of aircrafts for national and continental trips. Average, minimum and maximum thresholds are reported in the following table.

A fixed occupancy factor of 200 passengers/aircraft has been considered for intercontinental trips.

Table 9-10: Initial value of average EU27, minimum and maximum occupancy factor for collective modes (person / vehicle)

		Average	**Minimum**	**Maximum**
Bus	Urban	16	10	30
	Inter-urban	42	30	60
	National - international	44	30	60
Train	Inter-urban	145	130	260
	National - international	280	200	600
Air	National	98	90	180
	International	118	90	180

Source: TRT

9.7 Accident rates

Base data of the road accident rates are estimated from the IRTAD database and reported in the following table.

Table 9-11: Average road accident rates (cases / (Bio*vkm)])

		Fatality	Serious injury	Light injury	Material damage
EU15	Car	33	419	504	432
	Slow	34	351	351	1
	Bus	0.01	0.05	0.22	0.94
	LDV	9	42	196	216
	HDV	5	41	175	193
EU12	Car	69	437	526	496
	Slow	105	367	367	1
	Bus	0.02	0.05	0.23	1.08
	LDV	8	44	205	248
	HDV	11	43	183	222
EU27	Car	49	427	514	460
	Slow	66	358	358	1
	Bus	0.02	0.05	0.23	1.00
	LDV	9	43	200	231
	HDV	7	42	179	206

Source: TRT elaboration on IRTAD data

For most of the other modes the base accident rates were not available by country, therefore a common base value has been differentiated making reference to accidents statistics and applied in each context.

Table 9-12: Non-road base accident rates (cases / (Mio*vkm)])

	Fatality	**Serious injury**	**Light injury**	**Material damage**
Passenger train	0.09	0.13	0.20	0.14
Freight train	0.01	0.08	0.08	0.17
Air	0.000015	0.000015	0.00004	0.000008
Inland waterways	-	-	-	-
Maritime	-	-	-	0.01

Source: TRT elaboration on UIC, CE Delft – Infras - Fraunhofer ISI[42]*, Aviation Safety - Boeing Commercial Airplanes*[43] *data*

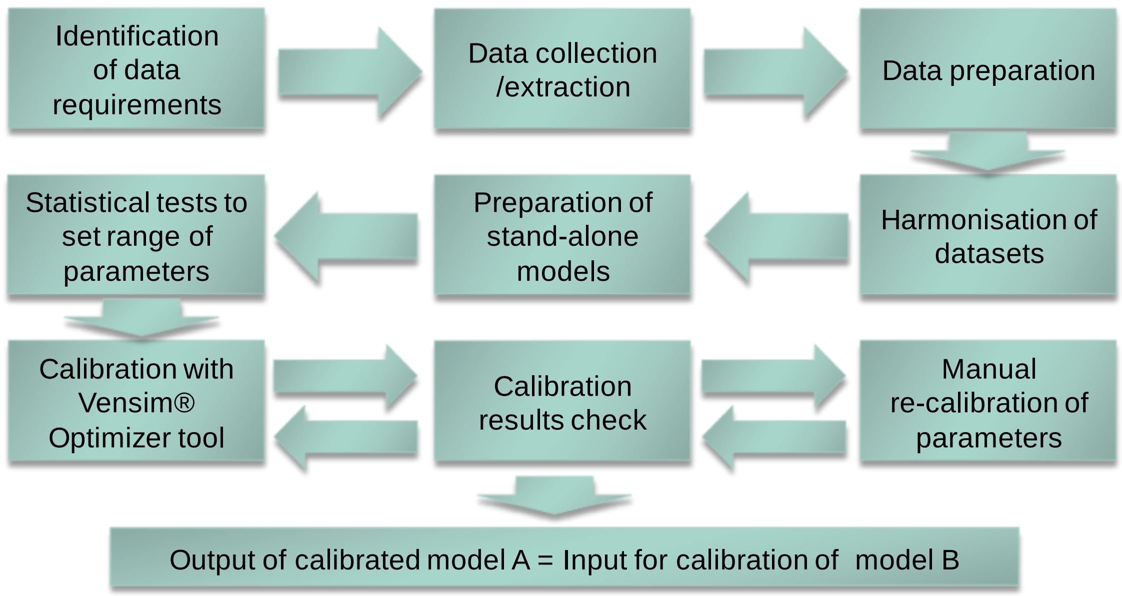
42 CE Delft, Infras, Fraunhofer ISI (2011), External Costs of Transport in Europe: Update Study for 2008, Delft.

43 Boeing Commercial Airplanes (2012), Statistical Summary of Commercial Jet Airplane Accidents - Worldwide Operations 1959 – 2011, Seattle (USA).

10 The calibration of ASTRA-EC

10.1 The calibration procedure

The accurate consideration of model development rules, for example described by Bossel (1994), and a comprehensive research of statistical correlation of indicators do not guarantee an exhaustive description of the behaviour of systems reflected by the established ASTRA-EC model. The modelling of complex social and economic systems like in ASTRA-EC can only provide a simplified picture of reality. In order to be able to provide a good basis for decision-making, models should consider uncertainties as well. The only way to integrate such factors, to make the model valid and to allow the comparability with other models is the implementation of calibration parameters. But before searching for an optimum value for these calibration parameters, the ASTRA-EC calibration approach has to follow a sequence of steps. Figure 10-1 presents an overview of the sequence of 10 steps which are required to calibrate the single modules of ASTRA-EC properly. Each module in ASTRA-EC needs to be calibrated stand-alone. ASTRA-EC is a large-scale and complex System Dynamics model. The dimension of the ASTRA-EC model including several million objects does not allow the calibration of the whole ASTRA-EC model within one calibration step.



Source: Fraunhofer-ISI

Figure 10-1: Overview of the ASTRA-EC calibration approach

After implementing the model structure for the single modules in ASTRA-EC, the data requirements for each module need to be identified. ASTRA-EC requires three different types of data as input. The first consists of time series data as well as projections for the time horizon to 2050 for exogenous inputs. As an example, purely exogenous inputs in ASTRA-EC are passenger trip rates which are requested to simulate the number of generated trips or labour productivities per sector which are essential to estimate the evolution of full-time-equivalent employment per sector. The second type of data concerns the variables that are represented via stock or so-called *level* variables. Mathematically, these level variables are composed of differential equations which require an initial value for the starting point. Hence, all these level variables need to be initialised with data from 1995. The last type of data required is time series data ideally from 1995 to 2010 for each major indicator simulated endogenously by ASTRA-EC. These time series data are a prerequisite for the calibration of the single ASTRA-EC modules. The major endogenous indicators need to match the development of the statistical data.

The second step in the calibration approach is then the data extraction and collection of the identified set of indicators from harmonised and validated data sources. Preferably, the majority of the time series and initializing data is taken from one major database. In the case of ASTRA-EC this database is Eurostat. Even if the majority of data is provided by Eurostat it does not fulfil all data requirements of ASTRA-EC. Therefore, other databases like the OECD database (e.g. for full-time-equivalent employment per sector) or the UN Comtrade database (e.g. for exports and imports per sector) are considered.

In the ideal case, the databases are able to provide the time series data in the specific level of detail requested by the ASTRA-EC model. This is only the case for some few examples. Therefore, the preparation of datasets to fit to the needs of ASTRA-EC is a very important further step belonging to the calibration approach. Three major cases appear in this context. Very often, the time series data from 1995 to 2010 are not completely available such that there are gaps in the time series. In this case, other databases are an option to fill these gaps. If no other database contains the requested type of data, then the gaps are filled by approximating the growth trend via:

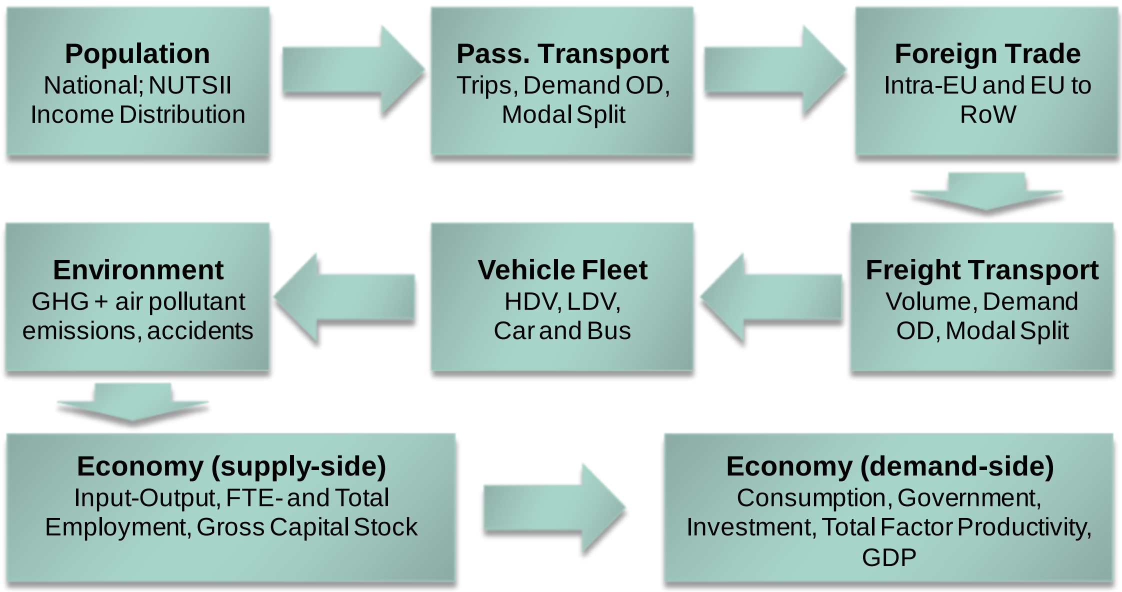
- related indicators (e.g. consumption of private households by final demand),
- available but more aggregate data,
- comparison with available data from countries that have a similar structure or
- linear interpolation.

Especially for economic indicators on a sectoral level there are often differences in the classification of economic sectors. ASTRA-EC uses a classification of economic sectors derived from NACE-CLIO (see Table 2-2) consisting of 25 sectors. The NACE classification is the dominant classification for most economic indicators in Eurostat. Nevertheless, there are different revisions used for different time periods (Revision 1, Revision 1.1 and Revision 2) and different number of economic sectors in each classification varying from 11 sectors at minimum (in NACE rev. 2) up to 89 sectors (in NACE rev. 2). Consumption of private household is differentiated by the COICOP classification of sectors while full-time-equivalent follows a specific classification used by the OECD database with 106 economic sectors. Hence, the transfer to the used specific level of aggregation plays a significant role in this step.

For some specific variables like labour productivity, the major European databases do not offer any datasets. Then, the data is calculated if possible by following the accounting framework or other economic theories. In the case of labour productivity a division of gross value added by the number of full-time-equivalent employment per sector is used to calculate this indicator.

Another important step in the calibration approach following the data preparation is the harmonization of data. In the Economic module this step is crucial as the demand side is supposed to affect the supply side as well as freight transport via the sectoral interweavement model. Therefore, the components of final use (consumption of private households, investments, government consumption and exports) need to match the demand-side data of the second quadrant of the input-output tables. In practice the sectoral demand-side data available at Eurostat or other databases differ from the numbers in the input-output tables.

After finishing the preparatory work on the input, initializing and calibration data, the single ASTRA-EC models which are calibrated in sequence need to be extracted into a separate Vensim® model file. All variables that are used in these so-called *stand-alone models* as an input coming from other models in ASTRA-EC need to be converted into variables of the type *Data*. Hence, the sequence of calibration of all ASTRA-EC stand-alone models starts preferably with the ASTRA-EC sub-model that receives the fewest inputs from other parts of ASTRA-EC. This sub-model is the Population model as the calculation of the demographic development in ASTRA-EC does not assume inputs from the Economic or any other ASTRA-EC module. Figure 10-2 shows the sequence of calibration of the single ASTRA-EC stand-alone models.



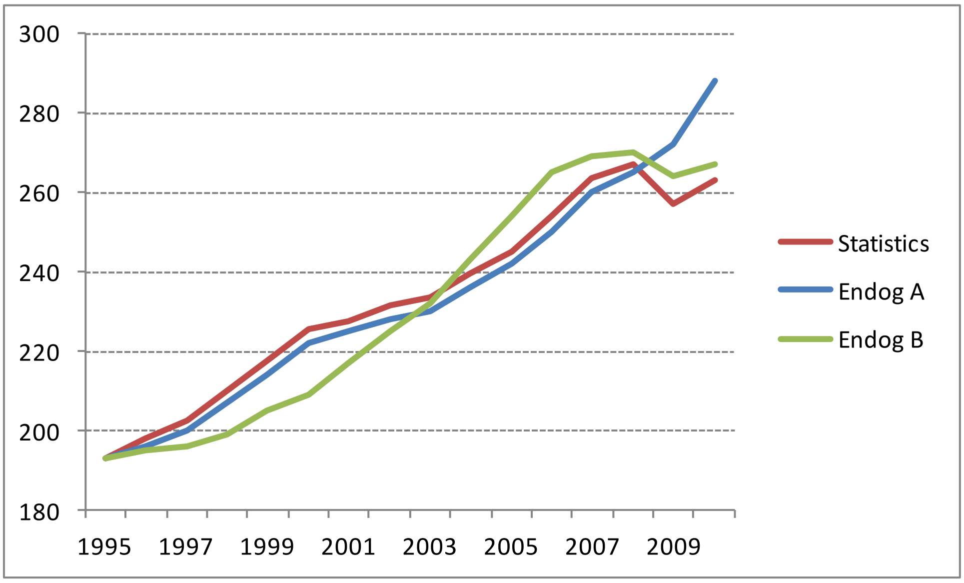
Source: Fraunhofer-ISI

Figure 10-2: Calibration sequence for the ASTRA-EC sub-models

After separating the stand-alone models from the full ASTRA-EC model, calibration parameters need to be determined and set. Therefore, statistical tests are carried out to check the degree of correlation between the expected driving factor and the main indicator in the single stand-alone models. These tests mainly consist of linear or multiple regression analysis. Carrying out these tests does not only validate the model structure in terms of a proven correlation between an input factor and an output factor. It also provides quantitative values for the calibration parameters and allows setting a range for these parameters from a minimum to a maximum value.

This is necessary as the automatic calibration with the Vensim® calibration toolset requires a definition of the calibration parameters with a range and an initial value. Furthermore, target values for the major indicators are set. The internal calibration tool applies the Powell Search algorithm. It is derived from the Taxi Cab method for finding a minimum deviation between an endogenous indicator and statistical data. The algorithm tries to optimise the set of calibration parameters such that the sum of annual deviations for the whole calibration period from 1995 to 2010 reaches a minimum.

The results of the automatic calibration need to be checked carefully as the search method only considers the minimum deviations between simulated indicator and the statistical time series data of this indicator. It does not take into account the shape of the curve over time. Figure 10-3 reflects this issue as an example. Two different results of a calibration can be seen in this figure in comparison with the statistical time series for an exemplary indicator from 1995 to 2010. According the search method, the minimum sum of annual deviations is achieved by the blue curve (Endog A). The problem with the resulting setting of calibration parameters is that the end of the curve shows just for two years a completely different shape than the statistical development. In this case, the green curve would be more valid even if the sum of deviations is higher than for the blue curve. Hence, a manual check of the calibration results is crucial to validate the projections until 2050.



Source: Fraunhofer-ISI

Figure 10-3: Manual check of calibration results

In the case that a calibration result is partially not acceptable in terms of relative and absolute deviations from the statistical value, the calibration needs to be improved by setting different ranges for calibration parameters. This can be done as well via the Vensim® calibration toolset or via a manual calibration in the case that an automatic calibration does not lead to an acceptable shape of the curve for the period from 1995 to 2010.

