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Assessment of Environmentally Sustainable Transport Scenarios by a Backcasting Approach with ESCOT

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Abstract

The aim of the System Dynamics Model ESCOT is to describe a path towards a sustainable transport system in Germany and to assess its economic impacts. ESCOT was developed within the **e**nvironmentally **s**ustainable **t**ransport (EST) project of the OECD that was designed to set-up the ecological and technical framework of a transition towards sustainable transportation. ESCOT comprises five models: the macroeconomic, the transport, the regional economic, the environmental and the policy model.

The economic assessment for environmentally sustainable scenarios shows that the departure from car- and road freight-oriented transport policy is far away from leading to an economic breakdown. By expanding the time period for the transition we derived even more encouraging economic results.

For the economic assessment it is important that ESCOT considers not only first round effects but also secondary effects. This ability makes ESCOT a powerful instrument for the assessment of such large system changes.

1 Introduction

The aim of ESCOT (Model for **e**conomic assessment of **s**ustainability poli**c**ies **o**f **t**ransport) is to describe a development path towards a sustainable transport system in Germany and to assess its economic impacts. In ESCOT the **System Dynamics Methodology** is applied for integrated modelling of transportation scenarios. The **Macroeconomic Model** of ESCOT forms the backbone of the economic assessment and enables to undertake complex policy studies.

The framework for the sustainable transport system is prescribed by strict environmental goals. As major driving forces for these changes we have to consider e.g. the development of population, the way of living and housing, car ownership, consumption and other macroeconomic variables. In addition to the complex interrelationships between these driving forces the investigated scenarios cover a long period of time. Complexity of considered systems and long-term time horizon for the assessment suggests to use a **System Dynamics Model** (SDM) (chapter 2).

ESCOT is used to assess a development path towards sustainable transport in Germany in the project on **e**nvironmentally **s**ustainable **t**ransport (EST) of the OECD (Umweltbundesamt 2000). Within the EST-project ESCOT contributes to the backcasting strategy of EST. The project is designed to set-up the ecological and technical framework of a transition towards sustainable transportation (chapter 3). For this purpose first ecological goals based on sustainability considerations are identified and a business-as-usual (BAU) scenario depicting the future development of different transport modes (road, rail, air, shipping) and their impacts on environmental indicators (air emission) is developed. As the BAU scenario is not sustainable it was necessary to design environmentally sustainable transport (EST) scenarios and policy strategies that would lead to sustainability. Two scenarios are developed by using a backcasting approach starting from the identified environmental goals in 2030 and describing a path to achieve these goals:

- the EST-80%, that leads to a reduction of 80% CO_2 in 2030, and
- the EST-50%, that expanded the time horizon till 2050 and leads in 2030 to a reduction of 50% CO_2. scenario.

Besides environmental protection economic feasibility forms a fundamental part of sustainability. The transition towards a sustainable transport system provides many economic impacts like changes in consumption of households, investment in infrastructure and technical progress. The objective of ESCOT is to describe these effects and especially their economic interactions entirely. ESCOT is divided in five models, the macroeconomic model, the transport model, the regional economic model, the environmental model and the policy model (chapter 4). Because this paper emphasises the economic evaluation we focus on the macroeconomic model. As a key element an Input-Output-Table is integrated into the System Dynamics Model. At the present stage the implementation of an Input-Output-Table into a System Dynamics Model is an important step ahead for long-term economic assessment.

The results of the assessment of economic impacts for EST-80% clearly show that the departure from car and road freight oriented transport policy is far away from leading to an economic breakdown. The effects concerning economic indices are rather low, even though the measures proposed in the EST-80% scenario foresee significant changes compared to today's transport policy. The impact on consumption and export, however, is clearly negative because of decreasing output in selected economic sectors. For the EST-50% scenario that expanded the time period for change in order to decrease the speed of change and gave more room to compensating measures we derived more encouraging results (chapter 5).

ESCOT offers the opportunity to analyse the macroeconomic development both considering first round effects and secondary effects. The former are in case of a development path towards sustainability mostly governed by negative influences like higher prices and restrictions on the demand side. The latter consider structural changes that occur only in the long run and tend to compensate for the negative first round effects. Renes et al. (2004) and Schade (2004) have shown that considering fully-fledged transport policies these secondary effects, which they named indirect effects, could even become significantly larger than the first round effects. Secondary effects arise because transport is highly interrelated with other social systems such that a policy measure e.g. charges for one mode causes a first round effect e.g. decrease in demand for this mode but also secondary effects e.g. technological changes for other modes because of increased demand for these modes, changes in state revenues or sectoral private consumption. This ability makes the System Dynamics Model ESCOT to a powerful instrument for the assessment of such large system changes.

2 Basics of System Dynamics

Based on the finding that socio-economic systems often behave counterintuitive, which means that measures that have a positive influence in the short run have a negative outcome in the long run, Forrester (1968,1972) concluded that such systems are composed of several interacting feedback loops. Two types of feedback loops can be distinguished: positive feedback loops enforcing developments over time finally even de-stabilizing systems, and negative feedback loops dampening developments over time and stabilizing systems. To model the feedback loops Forrester developed three types of structure elements: level variables (levels), flow variables (rates) and auxiliary variables. Levels represent the most important element of a system. They describe the state of a system and the system behaviour can be derived from their development. The values of levels change during a simulation according to their related rates. Rates can be inflows to a level in a way that the values of a rate are added to the values of the level within each time step. Or rates can be outflows from a level.

Three types of auxiliary variables are distinguished: parameters, exogenous factors and intermediate variables. Parameters are constant during the simulation period. Exogenous factors represent variables that have an influence on the system but they are not influenced by the system. Intermediate variables are calculated by other variables of the system at the same point of time. The different elements are composed by a special scheme to sets of difference equations that describe the interrelationships within the system dynamics model.

In particular time plays an important role in SDMs in that future system states develop out of past and current system states e.g. considering lags between variables such that the output of an SDM always constitutes of dynamic development paths for each variable instead of a static point-to-point forecast. Summarising, system dynamics has four theoretical foundations (Milling 1984):

- the mental problem solving process (e.g. evaluation of relevance of interrelationships),
- the information-feedback theory (e.g. constructing a model of several feedback loops),

- the decision theory (e.g. defining decision rules to move along the time path from one system state to another) and
- computer simulation.

The first step developing a system dynamics model is to define the system borders, the system variables and the relevance of their interrelationships. The second step is the most important one: the main feedback mechanisms have to be extracted and designed. The behaviour of a system is primary determined by these feedback mechanisms. Because of the impossibility to prove an analytic solution for such complex social systems in most cases it is the only solution to solve the problem by computer simulation (Sterman 2000). Results are produced within this computer simulation that calculate the system states step-by-step over the simulation period based on interrelationships between variables, feedback mechanisms and decision rules.

To evaluate policy packages that might lead to completely different transport systems than today it is necessary to assess long-term effects off these policy measures. For instance the construction and planning of transport infrastructure might take up to 10 years and the usage duration is often longer than 40 years. But this construction has impacts on e.g. development of population, the way of living and housing, car-ownership, investment and other macroeconomic variables.

The long-term time horizon of the assessment causes the problem of uncertainty. There might be changes on the behavioural or on the technical side. E.g. the population might change their habits into an environmentally friendly way or not. Car producers might construct cars with less carbon dioxide emissions and less fuel consumption. Or, maybe, cars with small fuel consumption will represent only a small share of the total car production.

Since forecasting has to cope with long-term effects and their uncertainties it is wise to apply a modelling technology that diminishes uncertainties. It is obvious that for a methodology relying strongly on data from the past like econometric or other modelling based mainly on statistical analysis results become less reliable the further into the future these models are applied (Schade/Rothengatter 1999)

Finally it has to be emphasised since system dynamics models are forecasting the development of the model variables over time the time path development of these variables can be used for assessment instead of using only one future point of time and neglecting to analyse the path dependency of the transitions over time.

3 The environmentally sustainable transport (EST) project

In 1994 the Pollution Prevention and Control Group of the OECD established a Task Force on Transport to look into ways and means to significantly reduce the environmental impact of transportation. Starting from December 1994 an Expert Group met several times to prepare a proposal and to start work on a project on environmentally sustainable transport comprising four phases:

1. To **identify key criteria** for what might be sustainable transport.
2. To construct a **business-as-usual (BAU)** scenario revealing how further unsustainable transport development in transport may look and an **environmentally sustainable transport (EST)** scenario, which demonstrates a path towards achievement of the key criteria, taking 1990 as the reference year and 2030 as the year for which attainment of the EST criteria is to be achieved.