After achieving an acceptable result of the calibration, the next stand-alone model in the sequence of calibration is calibrated. For the following calibrations, the stand-alone models use the output indicators of previously calibrated stand-alone models as an input. When the sequence of calibration is finished, the single ASTRA-EC stand-alone models are merged to one ASTRA-EC Vensim® file again. A comprehensive check of the simulation results of the merged model needs to follow. In general, closing the various reinforcing or balancing feedback loops leads to changes in the quality of the calibration. In case that parts of the ASTRA-EC model could not remain the good quality of calibration such that the deviation between an endogenous indicator and the statistical values does not remain in an acceptable range, the specific stand-alone models need to be re-calibrated. This re-calibration is then using the most up-to-date input in terms of variables calculated in other parts of ASTRA-EC.

As opposed to static models (like for most network-based transport models or computed general equilibrium models), ASTRA-EC as a System Dynamics model is not able to be calibrated such that there a deviation of zero is reached for each year between 1995 and 2010. The major benefit of a System Dynamics model that is used for assessing long-term impacts of transport policies until 2050 is that the causal relations between indicators are validated over a long period of calibration (1995 to 2010).

11 Policy simulation

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 and 2 of the ASSIST project cannot be simulated with the ASTRA-EC model.

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 TPMs.

With this respect, in order to identify the list of TPMs to be implemented in the ASTRA-EC model, the analysis of the policies which can be implemented and simulated in the model (directly or indirectly) have been performed, having in mind their relevance with reference to the scope of the model. In addition, since within the ASSIST project the ASTRA-EC model is expected to integrate the assessment provided with the factsheets in WP2, the identification of TPMs took into account which would complement best to possible quantitative gaps.

As a result, the policy leverages available to the users of the ASTRA-EC model are listed in the following table, structured with the same categories of Work Package 1 and 2.

Table 11-1: Policy leverages implemented in the ASTRA-EC model

Code	Policy category	Policy	Modelling	
			Direct	Indirect
1	Pricing	car road charging schemes		X
		urban road user charging / access restrictions		X
		Railway infrastructure charges directive (2001/14/EC)		X
		EUROVIGNETTE' Directive / road charging heavy-duty vehicles		X
		Internalisation of external costs for specific modes of transport (road, rail, iww, ports, air-ports)	X	
2	Taxation	'Energy Taxation Directive' (2003/96/EC)	X	
		Vehicle taxation (circulation & registration)	X	
		CO_2 certificate	X	
		Feebates	X	
3	Infrastructure (Transport & Information / Communica-tion)	TEN-T projects accelerated implementation		X
		Improving frequency and reliability of service		X
4	Internal Markets	EU-wide common job quality and working con-ditions for truck drivers SEC(2008)2632		X
		Elimination of restrictions on cabotage		X
		Opening of the domestic rail passenger mar-ket; Community railway liberalisation SEC(2004)236, COM(2004)139		X
		Stimulate the integration of inland waterways into the transport system (RIS integrated with eFreight and eCustoms)		X
		Simplification of formalities for ships travelling between EU ports (“Blue Belt”)		X
		Implementation of the Single European Sky Initiative - SESAR		X
5	Efficiency standards & Flanking Measures	CO_2 emission limits for HDV, LDV, cars etc.	X	
		Standards for controlling air pollution (CO, NOx, particulate matter)	X	

Code	Policy category	Policy	Modelling	
			Direct	Indirect
6	Transport Planning	Promotion of energy efficiency commercial vehicles (delivery vans, taxis, buses…)		X
		City logistic / Urban freight distribution / Urban consolidation centre etc.		X
7	Research and Innovation	Electro-mobility Road		X
		H_2 Fuel Cell vehicles		X
		Compulsory safety standards in road vehicles (Driver assistance systems, seat belt reminder, eCall, vehicle-infrastructure interface etc.)		X
		Increased replacement rate of inefficient and polluting vehicles		X

Source: TRT / Fraunhofer-ISI

Table 11-1 shows that the ASTRA-EC model is able to simulate a reasonable part of the transport policy measures listed and analysed 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 total, 25 TPMs are implemented in the ASTRA-EC model, covering the 7 main categories of transport policy analysis.

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.

11.1 Policy implementation 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 previous paragraph.

In general terms, the simulation of TPMs in the transport module is often implemented in terms of variation of transport costs and/or transport times. When costs and times are changed several impacts occur throughout the model (see figure below).

A variation of transport costs for passenger modes influences modal split via 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 if transport cost increases).

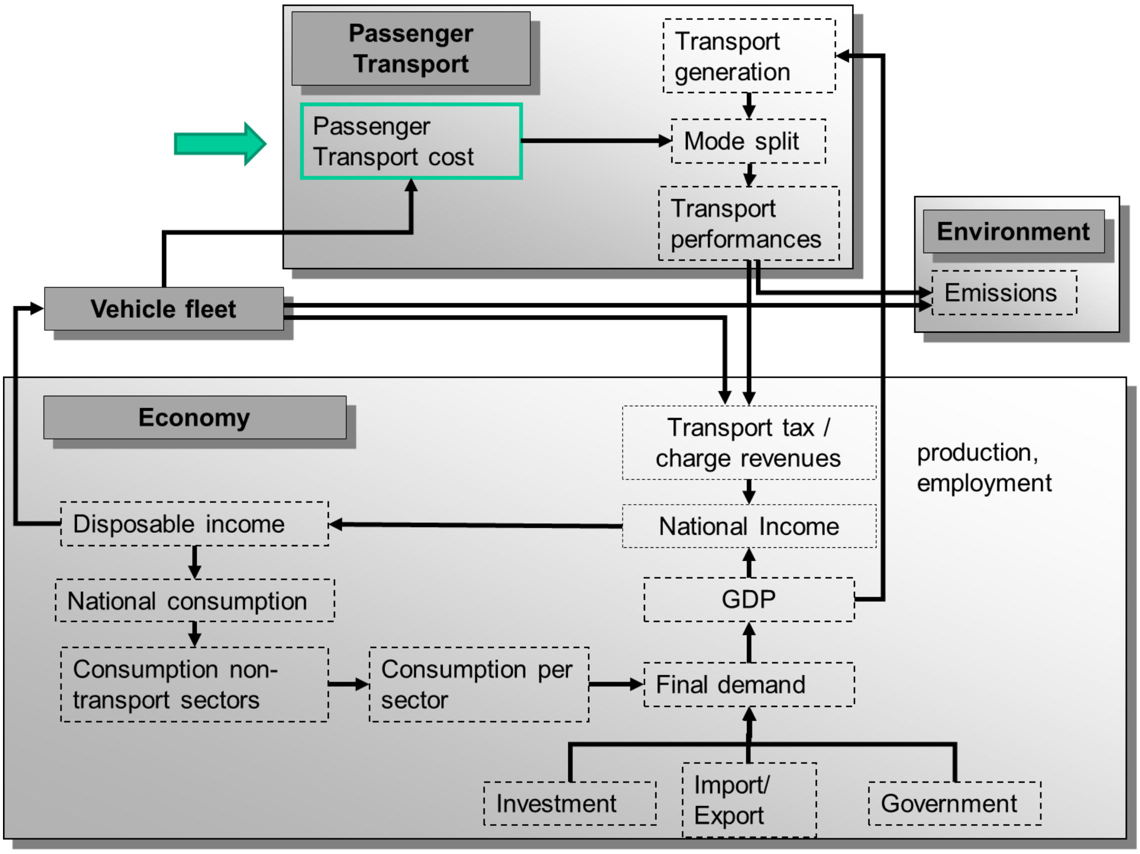
Another consequence of different transport costs is that transport expenditure of households changes. A larger or smaller share of income is required for mobility, reducing or increasing the remaining disposable income for consuming other goods and services. This affects the consumption of private households, the aggregated final demand and, finally, GDP (at national level).

At the same time, government revenues or road charge revenues will also change. For instance, in case of additional road charging revenues grow and this contributes positively to public budget and therefore on investments.

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 might 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.

Changes in terms of transport times of passenger modes generate a similar feedback chain, but the size of the impacts on the transport side is generally smaller due to the size of time elasticity parameters with respect to cost elasticity parameters. Furthermore, even if transport expenditure can be modified as result of a different mode split, the economic effects are only very indirect.

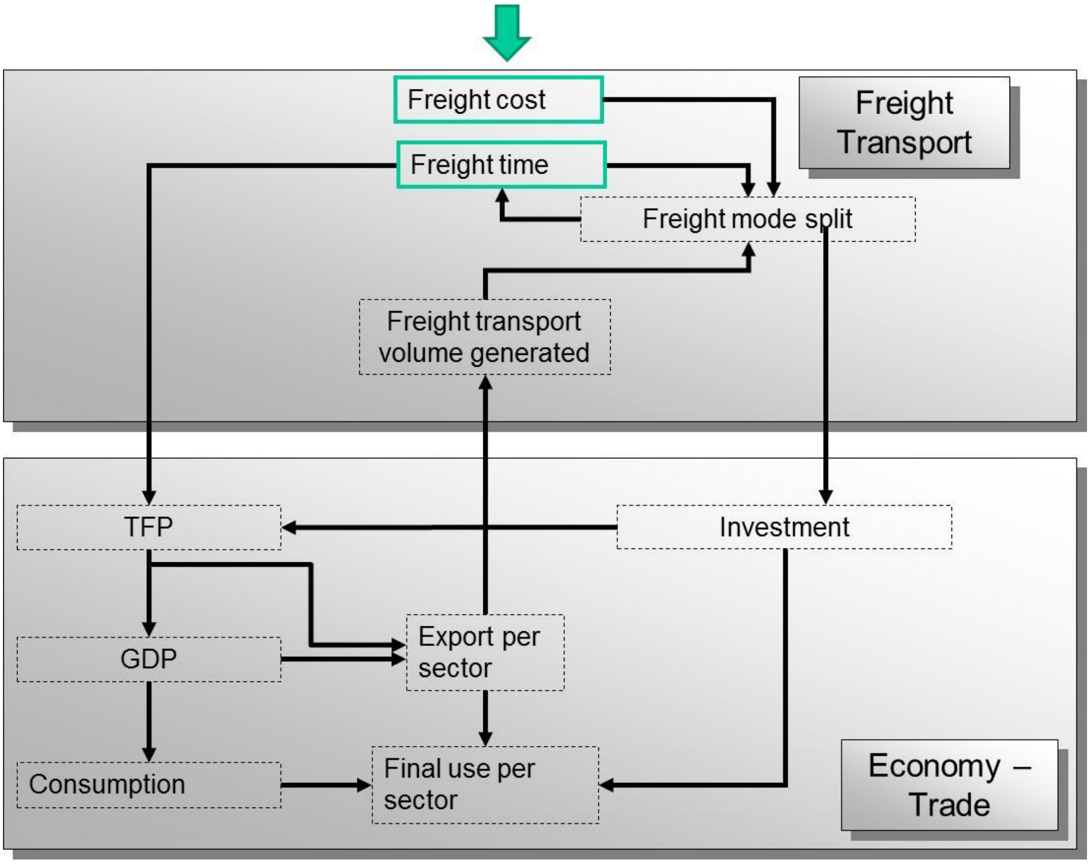


Source: Fraunhofer-ISI - TRT

Figure 11-1: Main feedback loops generated from passenger transport cost variations in ASTRA-EC

For the freight transport system, the first impact expected from variations of cost and/or time is again a different modal split resulting from the application of the related elasticities. The impact is larger for those geographical dimensions where there is more competition between modes. At the same time, on the economic side, the variations of transport costs and times would impact on Total Factor Productivity (TFP) on the ground that freight transport constitutes an element of today's production processes. The impact on TFP is transmitted to production, GDP and, indirectly, also export and consumption.

The feed-back on the transport side is that freight demand generation and distribution depends on production and export. Of course, the different transport activity by mode affects also energy consumption, emissions and accidents.



Source: Fraunhofer-ISI - TRT

Figure 11-2: Main feedback loops generated from freight transport cost/time variations in ASTRA-EC

The strength of the impact chains described depends on the size of the cost and time changes as well as on the specific costs modified. The paragraph below explain how the different measures are implemented in the model and highlight when the specific measures have other relevant impacts on model results in addition to those mentioned above.

11.1.1 Pricing policies

The following table summarises the pricing policies which are available in the model.

Table 11-2: Pricing policies

Policy	Modules	Main variables involved
Car road charging schemes	Transport passenger	Toll for car vehicles Share of tolled network used by cars
Urban road user charging / access restrictions	Transport passenger	Charge for car vehicles to enter urban areas
Railway infrastructure charges directive (2001/14/EC)	Transport passenger, Transport freight	Cost of rail transport for passenger Cost of rail transport for freight
EUROVIGNETTE' Directive / road charging heavy-duty vehicles	Transport freight	Toll for LDV and HDV vehicles Share of tolled network used by trucks
Internalisation of external costs for specific modes of transport (road, rail, iww, ports, airports)	Transport passenger, Transport freight	Cost by mode for passenger Cost by mode for freight

Source: TRT / Fraunhofer-ISI

Pricing policies affect directly transport costs: therefore, the TPMs mentioned above are implemented directly or indirectly in specific variables of the transport modules (for passenger or freight).

In case of **road charging (car or truck)**, tolls are related to just some part (e.g. motorways or other roads) of the 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 tolled network. The reference share is estimated on the basis of the length of tolled network, but the variable is also part of the policy input in case it is assumed an extension of the tolled network. Tolls are implemented in terms of €/vkm per mode (i.e. car, light duty vehicle, high duty vehicle, bus) and can change over time.

For simulating **urban car road charging schemes**, an additional term is added to the cost for car for trips at local level (intra NUTS II). The charge applies only to trips within a urban area: therefore, the share of trips in urban context by NUTS II zone and distance band is estimated on the basis of the classification by 'Urban-rural typology' of EUROSTAT.

In case of **railway infrastructure charges** an additional term is added to the transport cost for passenger and/or freight trains, in terms of Euro per train-km. Nevertheless, for passengers it is assumed that political and social elements contribute to drive the trend of the tariffs and therefore the charge is not completely transferred to user costs. On the contrary, for freight transport it is assumed that the cost of the additional charge has to be fully sustained by the final users.

To simulate the **internalisation of external costs** an additional term is added to the cost of each specific mode (car, bus, train, airplane for passenger or truck, train, ship and IWW for freight). The charge is applied on a distance basis, in terms of Euro/vkm, and can be differentiated by urban or non-urban context where meaningful (e.g. for road transport). Through the application of occupancy factors and load factors, the additional cost is transformed into a cost per pass-km or tonne-km directly borne by the final users.

11.1.2 Taxation policies

The following table summarises the taxation policies implemented in the model.

Table 11-3: Taxation policies

Policy	Modules	Main variables involved
'Energy Taxation Directive' (2003/96/EC)	Economic	Fuel taxes by fuel type
Vehicle taxation (circulation & registration)	Vehicle fleet	Circulation and registration taxes
CO_2 certificate	Economic	Fuel price for fossil fuel types
Feebates	Vehicle fleet	Car price

Source: TRT / Fraunhofer-ISI

Taxation policies affect directly a set of variables represented in the model: therefore, the TPMs mentioned above are implemented directly in the related modules and their impact is transferred to the rest of the model.

In particular, **energy taxation** and **CO_2 certificate** induce an impact more on transport cost for all motorised transport modes. Depending on the weight of fuel price with respect to total cost or tariff, the impact by mode might be more or less significant (i.e. car and truck will be more affected than bus or train).

On the other side, **vehicle taxation** and **feebates** affect directly the car vehicle fleet development and car ownership by changing the cost of purchasing a new vehicle and by modifying the relative attractiveness of different vehicle types (e.g. conventional cars vs. innovative cars). The behavioural parameters calibrated in the vehicle fleet module react to the different costs and modify the market shares of new cars as well as the total number of new cars sold.

As a secondary effect, the impact on the fleet is transferred to the average car cost (based on car fleet composition) which drives the mode split in the transport module. Then, the effects on the transport side are of the same type described before.

11.1.3 Infrastructure (Transport & Information / Communication)

The following table summarises the infrastructure policies implemented in the model.

Table 11-4: Infrastructure policies

Policy	Modules	Main variables involved
TEN-T projects accelerated implementation	Transport infrastructure, economic investments	Travel time by mode at national / international level, investments in transport networks
Improving frequency and reliability of PT service	Transport infrastructure, economic investments	Travel time of PT at local level (bus and rail), investments in transport services and PT vehicles

Source: TRT / Fraunhofer-ISI

Infrastructure policies are implemented indirectly in the model: therefore, exogenous assumptions and procedures have been applied to set up the simulation of these measures.

The modelling of the **accelerated implementation of TEN-T projects** in the transport module is based on the approach described in chapter 6.3, i.e. the assumption of transport time reductions related to the amount of investments in each NUTS I zone. The assumptions for this policy measure are that the core network will be completed by 2025 and the comprehensive by 2040.

The reduction of travel time impacts on the mode split according to the impact chain described above.

In economic terms, the amount of investments for TEN-T projects by country with the accelerated implementation is a direct input for the investment module. Since the policy measure consists of the acceleration of the completion of the TEN-T projects rather than in additional projects in comparison to the reference scenario, the total size of the investment does not change, just its timing is modified. Being ASTRA-EC a dynamic model, a different timing can give rise to a different economic path.

The **improvement of frequency and reliability of public transport services** (bus or train) is implemented in the model indirectly, in terms of reduction of travel time at local (intra-NUTS II) level for bus and/or train. The estimation of the reduction should take into account the effects of the local applications aiming at improving frequency and reliability of the service, e.g. via bus priority lane, ITS infrastructure for information services, etc. A dedicated parameter by country takes into account the current level of bus and train service, differentiating where there is more or less room for improvements. Finally, a ramp up period for the implementation of the policy is considered.

As above for the acceleration of the TEN-T projects changes of travel time influence modal split as an effect of the implemented elasticity parameters. However, for this policy the impact occurs in different spatial contexts, i.e. at local level rather than on long distance OD pairs.

In parallel, an estimation of the investments required to set up the infrastructures and services has been made, in order to simulate also the impact of the policy in economic terms. In this case the implementation of the policy envisages the expenditure of additional public resources. Therefore, the investments related to the improvement of public transport services affect the economic model in a twofold way. On the one side they increase the aggregate demand, which has a positive impulse on the economic growth. On the other side they increase the public expenditure and therefore the public deficit, which in ASTRA is negative for the growth. The net effect will depend on the relative strength of the two effects.

11.1.4 Internal Markets

The following table summarises the internal market policies implemented in the model.

Table 11-5: Internal market policies

Policy	Modules	Main variables involved
EU-wide common job quality and working conditions for truck drivers SEC(2008)2632	Transport freight, Transport infrastructure	Transport cost by truck, Truck travel time at national / international level
Elimination of restrictions on cabotage	Transport freight	Transport cost by truck, truck load factor
Opening of the domestic rail passenger market; Community railway liberalisation SEC(2004)236, COM(2004)139	Transport passenger, Transport infrastructure	Train passenger tariff, travel time by train at national / international level
Stimulate the integration of inland waterways into the transport system (RIS integrated with eFreight and eCustoms)	Transport infrastructure	Travel time by IWW at international level
Simplification of formalities for ships travelling between EU ports (“Blue Belt”)	Transport freight, Transport infrastructure	Transport cost by ship, ship in-port time
Implementation of the Single European Sky Initiative - SESAR	Transport passenger, Transport infrastructure, environment	Air passenger tariff, time at the airport, airplane fuel consumption

Source: TRT / Fraunhofer-ISI

Internal market policies are implemented indirectly in the model, since the domain where the TPMs apply cannot be simulated within the tool.

The policies are therefore simulated under assumptions and exogenous evaluations which allow the implementation in terms of variation of variables existing in the model, namely transport times and transport costs. The estimations are mainly based on the content of the factsheets prepared in WP2 and, where necessary, professional judgment.

Truck driver regulation is assumed to affect travel cost and travel time for the truck mode. More in details, it is assumed that labour cost is slightly increased, therefore impacting on a portion of the production cost. Stricter rules for the resting time of drivers might also cause an increase of travel time for long distance shipment. 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 addition, a ramp up period for the implementation of the policy is considered.

The **elimination of restriction on cabotage** is assumed to affect travel cost and the share of empty trips for the truck mode. In fact, it is assumed that labour cost is slightly decreased, therefore impacting on a portion of the production cost. The change is differentiated from country to country with a dedicated parameter, since the size of the impact depends on the current status and diffusion of cabotage. By eliminating the cabotage restrictions it is also expected that hauliers have opportunities for a more efficient use of vehicles, resulting in a reduction of the share of empty shipments. In turn this means that the average load factor of truck is larger and therefore costs per tonne-km is further reduced because of this indirect effect. In addition, a ramp up period for the implementation of the policy is considered.

The **opening of the domestic rail passenger market** is simulated under the assumption that travel time and cost of passenger transport may be reduced thanks to the competition between the operators and the availability of an integrated Europe-wide railway network. In this case, passenger ticket price is slightly decreased as well as train travel time at national / international level. Local services are not affected by the policy. Again, a ramp up period for the implementation of the policy is considered.

The development of the River Information Services (RIS) is expected to improve the efficiency of **inland waterway** and reduce IWW transport time thanks to the reduction of administration burdens and the provision of information exchange for freight transport. Within the model, this can be simulated as a reduction of travel time by IWW at international level, taking into account a ramp up period for the implementation of the policy.

The **Blue Belt** policy aim at reducing administrative procedures for sea transport (cargo and passengers) between European ports, therefore leading to shorter transport time. In the model, the policy is implemented as a reduction of time spent in port: of course, short distance maritime transport will benefit most from the reduction, because that portion of time have a higher weight on the overall journey time. In addition, a slight reduction on ship non fuel cost is implemented. Both variation in terms of time and cost are implemented taking into account a ramp up period.

The **Single European Sky initiative** (SESAR) is assumed to increase flight efficiency (reduction of delays, increase of punctuality), to decrease passenger cost and to increase fuel efficiency thanks to the improvement of flight path efficiencies. More in details, in terms of transport time a reduction of time spent at the airport is implemented, while air passenger tariff and fuel efficiency are directly affected. The impact of the policy on time is differentiated by zone with a dedicated parameter, in order to take into account the current level of efficiency of each airports in terms of punctuality. In addition, a ramp up period for the implementation of the policy is considered.

11.1.5 Efficiency standards & Flanking Measures

The following table summarises the efficiency standards & flanking measures implemented in the model.

Table 11-6: Efficiency standards & flanking measures

Policy	**Modules**	**Main variables involved**
CO_2 emission limits for HDV, LDV, cars etc.	Environment	Fuel consumption factor per vehicle
Standards for controlling air pollution (CO, NOx, particulate matter)	Environment	Emission factor per vehicle

Source: TRT / Fraunhofer-ISI

Efficiency standards & flanking measures are implemented directly in the model: in fact, fuel consumption or emission factors are directly affected by the required standards (which already take place in the reference scenario according to current Regulations[44]). The policies are simulated assuming the application of further limits in the future. As a result, changes of fuel consumption have direct impacts on the economic model as well as on the composition of the vehicle fleet. More efficient vehicles lead to increasing car ownership and to a stronger diffusion of these efficient vehicles. It changes private household consumption for vehicles and for fuels.

44 Regulation on CO_2 for cars (No 443/2009) and vans (No 510/2011), regulation on Euro V and VI standards for cars and vans (No 715/2007) and Euro VI for heavy duty vehicles (No 595/2009).

11.1.6 Transport Planning

The following table summarises the transport planning policies implemented in the model.

Table 11-7: Transport planning policies

Policy	Modules	Main variables involved
Promotion of energy efficiency commercial vehicles (delivery vans, taxis, buses…)	Environment, Vehicle fleet	LDV and bus fuel consumption factor at urban level Vehicle fleet composition Private household consumption and investments
City logistic / Urban freight distribution / Urban consolidation centre etc.	Transport freight	Truck load factor

Source: TRT / Fraunhofer-ISI

Transport planning policies are implemented indirectly in the model: therefore, exogenous assumptions and procedures have been applied to set up the simulation of these measures.

The **promotion of purchasing clean and energy-efficient commercial vehicles** (LDV and buses in the model) at urban level is simulated assuming an improvement of fuel consumption factors in this transport context, combined with an increase of the share of electric Light duty vehicles. A ramp up period is considered in the model for the implementation of the policy. On vehicle fleet side, an increased amount of energy efficient vehicles is assumed to be purchased, supported by incentives and investments. The model represents changing preferences of investors via higher benefits of clean and energy-efficient vehicles.

On the LDV side, the policy is expected to impact on fuel cost and therefore transport cost. Since LDVs are used mostly at the local level where there are not competing modes, mode split is basically not affected. Benefits take place in terms of LDV fuel consumption as well as CO_2 and pollutants emissions.

On the bus side, it is assumed that the reduction of fuel cost is small and is not transmitted on a reduction of tickets price. Therefore no impacts are expected on passenger mode split or transport activity. Nevertheless, also in this case a benefit in terms of bus fuel consumption as well as CO_2 and pollutants emissions appears.

The main target of **urban freight distribution** is to reduce the traffic of duty vehicles through cities and metropolitan areas by means of the implementation of technical and planning measures. For the ASTRA-EC model this policy is assumed to lead to a slight reduction of vehicle-kilometres of heavy vehicles combined with a reduction of light duty vehicle kilometres. This impact on heavy duty vehicles is related to the improvement of volume / weight utilisation rates of trucks, which should also avoid to enter the urban areas, where instead light vehicles should be used more intensively for local distribution. Therefore, in principle light duty vehicle kilometres should increase; nevertheless, within the model this aspect cannot be simulated due to the scale of the model.

The implementation in the model is therefore in terms of variation of load factors for LDVs and HDVs, taking into account a ramp up period. In the model structure, a variation of load factor affects not only vehicle kilometres, but also the production cost of truck mode. The variations of cost might produce impacts on modal split resulting from the application of the related elasticities. Nevertheless, since at local level LDV do not have competing modes, the overall impacts should be moderate. Anyway, on the economic side, the variations of transport costs would impact as described in paragraph 11.1.

11.1.7 Research and innovation

The following table summarises the research and innovation policies implemented in the model.

Table 11-8: Research and innovation policies

Policy	Modules	Main variables involved
Electro-mobility Road	Vehicle fleet, economic investments	Technological composition of car fleet; private household consumption for vehicles and fuels; investment in charging infrastructure
H_2 Fuel Cell vehicles	Vehicle fleet, economic investments	Technological composition of car fleet; private household consumption for vehicles and fuels; investment in charging infrastructure
Compulsory safety standards in road vehicles (Driver assistance systems, seat belt reminder, eCall, vehicle-infrastructure interface etc.)	Environment, transport passenger and freight	Accident rates for road modes; insurance cost for car and truck
Increased replacement rate of inefficient and polluting vehicles	Vehicle fleet	Technological composition of car fleet; Fuel consumption costs; Consumption for and investments in vehicles

Source: TRT / Fraunhofer-ISI

Research and innovation policies are implemented indirectly in the model: therefore, exogenous assumptions and procedures have been applied to set up the simulation of these measures.

Electro-mobility Road consists of measures to accelerate the diffusion of vehicles with electric propulsion into the European vehicle fleet. These measures should lead to an increased efficiency, safety and reliability of electric vehicles. ASTRA-EC can simulate the impacts of these measures indirectly by increasing the consumer preferences of battery electric, hybrid electric and plug-in hybrid vehicles. Besides the influences on consumer behaviour by improvements of the technology, investments in R&D can be implemented directly into the economic module. Two-factor learning curves including R&D investments directly relate the price of electric vehicles with learning-by-researching as well as learning-by-doing. Lower prices of cars accelerate the diffusion as well.

The TPM **H_2 Fuel Cell vehicles** can be simulated with ASTRA-EC in a similar way than the measures for Electro-mobility. As H_2 fuel cell vehicles are one possible option to choose in the vehicle fleet model, the consumer behaviour can be directly adapted as well as the other drivers of the purchasing decision.

Compulsory safety standards in road vehicles include a variety of technical safety systems: driver assistance systems, seat belt reminder, eCall, vehicle-infrastructure interface, etc. Within the model, this TPM is assumed to reduce the value of the accident rates for road modes (car and trucks) thanks to the implementation of the above mentioned systems. The definitive effect of the policy is reached after a ramp up period. Therefore, despite the positive impact on the amount of accidents, no feedbacks are foreseen in the transport modules. Nevertheless, the reduction of accidents and related cost would slightly reduce the insurance cost for road modes (especially cars), which are fed back to the economic module for the estimation of transport consumption.

The **increased replacement rate of inefficient and polluting vehicles** can be achieved with several incentives. Lower costs of operation are endogenous drivers. The German government offered a financial incentive during the Economic Crisis in 2009 for purchasers of cars that scrap their at least 9 year old car. In the ASTRA-EC modelling toolset, such a measure can be simulated by increasing the probabilities of scrappage for different vehicle age classes.

12 Linkage with other European models

12.1 Linkage with TRANS-TOOLS model

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 modelling runs because of incompatibility problems in the freight model and of insufficient documentation. In the ASSIST project a step beyond this experience has been made, allowing actual exchange of data between the two models.

In order to implement a working connection between the two models, it has been checked that the major basic assumptions and definitions were comparable.

In order to understand 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.

Linkage from TRANS-TOOLS to ASTRA-EC

The flow of information from TRANS-TOOLS to ASTRA-EC is expected to refer basically to three main elements:

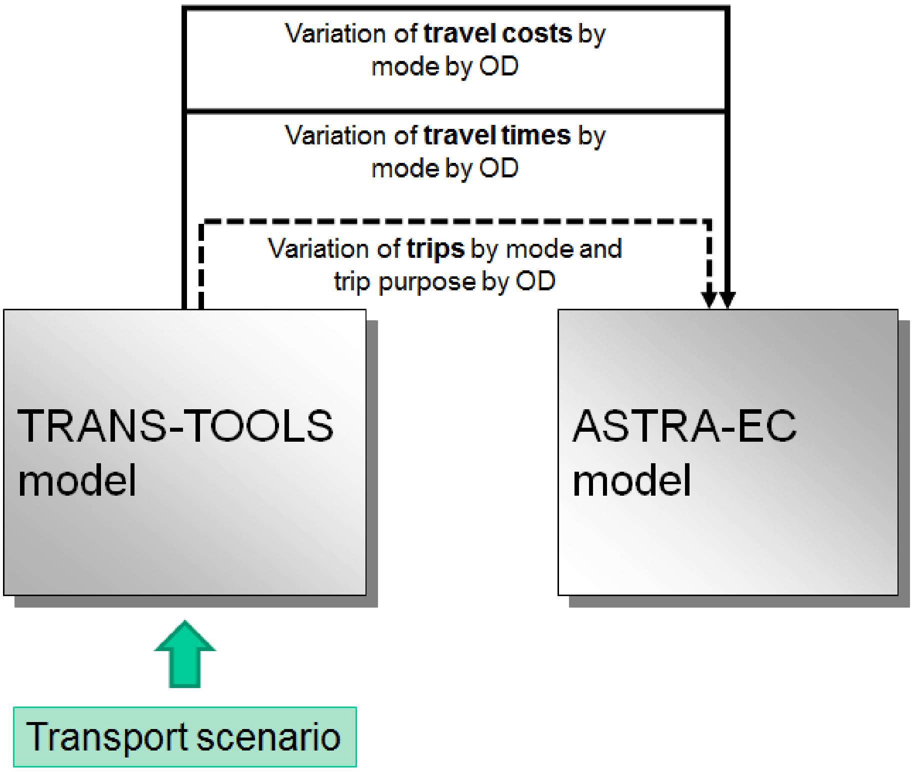
- trips by mode and trip purpose,
- travel times by mode and
- travel costs by mode.