3. To **identify packages of policy instruments,** which enable attainment of the criteria in the EST scenario with a backcasting approach.
4. To **assess the BAU and EST scenarios** with respect to their technical, economic and political feasibility.

3.1 Identification of Key criteria

Phase 1 of the EST project was dedicated to review government programmes in OECD member countries regarding evidence and thinking on transport and environment, and to identify the criteria for EST.

The environmental quality criteria identified to be the most important for a description of EST were emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x), volatile organic compounds (VOC), particulate matter (PM), noise from transport and land use for transport infrastructure (OECD 1996).

Table 1: Criteria for environmentally sustainable transport

Parameters	Criterion		Specification
CO_2	- 80 %	Emission reduction of the transport sector in 2030 compared to 1990	all areas
NO_x	- 90 %		all areas
VOC	- 90 %		all areas
PM	- 99 %		urban areas
Noise	<= 65 dB(A)		all areas
	<= 55 dB(A) daytime		residential areas
	<= 45 dB(A) night		residential areas
Land Use	criterion has to be developed		urban areas
	no extension of transport infrastructure		rural areas

3.2 BAU, EST-80% and EST-50% scenario

Research groups from the participating countries, Sweden, Norway, The Netherlands, Canada, France, Switzerland, Austria and Germany, described the future potentially sustainable development of transportation. The German group transferred this common picture into a BAU and an EST scenario for Germany considering its specific characteristics (OECD 1998).

The scenarios are of scientific nature and do neither describe officially envisaged policies, nor environmental targets established by governments. The BAU scenario assumes that no significant policy changes and no major technical changes will take place in the transport sector. Only those structural changes and technical innovations are assumed that can be expected to happen from today's point of view.

The EST-80% scenario describes a path towards sustainable transport that meets the identified criteria in 2030 (table 1). As CO_2 emissions are the most problematic gaseous emission we assume that if we would fulfil the criteria for CO_2 the criteria of other gaseous emissions are also fulfilled. For a better understanding we call this EST scenario EST-80% scenario because its aim is to reduce CO_2 emissions by 80%.

The EST-80% scenario was developed using a backcasting approach. So the construction of the scenario started with the CO_2 reduction goal and then tried to find out which technical progresses and which transport reduction strategies are necessary to reach this goal.

Table 2: Assumptions of EST scenarios (Umweltbundesamt, Wuppertal Institute 1997)

Assumption	BAU	EST-80%
Population	Slight growth until 2010 and than decrease	As in BAU
Economic growth	Moderate	As in BAU
Infrastructure	Federal Transport Master Plan	Increase of railway network, less road construction
Fuel Price	Moderate growth	Growth driven by taxes
Automobile fleet	Increase of 85%	Equal as today
Car occupancy	Decreases	Increases
Yearly travelled km/car	Decrease	Decrease
Specific emissions from road vehicles	Significant reduction	High reduction
Specific energy consump-tion for transport modes	Decrease	High decrease (e.g. 2.5l fuel per 100 km for cars)
Noise emissions	Moderate reduction	High reduction
Car Ownership rate	820 per 1000 inhabitants	Similar as today
Share of diesel cars	From 15% (today) to 30%	0%
Share of electric cars	10%	0%
Energy	Similar as today	50% from renewable energy

Both scenarios are based on assumptions. Concerning the development of population and economic growth they are the same. Concerning the development of transport figures they differ strongly between the scenarios. Because of the fact that the BAU scenario assumes no significant policy changes and no surprising technical development the future trends can be extrapolated by the trend of the last decade. The assumptions for EST-80% are completely different. Because of a new transport policy, this scenario expects e.g. higher road transport prices and a reduction of emissions.

To achieve an 80% reduction of CO_2 in the year 2030 biting restrictions and energy cost increases have to be introduced already decades ahead, which might cause economic risks. The negative first round effects would make such a scenario impossible to become implemented. This required to modify the scenario and to construct an EST-50% scenario. The EST-50% scenario follows a reduction goal of 50% CO_2 emissions till the year 2030[1]. With EST-50% we can observe the economic impacts if we apply the same time horizon, weaken the ecological goals and decrease the intensity of policy measures that change the transport behaviour of population or firms.