More in details, the linkage could be implemented in twofold way:

1. Variation of transport cost and transport time are implemented in ASTRA-EC on the basis of TRANS-TOOLS output; nevertheless, the evolution of transport demand is endogenously estimated in ASTRA-EC.

2. Variation of transport cost, transport time and trips by mode are implemented in ASTRA-EC on the basis of TRANS-TOOLS output; in this case, some feedbacks on transport demand are not activated.

The following figure summarises the linkages in the cases mentioned above.



Source: TRT- Fraunhofer-ISI

Figure 12-1: Overview on possible linkages from TRANS-TOOLS to ASTRA-EC

Data are exchanged between models in terms of relative variation over time, in order to keep the internal consistency of the ASTRA-EC model untouched in absolute terms. Therefore, since the TRANS-TOOLS model run simulations for fixed time thresholds, exogenous procedures are required for transformation of data from TRANS-TOOLS format to ASTRA-EC format. Exogenous Access database are used to:

- convert the data format (e.g. in terms of segmentation): in fact, since TRANSTOOLS cannot provide data exactly at the same level of segmentation used in ASTRA-EC, conversion procedures are applied;
- to estimate a trend starting from values at fixed time thresholds: interpolation procedures are required to estimate the trend to be implemented in ASTRA-EC. The trend resulting from TRANS-TOOLS simulations is applied for future development of the related variables (never before the year 2010).

Once the data are processed with exogenous database and trends ready to be imported in ASTRA-EC, the linkage between the models is activated through a specific “switch” variable, as reported in the following equation for truck production cost (euro/vkm).

$$\begin{aligned}
&C_{cGD}^{\text{truck}}(t) = \\
&\textit{if}\ \text{Time} \le 2010 \\
&\textit{then}\ C_{cGD}^{\text{truck}\,ASTRA-EC}(t) \\
&\textit{else}\ \text{if}\ s_{\text{TT}} > 0 \\
&\quad \textit{then}\ C_{cGD}^{\text{truck}\,ASTRA-EC}(2010) \cdot \Delta C_{cGD}^{\text{truck}\,TT}(t) \\
&\quad \text{else}\ C_{cGD}^{\text{truck}\,ASTRA-EC}(t)
\end{aligned}$$

Eq. 87

With: $C^{truck}{}_{cGD}\ (t)$ = average truck cost per tkm in country c for cargo type G within distance band D at time T [euro/tkm]

$C^{truck}{}_{cGD}{}^{\text{ASTRA-EC}}\ (t)$ = endogenous ASTRA-EC estimation of average truck cost per tkm in country c for cargo type G within distance band D at time T [euro/vkm]

$\Delta C^{truck}{}_{cGD}{}^{\text{TT}}\ (t)$ = variation of average truck cost per tkm in country c for cargo type G within distance band D in TRANS-TOOLS model between time T and 2010

s_{TT} = switch to activate linkage with TRANS-TOOLS (0= not activated, 1= cost and time, 2= cost, time and demand)

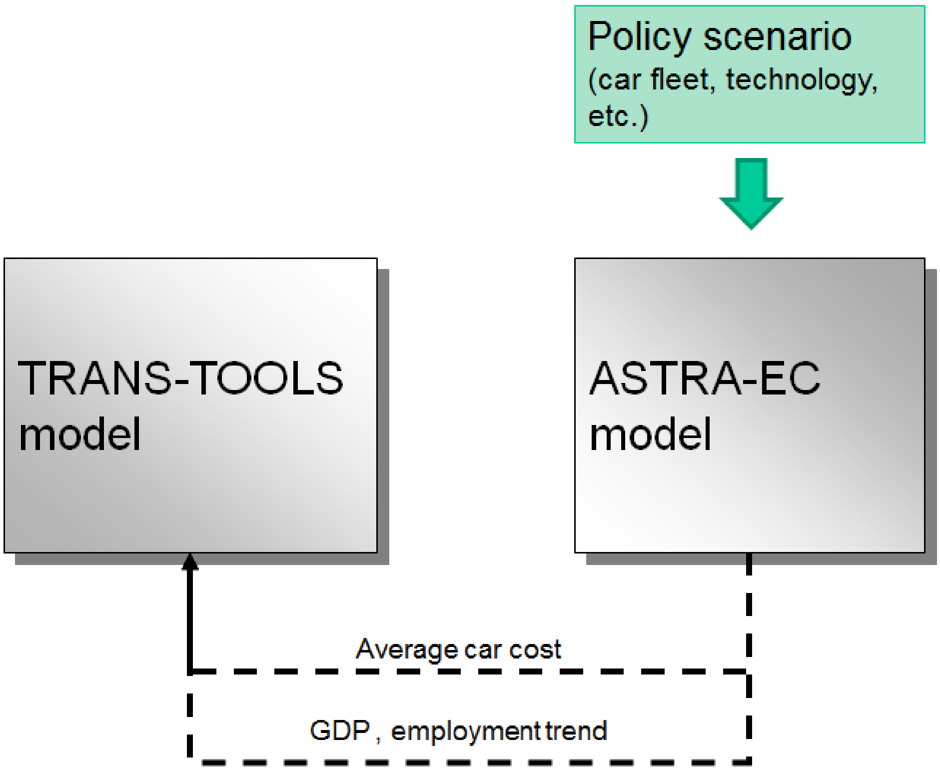
c = country

Similar equation applies for passenger and freight modes for time and cost, as well as for transport demand.

Linkage from ASTRA-EC to 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.



Source: TRT- Fraunhofer-ISI

Figure 12-2: Overview on possible linkages from ASTRA-EC to TRANS-TOOLS

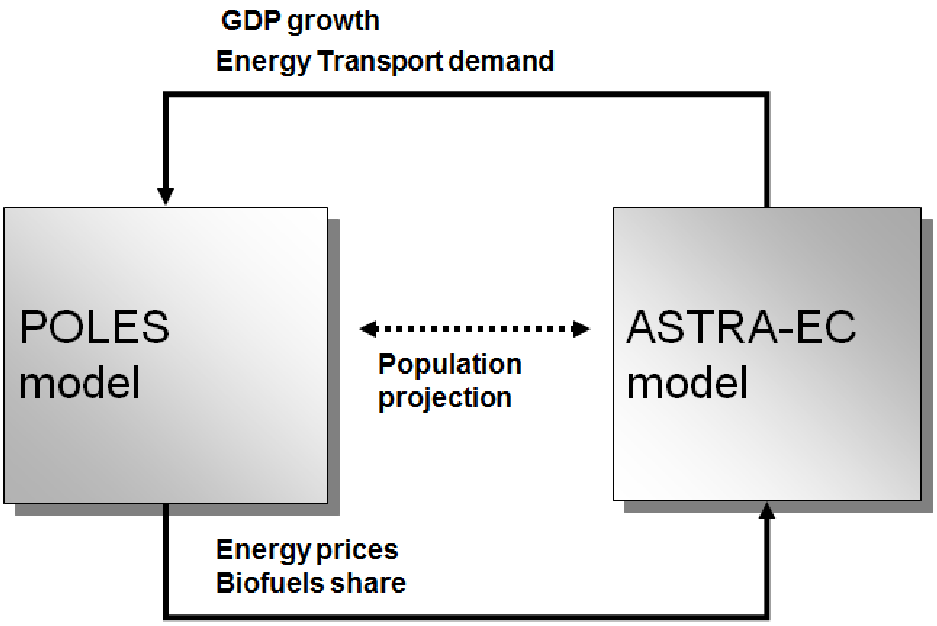
12.2 Linkage with POLES model

The POLES energy model and the ASTRA strategic model have been successfully linked in the past in various research projects (STEPS, TRIAS, HOP!, iTREN2030, GHG-TransPoRD); therefore, it is planned that the ASTRA-EC model developed in the ASSIST project allows the same connection.

The combination of the two models consists of using POLES to cover the energy field with supply of energy resources on world level, energy demand and development of energy prices with an exogenously given economic development; on the other side ASTRA-EC covers the transport field with infrastructure supply and transport demand and includes an economic model that endogenously forecasts economic development under varying policy conditions. For ASTRA-EC the energy prices for gasoline, diesel as well as other fuels (e.g. biofuels) are exogenous inputs and can be replaced with the estimation made by POLES. At the same time, POLES can receive the GDP development and the estimation of energy transport demand from ASTRA. In addition, even if ASTRA-EC and POLES models have different features and deal with a different set of variables, they both simulate the demographic trends for the EU countries and such trends play a role in the outcomes of the simulations. Therefore, it is necessary that also these trends are similar across the models.

The exchange of data between ASTRA and POLES is usually made in an iterative way, which allows to simulate an adjustment process where demand reacts to price and vice-versa, until a (dynamic) equilibrium is reached.

The simulation process using ASTRA and POLES is summarised in the following figure.



Source: TRT- Fraunhofer-ISI

Figure 12-3: Overview on linkages between ASTRA-EC and POLES model

13 The user interface

This chapter provide a description of the structure and main features of the ASTRA-EC user interface; a dedicated user guide is prepared to explain in details how to use it for analysis and policy simulations.

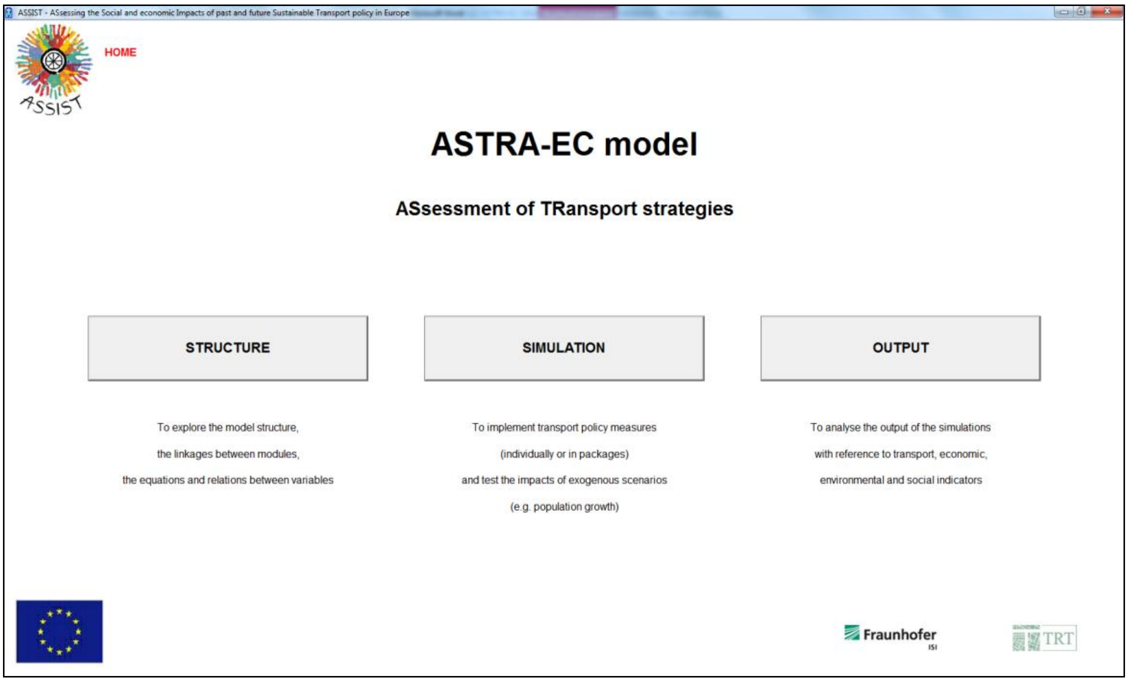
13.1 Overview

The user interface of the ASTRA-EC model provides the possibility of accessing the model to the users (including non-modelling experts) for exploring the model structure, 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 three main parts, concerning:

- the structure of the ASTRA-EC model,
- the inputs to set up the simulation of transport policies and scenarios,
- the outputs of a simulation.

All parts can be accessed from the home page, as shown in the following figure.



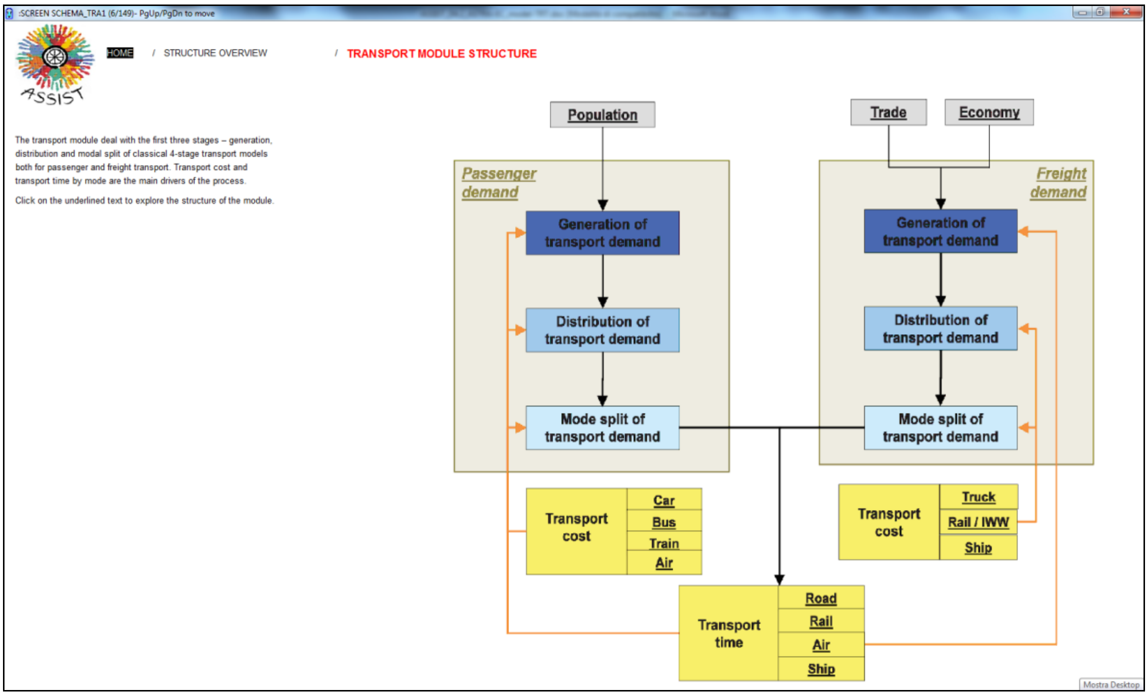
Source: TRT

Figure 13-1: Home page of the ASTRA-EC model interface

13.2 Exploring the ASTRA-EC model

The first feature of the interface allows the user to exlpore the model structure.

Starting from a scheme representing the modules of the ASTRA-EC model and the main linkages (i.e. Figure 2-1), the user can access a set of schemes (e.g. see figure below) representing the structure of each module (transport, population, vehcile fleet, etc.), in order to represent the key variables, linkages and feedbacks. Through the schemes, the user is driven in the exploration of the model, accessing directly the visual representations (i.e. the views) of the model code. The user can move through the modules by clicking the available boxes (those with underlined text).



Source: TRT

Figure 13-2: Example of scheme for exploring the model structure

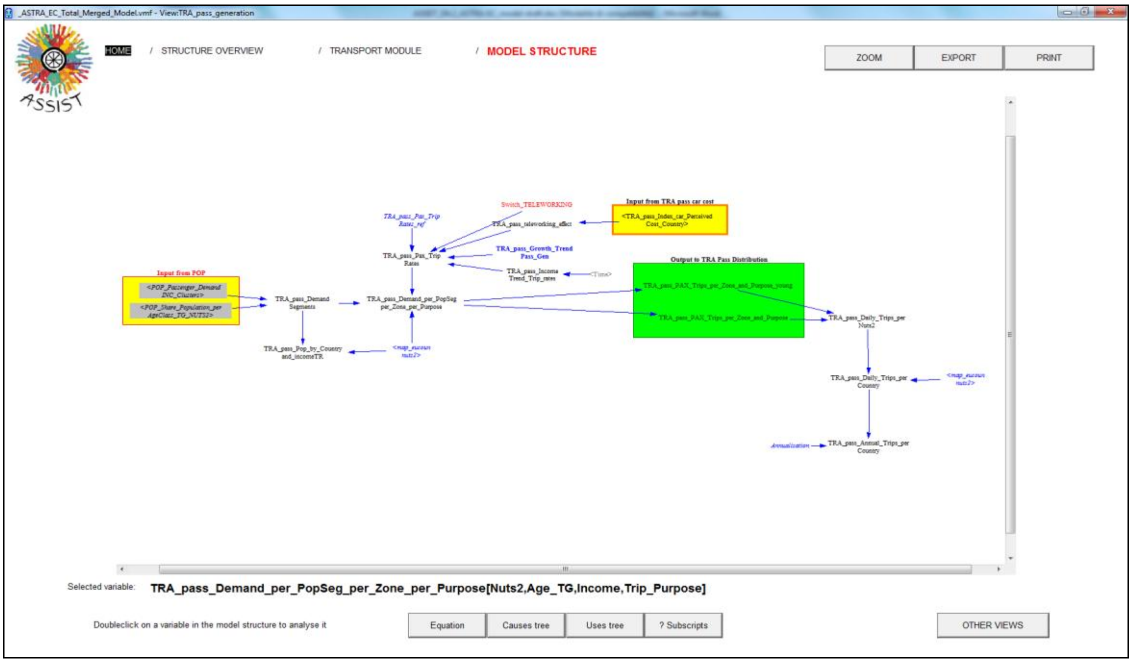
In the Vensim environment, a view is a visual representation of a set of mathematical relationships among variables. The views of the model allows to make the structure more simple and clean, showing a simple portion of the underlying model.

Through this part of the interface, the user can:

- Analyse the linkages between variables (thanks to the visual representation with boxes and arrows),
- Read the equation of each variable in text format,

- Explore the causes (and uses) tree of each variable, displaying structural relationships between variables.

The following figure represents an example of view of the transport module, accessed through the interface.



Source: TRT

Figure 13-3: Example of view for exploring the model structure

13.3 Simulating transport policies

The ASTRA-EC model interface provides the user with the possibility of simulating transport policies individually or as packages. The policies available for the simulation are listed in chapter 11, following the approach and categorisation of Work package 2.

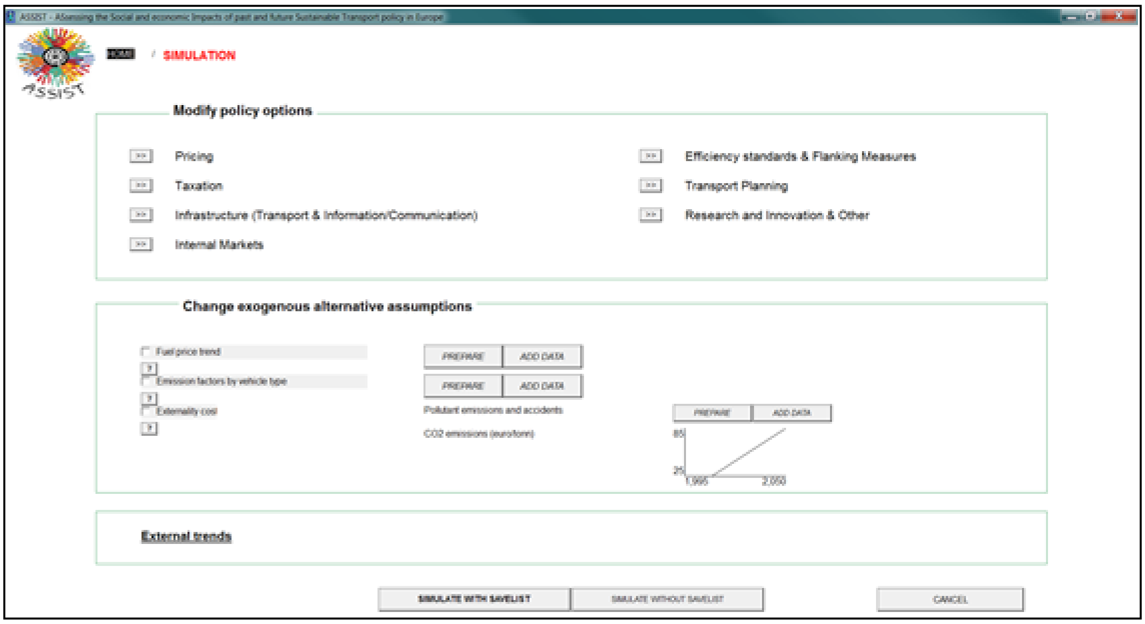
In addition, the interface allows to simulate scenarios with different exogenous assumptions (e.g. external cost, emission factors, etc.).

Finally, through the interface the ASTRA-EC model can use also external trends, in order to activate linkages with other models (TRANS-TOOLS and POLES) or to test exogenous trends of GDP or population. Nevertheless, it should be highlighted that with the implementation of these exogenous trend some feedbacks of the model are not activated and therefore some results might not be sensitive.

Once the user has completed the set-up of the scenario, this can be simulated through a button located in the lowest part of the page.

After the simulation, the results can be read in the third part of the interface, related to the representation of the outputs (see paragraph 13.4).

The following figure provides an example of the main page for setting the parameters and simulating a policy scenario.



Source: TRT

Figure 13-4: Main page of interface for policy scenario set up

In general terms, for activating the simulation of a transport policy the interface provides two different approaches:

- By changing in the model interface the value of the leverage variables used for describing the transport policy;
- By changing the value of the exogenous data used for describing the transport policy.

In addition, several transport policies can be activated through on / off switches, since the intensity of the policy is predefined in the model structure.

In the first case, the value of the input parameters is usually set in a pre-defined range of variation, in order to keep the consistency of the model unchanged. In addition, it is required to specify the first year of implementation of the policy (which is assumed to last till the end of the simulation, in 2050).

In case of a transport policy requiring a change of exogenous data, the interface drives the user in the preparation of the dataset. By clicking on the button "PREPARE" the Excel software opens on a dedicated file for the preparation of the dataset, specifying the values year by year. Then, the button “ADD DATA” allows the conversion in the Vensim format required by the model and the inclusion of the new exogenous file in the simulation.

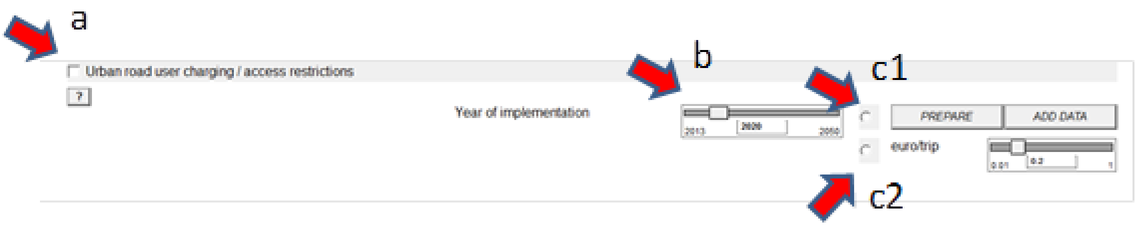
The following figure provide an example of policy where the user can choose between the implementation through a leverage variable with a slider or exogenous data. The example refers to car road pricing, where the user can choose to activate or modify the value of the car toll (expressed in euro/vkm) applied to the tolled network. In order to activate the policy measure, the following steps are needed:

a) Flag the selected policy by clicking in the checkbox corresponding to the policy title (see figure below, arrow a)

b) Set the implementation year by moving the slider or typing the year in the window (see figure below, arrow b)

c) If available, define the value to apply for the simulation. In the more general case this can be done in two alternative ways:

- In the detailed version (at the top on the right), the value can be differentiated and modulated year by year preparing the exogenous data. With reference to the policy, both the car toll and the share of car users travelling on the tolled network can be modified.
- In the simplified version with a slider (at the bottom on the right), a unique value is added to the toll of the reference scenario in all countries, from the year of implementation until the end of the simulation. The share of car users travelling on the tolled network is unchanged, except for those countries where the road network is not tolled: in this case a minimum predefined value is applied.



Source: TRT

Figure 13-5: Example of the two control versions to set car road pricing policy

13.4 Reading simulation results

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

- Read the outcome of the simulation of a given scenario (or more scenarios at the same time), i.e. looking at the values assumed over the simulation period (namely from 1995 to 2050) by the main variables of the model;
- Compare the inputs of two scenarios, i.e. listing the differences in the input variables existing in two different runs.

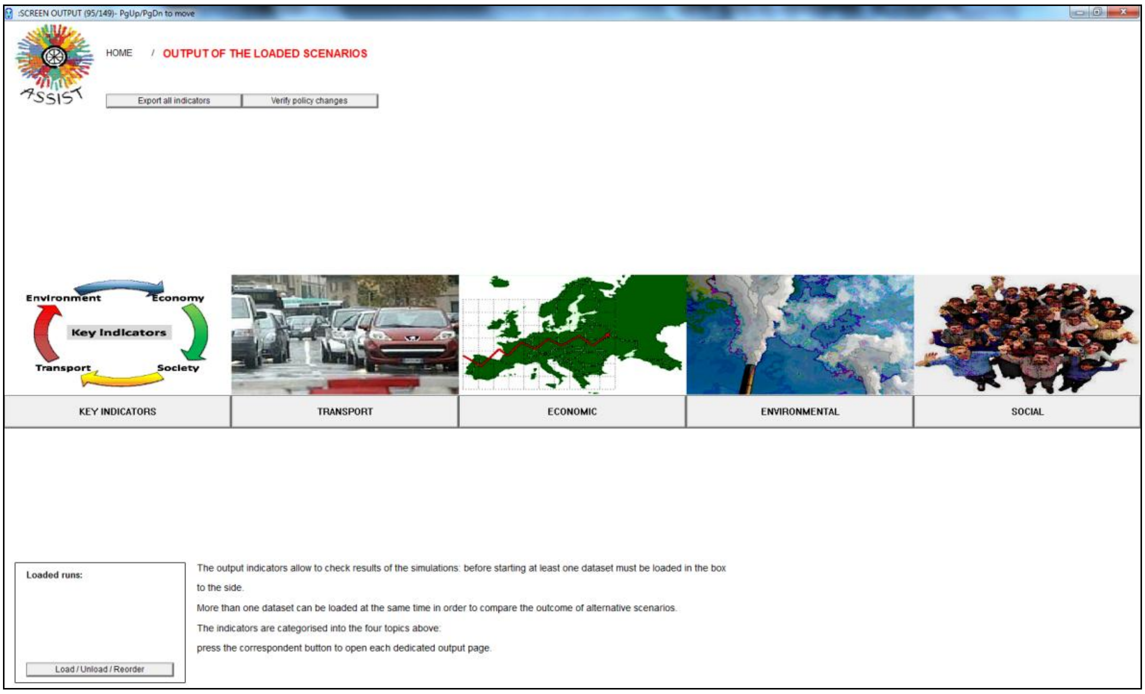
Before to start looking at the results, at least one dataset must be loaded in the interface: a box on the left side at the bottom corner of the main output page shows the loaded scenarios. More than one dataset can be loaded at the same time, in order to compare the outcome of alternative scenarios.

The output indicators are categorised into four topics:

- Transport
- Economy
- Environment
- Society

In addition, a short list of key indicators to summarise the results of policy scenarios is provided.

Each topic corresponds to an output page, which can be opened by clicking on the corresponding button.