3.3 Packages of policy instruments to reach EST-80% and EST-50%

Both EST scenarios can only be reached by a new transport policy. The most important policy instruments for the EST-80% scenario are (Umweltbundesamt 1997):

[1] Note that IPCC has proposed to achieve this goal in 2050, not in 2030

- **CO_2 Emission Regulation:** this policy instrument means the lowering of gaseous emissions of vehicles. The implementation of this instrument for cars occurs stepwise. CO_2 emissions of cars starting in 1990 at 260g/km are reduced to CO_2 emissions of 58g/km in 2030. Altogether the measure results in a decrease of fuel consumption of an average car (e.g. to 2.5 l/100km for gasoline cars in 2030) and CO_2-emissions by more than 75%.
- **Fuel Tax:** this policy instrument means an increase of the mineral oil tax for gasoline and diesel. It leads to lower fuel consumption for vehicles, shorter driving distances and to a reduction of urban sprawl. The fuel tax would have to increase in a way that the fuel costs per vehicle km will double until 2030.
- **Road Pricing:** this policy instrument means the implementation of a charge for heavy duty vehicle (HDV) based on their driven km. The charge will be balanced by fuel tax refunds and will be introduced stepwise. A charge level of 0.25 €/km will be introduced in 2003. It will rise up to 1.25 €/km in 2030.
- **Road and Rail Infrastructure:** this policy instrument means the adjustment of the Federal Transport Infrastructure Plan in a way that the rail network will be extended and the extension of the road network will be halted after 2010.

Besides these major instruments it is necessary to implement measures for traffic calming strategies in towns, public transport services, railway services for freight transport, regional economic structures, local and regional tourist and recreational areas and low traffic land-use patterns.

For the EST-50% scenario the same policy measures are applied. But the intensity of each policy measure is different to EST-80%. They are changed as follows:

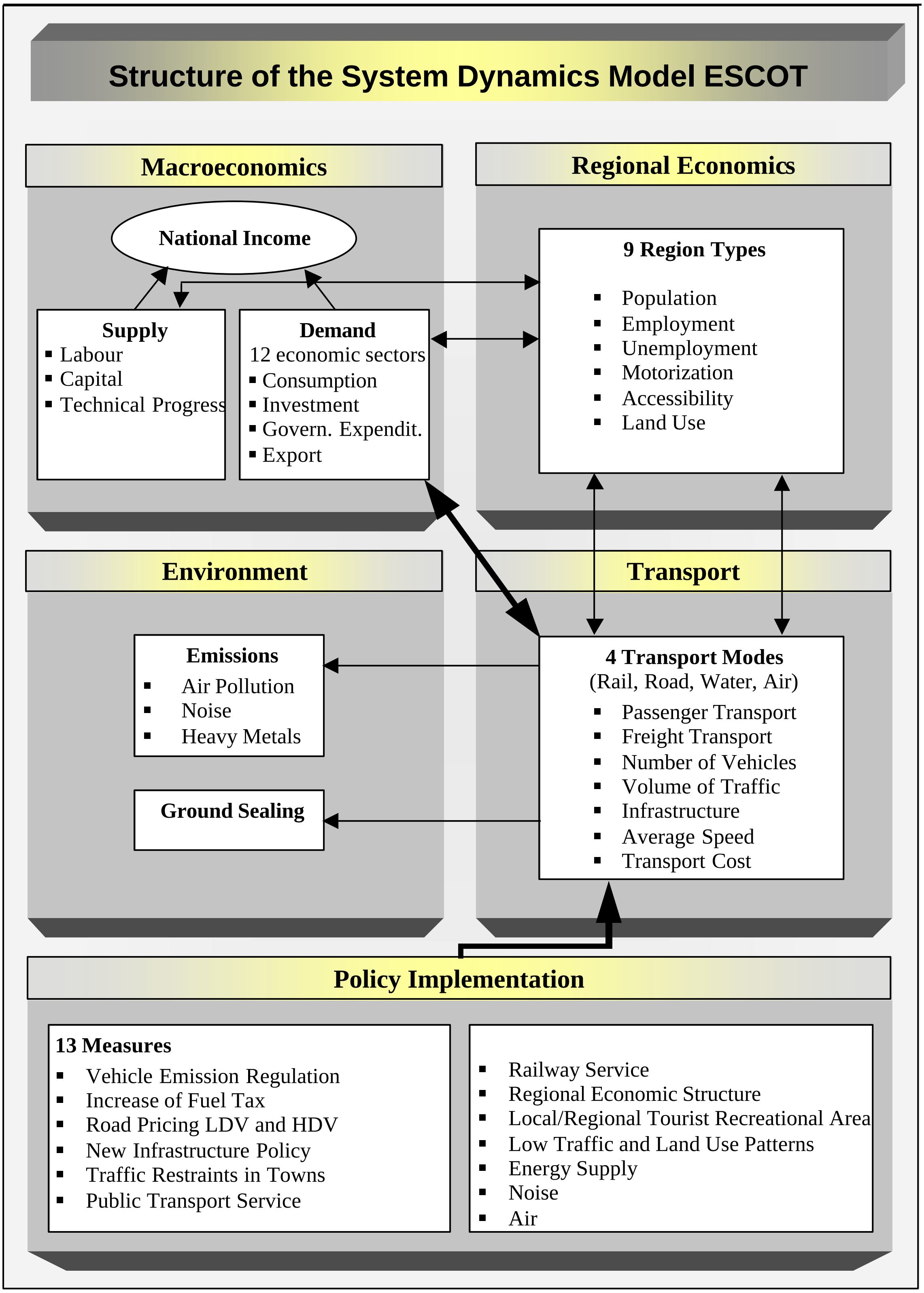
- Increase of fuel tax less than 50% compared to EST-80%
- Increase of road pricing only 50% of EST-80% (e.g. charge level 0.125-0.62 €/km)
- Improvements in emission regulation about 70% of EST-80%
- Expansion of railway infrastructure about 70% of EST-80%
- Inner city, railway service, regional economic and land use measures same as in EST-80%
- Energy policy measures same as in EST-80%.