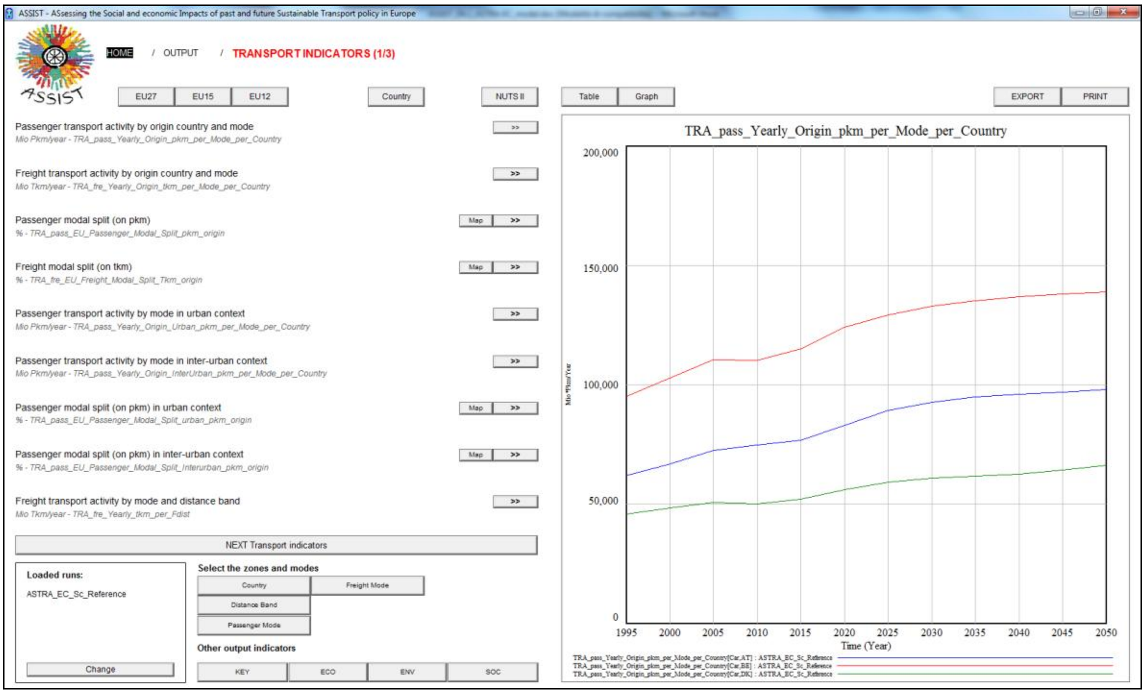


Source: TRT

Figure 13-6: Main page of interface for reading scenario results

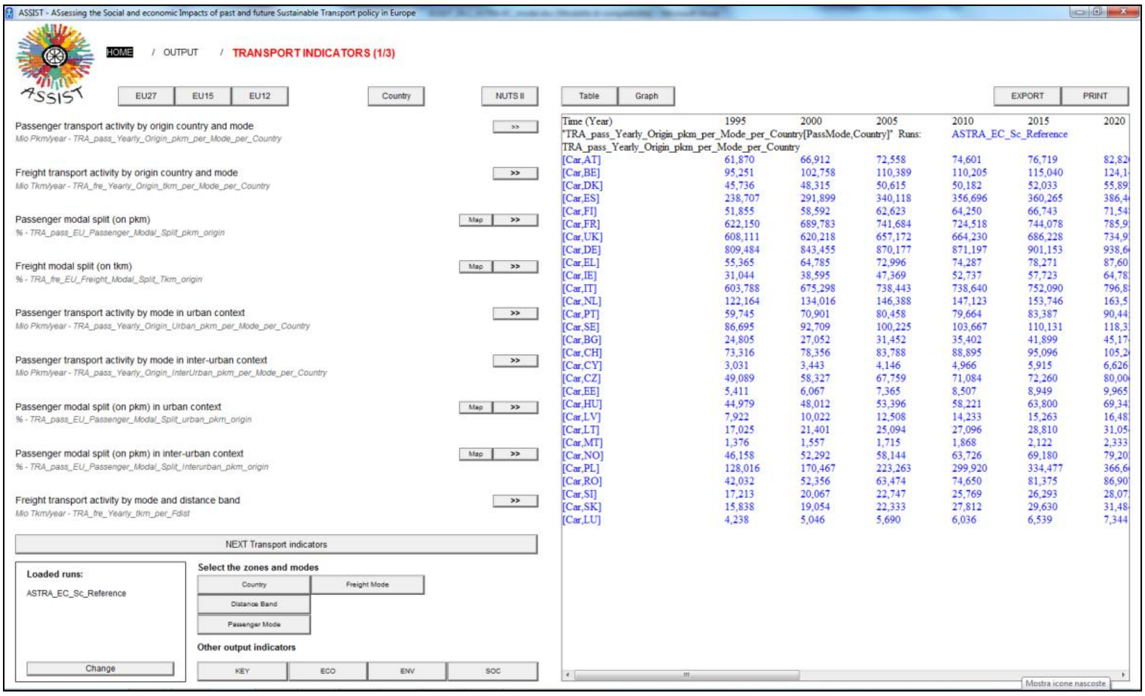
The output pages of each topic are basically structured as follows (see example in the figure):

- On the left side the available indicators are listed.
- On the right side there is an area dedicated to the representation of the values in terms of tables or graphs. A dedicated button allows to switch from one representation to the other. Results in table format can be copied and pasted in Excel for further processing (while graphs are exported as images).
- Next to the area of graphs / tables at the bottom there are specific buttons to select the segmentation of the variables (e.g. the countries for which results should be shown).
- On the left side at the bottom corner there is a box showing the loaded scenarios.
- At the top, above the list of indicators, there are specific buttons to change the level of geographical detail of the variables (i.e. Country, NUTS II, EU27, EU15, EU12).



Source: TRT

Figure 13-7: Example of scenario results in graph format



"TRA_pass_Yearly_Origin_pkm_per_Mode_per_Country[PassMode,Country]" Runs: ASTRA_EC_Sc_Reference

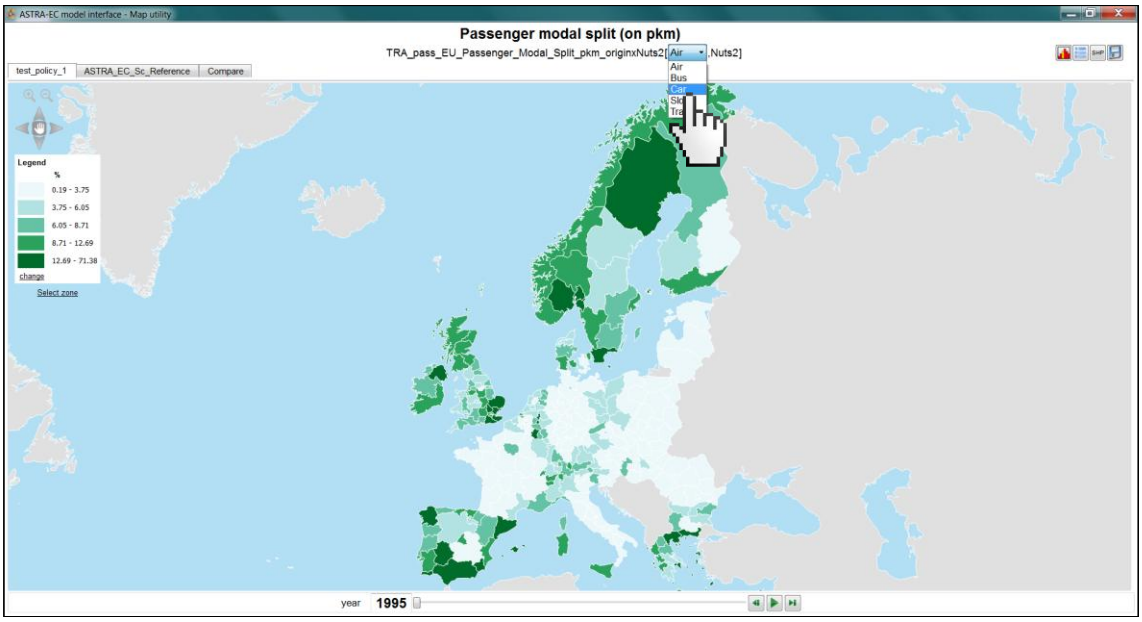
TRA_pass_Yearly_Origin_pkm_per_Mode_per_Country

Time (Year)	1995	2000	2005	2010	2015	2020
[Car,AT]	61,870	66,912	72,558	74,601	76,719	82,82
[Car,BE]	95,251	102,758	110,389	110,205	115,040	124,1
[Car,DK]	45,736	48,315	50,615	50,182	52,033	55,89
[Car,ES]	238,707	291,899	340,118	356,696	360,265	386,4
[Car,FI]	51,855	58,592	62,623	64,250	66,743	71,54
[Car,FR]	622,150	689,783	741,684	724,518	744,078	785,9
[Car,UK]	608,111	620,218	657,172	664,230	686,228	734,9
[Car,DE]	809,484	843,455	870,177	871,197	901,153	938,6
[Car,EL]	55,365	64,785	72,996	74,287	78,271	87,60
[Car,IE]	31,044	38,595	47,369	52,737	57,723	64,78
[Car,IT]	603,788	675,298	738,443	738,640	752,090	796,8
[Car,NL]	122,164	134,016	146,388	147,123	153,746	163,5
[Car,PT]	59,745	70,901	80,458	79,664	83,387	90,44
[Car,SE]	86,695	92,709	100,225	103,667	110,131	118,3
[Car,BG]	24,805	27,052	31,452	35,402	41,899	45,17
[Car,CH]	73,316	78,356	83,788	88,895	95,096	105,2
[Car,CY]	3,031	3,443	4,146	4,966	5,915	6,626
[Car,CZ]	49,089	58,327	67,759	71,084	72,260	80,00
[Car,EE]	5,411	6,067	7,365	8,507	8,949	9,965
[Car,HU]	44,979	48,012	53,396	58,221	63,800	69,34
[Car,LV]	7,922	10,022	12,508	14,233	15,263	16,48
[Car,LT]	17,025	21,401	25,094	27,096	28,810	31,05
[Car,MT]	1,376	1,557	1,715	1,868	2,122	2,333
[Car,NO]	46,158	52,292	58,144	63,726	69,180	79,20
[Car,PL]	128,016	170,467	223,263	299,920	334,477	366,6
[Car,RO]	42,032	52,356	63,474	74,650	81,375	86,90
[Car,SI]	17,213	20,067	22,747	25,769	26,293	28,07
[Car,SK]	15,838	19,054	22,333	27,812	29,630	31,48
[Car,LU]	4,238	5,046	5,690	6,036	6,539	7,344

Source: TRT

Figure 13-8: Example of scenario results in tabular format

For selected variables an additional feature for representing results on maps with GIS software is provided (provided with the button “MAP”). In this case, the values for the selected variable (according to the segmentation activated) are represented on maps through an extension of the Vensim application developed with Python language. Results are represented on maps at a specific time threshold (the map opens showing data at 1995, see below for the representation of the following years) at country, NUTS II or NUTS I level, depending on the variable selected. The legend of the map to interpret colours is on the left side of the map canvas. Different intervals can be defined by the user.



Source: TRT

Figure 13-9: Example of scenario results in map format

If more scenario datasets are activated, a different map is produced for each scenario. The maps for each scenario are accessible by means of tabs at the top of the map canvas. An additional tab, named “compare”, is displayed when at least two scenarios are loaded, in order to see the relative differences between two scenarios.

On the lower side of the main window you can see the year the map refers to. By clicking the “PLAY” button, the representation on the map evolves year by year over the simulation period, according to the legend defined by the user. The user can stop the evolution (and representation) at any year.

A dedicated button below the legend allow to select a specific zone: then a histogram graph will be displayed above the time line, depicting the corresponding values over time for the whole simulation period. The zone can be selected by clicking on its shape as well.

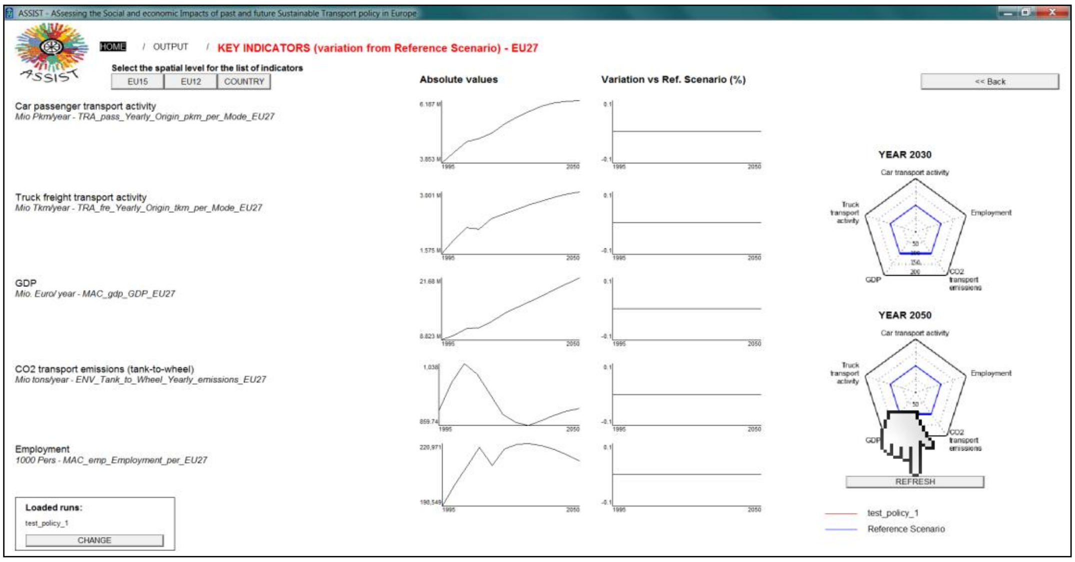
It is possible to save results as shapefile through a button in the right upper part of the page.

Finally, the output page related to the key variables aim at providing an overview of main scenario results.

The structure is the same as the other output pages in terms of graphs and tables, representing five selected indicators:

- Car passenger transport activity
- Truck freight transport activity
- GDP
- CO2 transport emissions (tank-to-wheel)
- Employment.

Nevertheless, an additional feature provides a comparison of the output of key indicators for a selected scenario with results of the Reference scenario. At country level the representation is made by table and graphs, while at aggregate level (EU27, EU15 and EU12) the comparison is represented by line and radar graphs (see example in the figure below).



Source: TRT

Figure 13-10: Example of key indicators results at EU aggregate level

Annexes

Annex 1: Zoning system

Table A-1: Zones at NUTS II, NUTS I and Country level

Zone	NUTS II	NUTS I	COUNTRY
Burgenland (A)	AT11	AT1	AT
Niederösterreich	AT12		
Wien	AT13		
Kärnten	AT21	AT2	
Steiermark	AT22		
Oberösterreich	AT31	AT3	
Salzburg	AT32		
Tirol	AT33		
Vorarlberg	AT34		
Région de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest	BE10	BE1	BE
Prov. Antwerpen	BE21	BE2	
Prov. Limburg (B)	BE22		
Prov. Oost-Vlaanderen	BE23		
Prov. Vlaams-Brabant	BE24		
Prov. West-Vlaanderen	BE25		
Prov. Brabant Wallon	BE31	BE3	
Prov. Hainaut	BE32		
Prov. Liège	BE33		
Prov. Luxembourg (B)	BE34		
Prov. Namur	BE35		
Северозападен / Severozapaden	BG31	BG3	BG
Северен централен / Severen tsentralen	BG32		
Североизточен / Severoiztochen	BG33		
Югоизточен / Yugoiztochen	BG34		
Югозападен / Yugozapaden	BG41	BG4	
Южен централен / Yuzhen tsentralen	BG42		

Lake Geneva region	CH01	CH0	CH
Espace Mittelland	CH02		
Northwestern Switzerland	CH03		
Zurich	CH04		
Eastern Switzerland	CH05		
Central Switzerland	CH06		
Ticino	CH07		
Κύπρος / Kıbrıs	CY00	CY0	CY
Praha	CZ01	CZ0	CZ
Střední Čechy	CZ02		
Jihozápad	CZ03		
Severozápad	CZ04		
Severovýchod	CZ05		
Jihovýchod	CZ06		
Střední Morava	CZ07		
Moravskoslezsko	CZ08		
Stuttgart	DE11	DE1	DE
Karlsruhe	DE12		
Freiburg	DE13		
Tübingen	DE14		
Oberbayern	DE21	DE2	
Niederbayern	DE22		
Oberpfalz	DE23		
Oberfranken	DE24		
Mittelfranken	DE25		
Unterfranken	DE26		
Schwaben	DE27		
Berlin	DE30	DE3	
Brandenburg - Nordost	DE41	DE4	
Brandenburg - Südwest	DE42		
Bremen	DE50	DE5	
Hamburg	DE60	DE6	

Darmstadt	DE71	DE7	
Gießen	DE72		
Kassel	DE73		
Mecklenburg-Vorpommern	DE80	DE8	
Braunschweig	DE91	DE9	
Hannover	DE92		
Lüneburg	DE93		
Weser-Ems	DE94		
Düsseldorf	DEA1	DEA	
Köln	DEA2		
Münster	DEA3		
Detmold	DEA4		
Arnsberg	DEA5		
Koblenz	DEB1	DEB	
Trier	DEB2		
Rheinhessen-Pfalz	DEB3		
Saarland	DEC0	DEC	
Chemnitz	DED1	DED	
Dresden	DED2		
Leipzig	DED3		
Sachsen-Anhalt	DEE0	DEE	
Schleswig-Holstein	DEF0	DEF	
Thüringen	DEG0	DEG	
Hovedstaden	DK01	DK0	DK
Sjælland	DK02		
Syddanmark	DK03		
Midtjylland	DK04		
Nordjylland	DK05		
Eesti	EE00	EE0	EE
Galicia	ES11	ES1	ES
Principado de Asturias	ES12		
Cantabria	ES13		