4 Structure of ESCOT

The structure of ESCOT is based on five different models representing four of the most important subsystems describing the impact areas and the policy sphere (Schade/Rothengatter 2004).

The **macroeconomic model** supplies information on the aggregate economic level (e.g. national income). The **regional economic model** is disaggregated into 32 different economic sectors. Furthermore, 9 functional types of regions are defined (e.g. rural regions or highly agglomerated areas (Kuchenbecker 1998)). This classification is also applied for the **transport model**. In addition, this model distinguishes between different transport modes (road, rail, water, air) and different types of infrastructure links (e.g. high-speed links between agglomerations). The **environmental model** calculates data on emissions of transport activities and estimates their first round effects. The **policy model** drives the scenarios that influence the other model systems. The most policy implementations intervene in the transport model so that this model usually is the steering area for simulating the impact mechanisms.

Figure 1: Structure of the System Dynamics Model ESCOT with BAU/EST Policy Implementation



In figure 1 we see that the policy model contains only exogenous variables. Changes starting in this model (depicted by arrows) have their influence mostly on the transport model. In contrast the environmental model is driven by the transport model and has nearly no impact on other models. A high integration and many feedbacks we developed for the macroeconomic model, regional economic model and transport model that is stressed by two-directional arrows.

4.1 The Transport Model

The transport model is divided into passenger and freight transport, and into non-urban and urban traffic. Non-urban traffic has higher dependencies on macroeconomic influences, cost, time and infrastructure changes. Passenger transport is divided into the different modes road, rail and air while freight transport is distinguished into road, rail and shipping (Umweltbundesamt 1994).

Figure 2: Structure of the Transport Model and its Main Linkages to Other Models

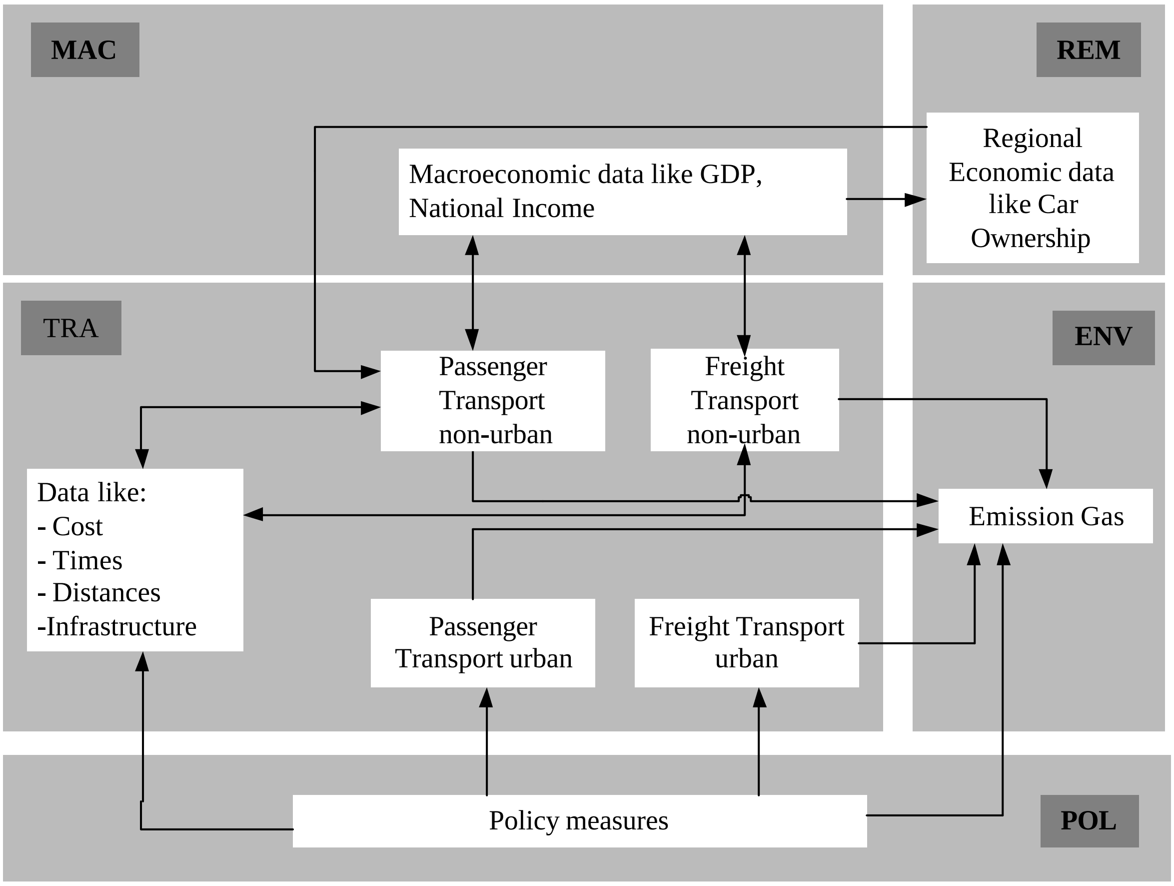
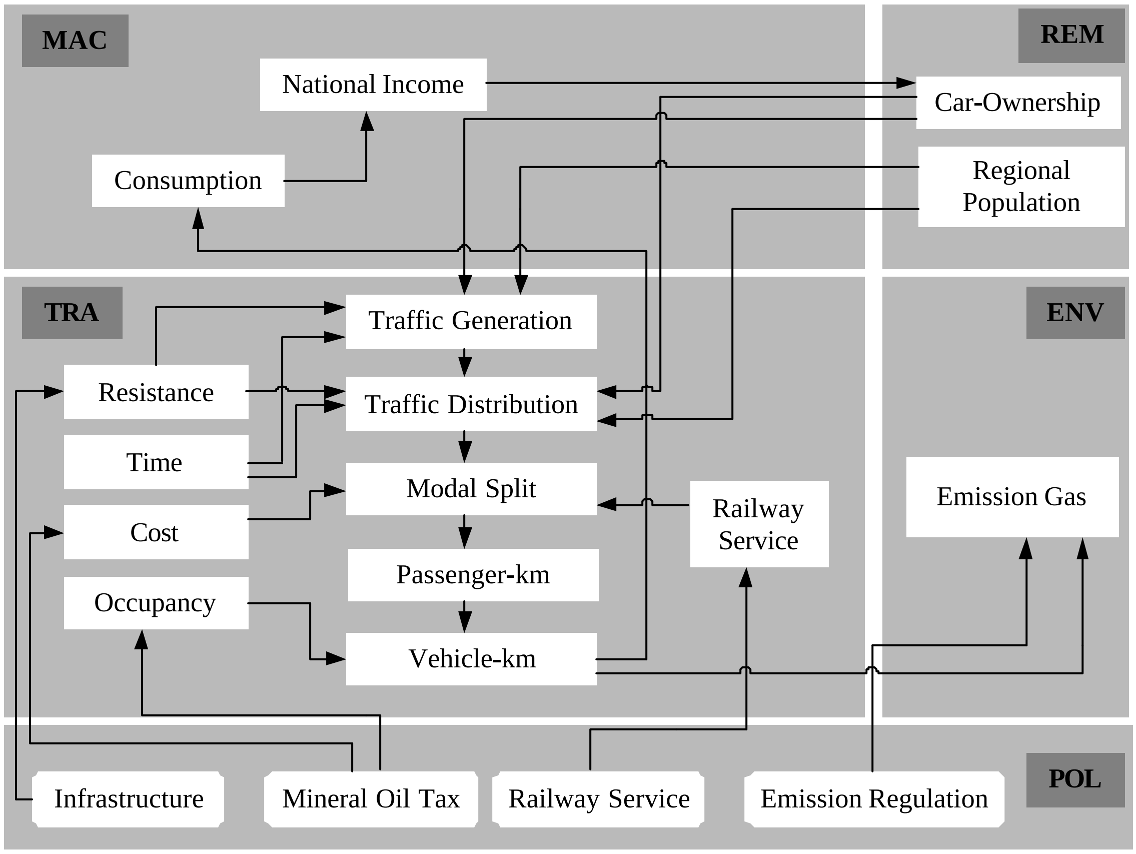