País Vasco	ES21	ES2	
Comunidad Foral de Navarra	ES22		
La Rioja	ES23		
Aragón	ES24		
Comunidad de Madrid	ES30	ES3	
Castilla y León	ES41	ES4	
Castilla-La Mancha	ES42		
Extremadura	ES43		
Cataluña	ES51	ES5	
Comunidad Valenciana	ES52		
Illes Balears	ES53		
Andalucía	ES61	ES6	
Región de Murcia	ES62		
Itä-Suomi	FI13	FI1	FI
Etelä-Suomi	FI18		
Länsi-Suomi	FI19		
Pohjois-Suomi	FI1A		
Åland	FI20	FI2	
Île de France	FR10	FR1	FR
Champagne-Ardenne	FR21	FR2	
Picardie	FR22		
Haute-Normandie	FR23		
Centre	FR24		
Basse-Normandie	FR25		
Bourgogne	FR26		
Nord - Pas-de-Calais	FR30	FR3	
Lorraine	FR41	FR4	
Alsace	FR42		
Franche-Comté	FR43		
Pays de la Loire	FR51	FR5	
Bretagne	FR52		
Poitou-Charentes	FR53		

Aquitaine	FR61	FR6	
Midi-Pyrénées	FR62		
Limousin	FR63		
Rhône-Alpes	FR71	FR7	
Auvergne	FR72		
Languedoc-Roussillon	FR81	FR8	
Provence-Alpes-Côte d'Azur	FR82		
Corse	FR83		
Ανατολική Μακεδονία, Θράκη / Anatoliki Makedonia, Thraki	GR11	GR1	GR
Κεντρική Μακεδονία / Kentriki Makedonia	GR12		
Δυτική Μακεδονία / Dytiki Makedonia	GR13		
Θεσσαλία / Thessalia	GR14		
Ήπειρος / Ipeiros	GR21	GR2	
Ιόνια Νησιά / Ionia Nisia	GR22		
Δυτική Ελλάδα / Dytiki Ellada	GR23		
Στερεά Ελλάδα / Sterea Ellada	GR24		
Πελοπόννησος / Peloponnisos	GR25		
Αττική / Attiki	GR30	GR3	
Βόρειο Αιγαίο / Voreio Aigaio	GR41	GR4	
Νότιο Αιγαίο / Notio Aigaio	GR42		
Κρήτη / Kriti	GR43		
Közép-Magyarország	HU10	HU1	HU
Közép-Dunántúl	HU21	HU2	
Nyugat-Dunántúl	HU22		
Dél-Dunántúl	HU23		
Észak-Magyarország	HU31	HU3	
Észak-Alföld	HU32		
Dél-Alföld	HU33		
Border, Midland and Western	IE01	IE0	IE
Southern and Eastern	IE02		
Piemonte	ITC1	ITC	IT
Valle d'Aosta/Vallée d'Aoste	ITC2		

Liguria	ITC3		
Lombardia	ITC4		
Provincia Autonoma Bolzano/Bozen	ITD1	ITD	
Provincia Autonoma Trento	ITD2		
Veneto	ITD3		
Friuli-Venezia Giulia	ITD4		
Emilia-Romagna	ITD5		
Toscana	ITE1	ITE	
Umbria	ITE2		
Marche	ITE3		
Lazio	ITE4		
Abruzzo	ITF1	ITF	
Molise	ITF2		
Campania	ITF3		
Puglia	ITF4		
Basilicata	ITF5		
Calabria	ITF6		
Sicilia	ITG1	ITG	
Sardegna	ITG2		
Lietuva	LT00	LT0	LT
Luxembourg (Grand-Duché)	LU00	LU0	LU
Latvija	LV00	LV0	LV
Malta	MT00	MT0	MT
Groningen	NL11	NL1	NL
Friesland (NL)	NL12		
Drenthe	NL13		
Overijssel	NL21	NL2	
Gelderland	NL22		
Flevoland	NL23		
Utrecht	NL31	NL3	
Noord-Holland	NL32		
Zuid-Holland	NL33		

Zeeland	NL34		
Noord-Brabant	NL41	NL4	
Limburg (NL)	NL42		
Oslo og Akershus	NO01	NO0	NO
Hedmark og Oppland	NO02		
Sør-Østlandet	NO03		
Agder og Rogaland	NO04		
Vestlandet	NO05		
Trøndelag	NO06		
Nord-Norge	NO07		
Łódzkie	PL11	PL1	PL
Mazowieckie	PL12		
Małopolskie	PL21	PL2	
Śląskie	PL22		
Lubelskie	PL31	PL3	
Podkarpackie	PL32		
Świętokrzyskie	PL33		
Podlaskie	PL34		
Wielkopolskie	PL41	PL4	
Zachodniopomorskie	PL42		
Lubuskie	PL43		
Dolnośląskie	PL51	PL5	
Opolskie	PL52		
Kujawsko-Pomorskie	PL61	PL6	
Warmińsko-Mazurskie	PL62		
Pomorskie	PL63		
Norte	PT11	PT1	PT
Algarve	PT15		
Centro (P)	PT16		
Lisboa	PT17		
Alentejo	PT18		
Nord-Vest	RO11	RO1	RO

Centru	RO12		
Nord-Est	RO21	RO2	
Sud-Est	RO22		
Sud - Muntenia	RO31	RO3	
Bucureşti - Ilfov	RO32		
Sud-Vest Oltenia	RO41	RO4	
Vest	RO42		
Stockholm	SE11	SE1	SE
Östra Mellansverige	SE12		
Småland med öarna	SE21	SE2	
Sydsverige	SE22		
Västsverige	SE23		
Norra Mellansverige	SE31	SE3	
Mellersta Norrland	SE32		
Övre Norrland	SE33		
Vzhodna Slovenija	SI01	SI0	SI
Zahodna Slovenija	SI02		
Bratislavský kraj	SK01	SK0	SK
Západné Slovensko	SK02		
Stredné Slovensko	SK03		
Východné Slovensko	SK04		
Tees Valley and Durham	UKC1	UKC	UK
Northumberland and Tyne and Wear	UKC2		
Cumbria	UKD1	UKD	
Cheshire	UKD2		
Greater Manchester	UKD3		
Lancashire	UKD4		
Merseyside	UKD5		
East Yorkshire and Northern Lincolnshire	UKE1	UKE	
North Yorkshire	UKE2		
South Yorkshire	UKE3		
West Yorkshire	UKE4		

Derbyshire and Nottinghamshire	UKF1	UKF	
Leicestershire, Rutland and Northamptonshire	UKF2		
Lincolnshire	UKF3		
Herefordshire, Worcestershire and Warwickshire	UKG1	UKG	
Shropshire and Staffordshire	UKG2		
West Midlands	UKG3		
East Anglia	UKH1	UKH	
Bedfordshire and Hertfordshire	UKH_2		
Essex	UKH_3		
Inner London	UKI1	UKI	
Outer London	UKI2		
Berkshire, Buckinghamshire and Oxfordshire	UKJ1	UKJ	
Surrey, East and West Sussex	UKJ2		
Hampshire and Isle of Wight	UKJ3		
Kent	UKJ4		
Gloucestershire, Wiltshire and Bristol/Bath area	UKK1	UKK	
Dorset and Somerset	UKK2		
Cornwall and Isles of Scilly	UKK3		
Devon	UKK4		
West Wales and The Valleys	UKL1	UKL	
East Wales	UKL2		
Eastern Scotland	UKM2	UKM	
South Western Scotland	UKM3		
North Eastern Scotland	UKM5		
Highlands and Islands	UKM6		
Northern Ireland	UKN0	UKN	

Annex 2: Value of Time

Table A-2: Reference Value of Time passenger by purpose (Euro per trip per hour, in Euro2005)

Country	Local commut-ing	Local business	Local personal	Long commut-ing	Long business	Long personal
AT	7.9	28.8	6.7	24.9	24.8	6.8
BE	7.6	28.0	6.5	24.9	24.9	7.0
DK	8.9	34.2	7.5	26.1	26.2	6.9
ES	8.2	22.3	7.1	18.1	18.0	5.3
FI	7.2	27.4	6.2	22.5	22.3	6.0
FR	10.7	27.9	9.2	21.9	21.8	5.8
UK	8.1	28.7	6.9	22.3	22.2	6.1
DE	8.0	28.3	6.8	23.9	23.9	6.8
EL	6.4	18.5	5.6	15.1	15.0	4.2
IE	7.9	28.8	6.8	24.0	23.9	6.6
IT	9.8	25.8	8.4	22.2	22.1	5.6
NL	7.5	28.0	6.5	25.0	24.9	6.9
PT	6.4	19.4	5.6	16.4	16.3	4.5
SE	8.0	30.2	6.8	22.2	22.1	6.0
BG	2.8	7.4	2.4	4.8	4.7	0.9
CH	10.8	33.6	9.4	28.0	27.9	8.7
CY	7.6	21.5	6.7	17.4	17.4	4.5
CZ	5.5	14.1	4.7	13.4	13.3	3.5
EE	4.5	12.1	3.8	9.8	9.7	2.5
HU	4.6	12.7	4.0	10.8	10.7	2.8
LV	4.1	11.1	3.5	7.0	6.9	1.8
LT	4.2	11.2	3.5	6.9	6.9	1.8
MT	6.3	19.8	5.6	13.6	13.6	3.5
NO	12.3	41.3	10.6	28.4	28.2	7.6
PL	4.6	12.2	4.0	10.1	10.0	2.6
RO	2.9	7.8	2.5	6.3	6.3	1.2
SI	7.7	18.3	6.5	13.2	13.1	3.4
SK	4.1	11.7	3.6	9.8	9.7	2.5
LU	11.8	39.0	10.2	24.9	24.9	7.0

Table A-3: Reference Value of Time freight by commodity type (Euro per ton per hour, in Euro2005)

Country	Bulk	General cargo	Unitised
AT	1.04	1.44	4.68
BE	0.96	1.31	4.28
DK	1.01	1.39	4.54
ES	0.80	1.10	3.59
FI	0.94	1.29	4.21
FR	0.87	1.19	3.88
UK	0.87	1.20	3.92
DE	0.97	1.34	4.36
EL	0.66	0.91	2.98
IE	1.03	1.41	4.61
IT	0.82	1.12	3.67
NL	1.06	1.46	4.76
PT	0.62	0.86	2.80
SE	1.02	1.40	4.57
BG	0.36	0.50	1.63
CH	1.22	1.68	5.48
CY	0.75	1.02	3.34
CZ	0.65	0.89	2.90
EE	0.54	0.75	2.43
HU	0.53	0.74	2.40
LV	0.47	0.65	2.11
LT	0.50	0.69	2.25
MT	0.67	0.92	3.01
NO	1.53	2.11	6.86
PL	0.53	0.72	2.36
RO	0.40	0.55	1.78
SI	0.68	0.94	3.05
SK	0.59	0.81	2.65
LU	1.27	1.75	5.69

Annex 3: Main model variables

Table A-4: Main model variables and related equations

Module	Variable	Model variable name	Equation number in D4.2
TRA	Generated trips by NUTS II zone, purpose and population group (adults)	TRA_pass_PAX_Trips_per_Zone_and_Purpose	Eq. 27
TRA	Generated trips by NUTS II zone, purpose and population group (individuals <17 years old)	TRA_pass_PAX_Trips_per_Zone_and_Purpose_young	Eq. 27
TRA	Trip rates by country, age, income and purpose	TRA_pass_Pax_Trip_Rates	Eq. 27
TRA	intra NUTS II trips generated by the NUTS II zone, purpose and (aggregated) income group	TRA_pass_INTRA_gen_trips	Eq. 30
TRA	extra NUTS II trips generated by the NUTS II zone, purpose and (aggregated) income group	TRA_pass_EXTRA_gen_trips	Eq. 33
TRA	intra NUTS II trips of the distance band local, generated by the NUTS II zone, purpose and (aggregated) income group	TRA_pass_LC_Demand	Eq. 34
TRA	intra NUTS II trips of the distance band very short, generated by NUTS II zone, purpose and (aggregated) income group	TRA_pass_VS_Demand	Eq. 35
TRA	intra NUTS II trips of the distance band short, generated by NUTS II zone, purpose and (aggregated) income group	TRA_pass_ST_Demand	Eq. 36
TRA	domestic extra NUTS II trips generated by NUTS II zone, purpose and (aggregated) income group	TRA_pass_EXTRA_gen_trips_NAT	Eq. 40
TRA	international intercontinental extra NUTS II trips generated by NUTS II zone, purpose and (aggregated) income group	TRA_pass_EXTRA_gen_trips_INTERCONT	Eq. 41

TRA	international European extra NUTS II trips generated by NUTS II zone, purpose and (aggregated) income group	TRA_pass_EXTRA_gen_trips_ INTERNAT	Eq. 42
TRA	national trips from origin NUTS I zone to destination NUTS I zone by purpose and (aggregated) income group of country XXX	TRA_pass_EXTRA_demand_NAT_ XXX	Eq. 43
TRA	international European trips from origin Country *O* to destination country *D* by purpose and (aggregated) income group	TRA_pass_EXTRA_demand_ INTERNAT_eu	Eq. 44
TRA	international extra-European trips from origin Country *O* to destination region *DR*	TRA_pass_EXTRA_demand_ INTERCONT	Eq. 46
TRA	passenger trips generated by NUTS II zone in the distance band local, by purpose, (aggregated) income group and mode	TRA_pass_LC_trips	Eq. 52
TRA	passenger trips generated by NUTS II zone in the distance band very short, by purpose, (aggregated) income group and mode	TRA_pass_VS_trips	Eq. 52
TRA	passenger trips generated by NUTS II zone in the distance band short, by purpose, (aggregated) income group and mode	TRA_pass_ST_trips	Eq. 52
TRA	passenger trips from origin NUTS I zone to destination NUTS I zone, at national level, by purpose, (aggregated) income group and mode of country XXX	TRA_pass_XXX_trips_NAT	Eq. 52
TRA	international European trips from origin Country *O* to destination country *D* by purpose, (aggregated) income group and mode	TRA_pass_trips_INTERNAT	Eq. 52
TRA	pkm generated by NUTS II zone in the distance band local, by mode	TRA_pass_LC_pkm_per_MxOrigin	Eq. 58

TRA	pkm generated by NUTS II zone in the distance band very short, by mode	TRA_pass_VS_pkm_per_MxOrigin	Eq. 58
TRA	pkm generated by NUTS II zone in the distance band short, by mode	TRA_pass_ST_pkm_per_MxOrigin	Eq. 58
TRA	Pkm from NUTS I zone of transit, at national level, by mode of country XXX	TRA_pass_XXX_pkm_NAT_per_ MxTrans	Eq. 58
TRA	international European pkm from origin Country *O* by mode	TRA_pass_pkm_INTERNAT_per_ MxOrig	Eq. 58
TRA	domestic volumes transported by country and flow group	TRA_fre_Volumes_NAT_per_ GCxEC	Eq. 61
TRA	international volumes between country *O* and country *D* by flow group	TRA_fre_Volumes_INTRA_EU_per _GC	Eq. 62
TRA	intercontinental volumes between country *O* and world region *R* by flow group	TRA_fre_Volumes_EU_to_RoW_ per_GC	Eq. 63
TRA	domestic volumes transported by origin NUTS II zone by flow group	TRA_fre_Volumes_NAT_per_GCx EC_nuts2	Eq. 64
TRA	intra NUTS II volumes generated by NUTS II zone and flow group	TRA_fre_demand_nuts2_INTRA	n.a.
TRA	intra NUTS II volumes of the distance band local, generated by the NUTS II zone and flow group	TRA_fre_LOC_Demand	n.a.
TRA	intra NUTS II volumes of the distance band short, generated by NUTS II zone and flow group	TRA_fre_SRT_Demand	n.a.
TRA	domestic extra NUTS II trips generated by NUTS II zone, purpose and (aggregated) income group	TRA_fre_Volumes_NAT_per_ GCxEC_nuts2_EXTRA	n.a.
TRA	national volumes from origin NUTS I zone to destination NUTS I zone by flow group of country XXX	TRA_fre_EXTRA_demand_NAT_ XXX	n.a.
TRA	volumes generated by NUTS II zone in the distance band short, by flow group and mode	TRA_fre_SRT_Vol	n.a.