Figure 2 shows a more detailed view of non-urban passenger transport and its influences. We notice that the policy sector is an exogenous sector introducing different policy measures (chapter 2). The policy measure infrastructure has a direct influence on the resistance to travel between two regions. The resistance variable itself changes the traffic generation that has an influence on the traffic distribution. The modal-split is calculated in the next step. Among other influencing variables, the modal-split is affected by transport cost and railway services, which again are affected by other policy measures.

In figure 3 we also see a feedback loop between the variables traffic generation - traffic distribution - modal-split (Oum et al. 1992, Wardman 1997) - passenger-km per mode - vehicle-km per mode - transport time - traffic generation. This feedback loops implies, that a higher traffic generation leads in the end to higher vehicle-kilometres per mode. The increase of vehicle-km per mode leads to higher transport times and this effect puts a dampener on traffic generation.

Another interesting feedback loop is traffic generation - traffic distribution - modal-split - passenger-km per mode - vehicle-km per mode - consumption - national income - car ownership - traffic generation - traffic distribution. It means that a growth of traffic leads to higher values for consumption and national income. The more money people earn, the more they spend on owning a car. This effect leads in the end to a higher growth of traffic. This loop shows a positive feedback between the macroeconomic model, regional economic model and transport model.

Figure 3: Passenger Transport in ESCOT



4.2 The Environmental Model

The basic objective of the environmental model is to supply information that will lead to indicators (e.g. volume of emissions), which can be used as a control for the different scenarios.

The main link between other models is the link to passenger-, freight- and vehicle-km of the transport model and one link from the policy measure that is called emission regulation to the emission factors of different vehicle types. The emission factors themselves depend on the technical standards of the vehicles. For air emissions, we have a classification into four types of emissions: CO_2, VOC, NO_x and particulate matter. The transport volume is combined with these emission factors to derive the yearly emitted amount of emission gas.

4.3 The Macroeconomic Model

The structure of the macroeconomic model was developed within the model KEYNEO[2]. Keynesian and neoclassical elements form the base of KEYNEO. The feedback structure of KEYNEO was verified for the German economy for a long time horizon (40 years). Optimization

[2] KEYNEO will be presented to the 23rd International Conference of the System Dynamics Society too.

tools were used to estimate the parameters. The results of KEYNEO showed high significance for all economic variables like employment, investment, final demand etc. on an aggregate level.

This feedback structure was implemented in ESCOT and modified in many aspects:

- ESCOT considers 32 economic sectors instead of aggregated variables.
- A dynamic input-output-table is integrated in ESCOT.
- ESCOT links other models like transport to the macroeconomic model.