TRA	Volumes transported from origin NUTS I zone to destination NUTS I zone, at national level, by flow group and mode of country XXX	TRA_fre_XXX_Vol_NAT	n.a.
TRA	international European volumes transported from origin Country *O* to destination country *D* by flow group and mode	TRA_fre_Vol_INTERNAT	n.a.
TRA	tkm generated by NUTS II zone in the distance band local and short, by mode	TRA_fre_local_tkm_per_MxOrigin	Eq. 67
TRA	tkm from NUTS I zone of transit, at national level, by mode of country XXX	TRA_fre_XXX_tkm_NAT_per_ MxTrans	Eq. 67
TRA	international European tkm from origin Country *O* by flow group and mode	TRA_fre_tkm_INTERNAT_per_ MxOrig	Eq. 67
ENV	hot pollutants emissions by mode YYY[45] by vehicle category and distance band produced by NUTS I zone	ENV_YYY_Poll_HotEm_per_ UrbDbxCatxNuts1	Eq. 74
ENV	hot pollutants emissions produced by ship per flow group from origin country	ENV_Ship_Poll_HotEm_per_ECxG C	Eq. 74
ENV	hot pollutants emissions produced by airplane from origin country	ENV_air_Poll_HotEm_per_ECxTP	Eq. 74
ENV	Cold start pollutants emissions by car by vehicle category produced by NUTS I zone	ENV_CAR_Yearly_Poll_CSE_per_ CatxNuts1	Eq. 75
ENV	Pollutants and CO_2 emissions for vehicle production of mode ZZZ[46] by country	ENV_ZZZ_Yearly_VPE_per_EC	Eq. 76
ENV	Pollutants and CO_2 emissions for fuel production of fuel JJJ[47] by mode YYY	ENV_YYY_Yearly_JJJ_FPE	Eq. 77

45 YYY stands for: car, bus, PassTrain_diesel, PassTrain_electric, HDV, LDV, FreTrain_Diesel, FreTrain_Electric.

46 ZZZ stands for: car, bus, HDV, LDV.

47 JJJ stands for diesel, gasoline, kerosene, electricity, bioethanol, hydrogen, LPG, CNG.

ENV	Tank-to-wheel CO_2 emissions by mode KKK[48] by country	ENV_YYY_Yearly_CO2_Hot_per_EC	Eq. 79
ENV	Fuel consumption by mode ZZZ by distance band by Country	ENV_ZZZ_Fuel_Consumption_per_Urbdb	Eq. 78
ENV	Fuel consumption by car vehicle category and distance band by Country	ENV_car_Fuel_Consumption_per_UrbdbxCat	Eq. 78
ENV	Fuel consumption by freight train by Country	ENV_FreTrain_Biodiesel_Consumption ENV_FreTrain_diesel_Consumption ENV_FreTrain_Electricity_Consumption	Eq. 78
ENV	Fuel consumption by freight train by Country	ENV_PassTrain_Biodiesel_Consumption ENV_PassTrain_diesel_Consumption ENV_PassTrain_Electricity_Consumption	Eq. 78
ENV	Fuel consumption by airplane by origin Country	ENV_Air_Fuel_Consumption	Eq. 78
ENV	Fuel consumption by ship mode by origin Country	ENV_Ship_Fuel_Consumption	Eq. 78
ENV	car accidents by category, NUTS I zone and context XXX (urban or rural)	ENV_acc_XXX_Car_Accidents_per_Nuts1	Eq. 82
ENV	accidents by category by mode (HDV, LDV, freight train) and NUTS I zone	ENV_acc_Fre_Accidents_per_FreModexNuts1	n.a.
ENV	accidents by category by freight mode (HDV, LDV, freight train, ship) and country	ENV_acc_Accidents_per_FreModexEC	n.a.
ENV	accidents by category by mode (bus, slow, passenger train) and NUTS I zone	ENV_acc_No_Car_Pass_Accidents_per_Nuts1	n.a.
ENV	accidents by category by passenger mode (car, bus, slow, passenger train, air) and country	ENV_acc_Accidents_per_PassModexEC	n.a.

48 KKK stands for: car, bus, PassTrain_diesel, PassTrain_electric, HDV, LDV, FreTrain_Diesel, FreTrain_Electric, IWW, air, ship.

ENV	Total externality Cost of pollutant XXX[49] emissions by country and mode	ENV_External_Costs_of_XXX_per_Mode	Eq. 83
ENV	Total externality Cost of accident by type, country and mode	ENV_Externality_Cost_of_PassAccidents ENV_Externality_Cost_of_FreAccidents	Eq. 84
POP	Population by country and age cohort	POP_PopulationConveyor	Eq.1
POP	Income mobility by young people finishing their eduction to income group by country	POP_INC_Mobility_L_LM POP_INC_Mobility_L_M POP_INC_Mobility_M_MH POP_Inflows_MH POP_Inflows_H	Eq.2
POP	Income mobility by ageing from/to income group by country	POP_Pot_Emp_Reaching_next_IG_by_Ageing	Eq.3
POP	Income mobility by retirement of employed and self-employed persons from/to income group by country	POP_INC_Mobility_L_LM POP_INC_Mobility_L_M POP_INC_Mobility_M_MH POP_Inflows_MH POP_Inflows_H	Eq.4
POP	Income mobility by unemployment from/to income group by country	POP_INC_Mobility_L_LM POP_INC_Mobility_L_M POP_INC_Mobility_M_MH POP_Inflows_MH POP_Inflows_H	Eq.5
POP	Income mobility by persons changing jobs between economic sectors from/to income group by country	POP_Potential_Income_Mobility_from_Labour_Market	Eq.6
POP	Income mobility by persons induced by changing direct taxes and social contributions from/to income group by country	POP_Potential_Income_Mobility_from_Taxation_per_IG	Eq.7
MAC	Gross domestic product by country	MAC_gdp_Gross_Domestic_Product	Eq.8
MAC	Final Demand by country and economic sector	MAC_gdp_Final_Demand_per_Sector	Eq.9

49 XXX stands for CO_2, PM, NOx, VOC.

MAC	Potential domestic consumption of private households by country and income group	MAC_con_Current_Income_Actually_Spent	Eq.10
MAC	Potential domestic consumption of private households for transport by country and income group	MAC_con_Possible_Consumption_Transport_per_Income	Eq.11
MAC	Domestic consumption of private households for non-transport products and services by country and income group	MAC_con_Possible_Consumption_Without_Transport	Eq.12
MAC	Domestic consumption of private households for non-transport products and services by country, by sector and income group	MAC_con_Consumption_per_Income_Without_Transport	Eq.13
MAC	Domestic consumption of private households by country, sector and income group	MAC_con_Consumption_per_Income_and_Sector	Eq.14
MAC	Trend influence of consumption on investments by country for investing sectors	MAC_inv_Change_Consumption_Enforced	Eq.15
MAC	Trend influence of exports on investments by country for investing sectors	MAC_inv_Export_Influence_on_Investments_Sectoral	Eq.16
MAC	Investments by country and sector excluding vehicle production sector	MAC_inv_Investment_Without_Transport	Eq.17
MAC	Potential output by country	MAC_gdp_Potential_Output	Eq.18
MAC	Private gross capital stock	MAC_gdp_Gross_Private_Capital	Eq.19
MAC	Public gross capital stock	MAC_gdp_Gross_Public_Capital	Eq.20
MAC	Gross capital stock	MAC_gdp_Gross_Capital	Eq.21
MAC	Input-output table by country, input sector and output sector	MAC_iot_Input_Output_Table	Eq.22
MAC	Full-time-equivalent employment by country and sector	MAC_emp_Employment_FTE_per_Sector	Eq.23
MAC	Employment by country and sector	MAC_emp_Employment_Sectoral_incl_Part_Time	Eq.24
MAC	Government budget balance by country	MAC_gov_Government_Balance_Accumulated	Eq.25
FOT	Exports between EU27 (+2) countries by exporting country, importing country and sector	FOT_weu_Export_INTRA_EU_Sect	Eq.26

VFT	Share of purchased cars by country and car/fuel category	VFT_car_Car_Category_Logit	Eq.69
VFT	Perceived car costs by country and car/fuel category	VFT_car_Total_Car_Cost_Function	Eq.70
VFT	Perceived LDV costs by country and LDV/fuel category	VFT_ldv_total_cost_per_vkm	Eq.71
VFT	Share of purchased LDVs by country and LDV/fuel category	VFT_ldv_Logit_calculation	Eq.72
VFT	Transport supply of buses by country	VFT_bus_Needed_Buses_for_VKT_Demand	Eq.73

Annex 4: Conversion of economic sectors

Table A-5: Conversion factors from NACE Rev. 2 CPA 65 classification to ASTRA-EC NACE-CLIO 25 classification

NACE Rev.2	Sector Name	IOSector	Con-version
A_01	Products of agriculture, hunting and related services	Agriculture	1
A_02	Products of forestry, logging and related services	Agriculture	1
A_03	Fish and other fishing products; aquaculture products; support services to fishing	Agriculture	1
B	Mining and quarrying	Metals	0.43
B	Mining and quarrying	Minerals	0.21
B	Mining and quarrying	Energy	0.36
C_10-12	Food products, beverages and tobacco products	Food	0.9
C_10-12	Food products, beverages and tobacco products	Other_ Manufacturing	0.1
C_13-15	Textiles, wearing apparel and leather products	Textiles	1
C_16	Wood and of products of wood and cork, except furni-ture; articles of straw and plaiting materials	Other_ Manufacturing	1
C_17	Paper and paper products	Paper	1
C_18	Printing and recording services	Paper	0.5
C_18	Printing and recording services	Other_ Manufacturing	0.5
C_19	Coke and refined petroleum products	Energy	1
C_20	Chemicals and chemical products	Chemicals	1
C_21	Basic pharmaceutical products and pharmaceutical preparations	Chemicals	1
C_22	Rubber and plastics products	Plastics	1
C_23	Other non-metallic mineral products	Minerals	1
C_24	Basic metals	Metals	1
C_25	Fabricated metal products, except machinery and equipment	Metal_ Products	1
C_26	Computer, electronic and optical products	Computers	1
C_27	Electrical equipment	Electronics	1
C_28	Machinery and equipment n.e.c.	Indus-	1

		trial_Machines	
C_29	Motor vehicles, trailers and semi-trailers	Vehicles	1
C_30	Other transport equipment	Vehicles	1
C_31-32	Furniture; other manufactured goods	Other_ Manufacturing	1
C_33	Repair and installation services of machinery and equipment	Trade	1
D	Electricity, gas, steam and air-conditioning	Energy	1
E_36-37	Natural water; water treatment and supply services	Energy	1
E_38-39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	Non_Market_ Services	1
F	Constructions and construction works	Construction	1
G_45	Wholesale and retail trade and repair services of motor vehicles and motorcycles	Trade	1
G_46	Wholesale trade services, except of motor vehicles and motorcycles	Trade	1
G_47	Retail trade services, except of motor vehicles and motorcycles	Trade	1
H_49	Land transport services and transport services via pipelines	Transport_Inland	1
H_50	Water transport services	Transport_Air_ Maritime	1
H_51	Air transport services	Transport_Air_ Maritime	1
H_52	Warehousing and support services for transportation	Transport_Auxiliary	1
H_53	Postal and courier services	Communication	1
I	Accommodation and food services	Catering	1
J_58	Publishing services	Other_Market_ Services	1
J_59	Motion picture, video and television programme production services, sound recording and music publishing; programming and broadcasting services	Other_Market_ Services	1
J_60	Telecommunications services	Other_Market_	1

		Services	
J_62-63	Computer programming, consultancy and related services; information services	Other_Market_ Services	1
K_64	Financial services, except insurance and pension funding	Banking	1
K_65	Insurance, reinsurance and pension funding services, except compulsory social security	Banking	1
K_66	Services auxiliary to financial services and insurance services	Banking	1
L	Real estate services	Other_Market_ Services	1
L_68	Of which: imputed rents of owner-occupied dwellings	Other_Market_ Services	1
M_69-70	Legal and accounting services; services of head offices; management consulting services	Other_Market_ Services	1
M_71	Architectural and engineering services; technical testing and analysis services	Other_Market_ Services	1
M_72	Scientific research and development services	Other_Market_ Services	1
M_73	Advertising and market research services	Other_Market_ Services	1
M_74-75	Other professional, scientific and technical services; veterinary services	Other_Market_ Services	1
N_77	Rental and leasing services	Other_Market_ Services	1
N_78	Employment services	Other_Market_ Services	1
N_79	Travel agency, tour operator and other reservation services and related services	Catering	1
N_80-82	Security and investigation services; services to buildings and landscape; office administrative, office support and other business support services	Other_Market_ Services	1
O	Public administration and defence services; compulsory social security services	Non_Market_ Services	1
P	Education services	Non_Market_ Services	0.8

P	Education services	Other_Market_ Services	0.2
Q_86-87	Human health services	Non_Market_ Services	0.8
Q_86-87	Human health services	Other_Market_ Services	0.2
Q_88	Social work services	Non_Market_ Services	1
R_90-91	Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services	Non_Market_ Services	0.1
R_90-91	Creative, arts and entertainment services; library, archive, museum and other cultural services; gambling and betting services	Other_Market_ Services	0.9
R_92-93	Sporting services and amusement and recreation services	Other_Market_ Services	1
S_94	Services furnished by membership organisations	Non_Market_ Services	1
S_95	Repair services of computers and personal and household goods	Other_Market_ Services	1
S_96	Other personal services	Other_Market_ Services	1
T	Services of households as employers; undifferentiated goods and services produced by households for own use	Other_Market_ Services	1
U	Services provided by extraterritorial organisations and bodies	Other_Market_ Services	1

Annex 5: Income distribution

Table A-6: Upper monthly net income[50] from work for each income group

Country	Inc1	Inc2	Inc3	Inc4
AT	583	1,167	1,750	2,333
BE	540	1,081	1,621	2,162
DK	819	1,637	2,456	3,274
ES	486	972	1,458	1,945
FI	652	1,304	1,955	2,607
FR	533	1,066	1,599	2,131
UK	630	1,260	1,890	2,520
DE	548	1,095	1,643	2,190
EL	426	853	1,279	1,706
IE	600	1,199	1,799	2,399
IT	523	1,045	1,568	2,090
NL	626	1,253	1,879	2,505
PT	507	1,015	1,522	2,029
SE	651	1,301	1,952	2,603
BG	299	597	896	1,195
CH	599	1,198	1,797	2,396
CY	508	1,016	1,524	2,031
CZ	381	763	1,144	1,525
EE	374	747	1,121	1,495
HU	451	902	1,352	1,803
LV	344	689	1,033	1,377
LT	353	705	1,058	1,410
MT	481	961	1,442	1,923
NO	847	1,695	2,542	3,389
PL	411	822	1,234	1,645
RO	343	687	1,030	1,373
SI	427	855	1,282	1,710
SK	386	772	1,159	1,545
LU	495	990	1,484	1,979

50 Average monthly net income from work of households per person including household members not working (e.g. children).

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