Figure 4: Feedback loops in ESCOT

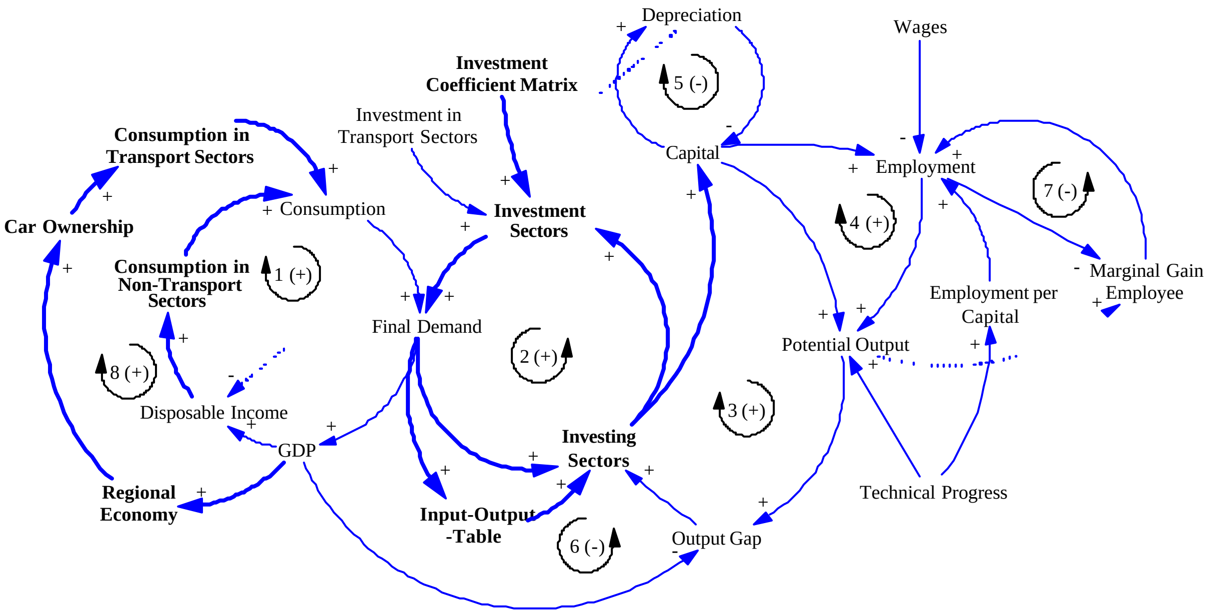


Figure 4 describes the feedback structure of ESCOT. Thin lines indicate links that stem from KEYNEO. Fat lines indicate new or modified links.

Loop 1 is the consumption feedback loop. Consumption has a positive impact on final demand, final demand on disposable income, and disposable income on consumption. As all impacts are positive this loop is a positive feedback loop.

Loop 2 is the investment feedback loop. Higher investments lead to an increase of final demand and of the expected final demand. Higher expected final demands lead to an increase of investment of the investing sectors[3]. This is also a positive feedback loop.

Loop 3 and 4 relate to the potential output[4]. The output gap is the difference between the potential output and the gross domestic product (GDP). This output gap has a positive impact on investment. Higher investments lead to an increase of capital. In loop 3 there is a direct link between capital and potential output. In loop 4 a higher capital leads to an increase of employment that increases the potential output.

[3] See Sterman (1986), S. 102.

[4] The potential output is defined as the long term trend of GDP. For further information see chapter 3.2.2 and 3.2.3.

Loop 5 is the depreciation loop. Depreciation depends on capital. This feedback loop damps the previous described feedback loops. Loop 6 is also a negative feedback loop. Investment has a positive impact on final demand and GDP. An increase of GDP leads to a decrease of the output gap and this leads to lower investments of investing sectors.

Loop 7 balances out the marginal gain of labour with employment. An increase of the marginal gain of labour has a positive impact on employment. The increase of employment leads to a decrease of the marginal gain of labour (by the production function).

Loop 8 is an example for the link between the transport model and the macroeconomic model. A higher GDP leads to higher income in the regional economy's. This increases the car ownership, which has a positive impact on consumption in transport sectors and in the aggregate consumption.

There are many more links between the macroeconomic and other models than shown in Figure 4.

Constructed as a Keynesian and neoclassical model the macroeconomic model is divided into two main parts: the demand and the supply side (Schade et al. 2002). Demand is split into four main demand sectors: consumption, investment, government expenditure and export. Each of the four demand sectors is disaggregated into 12 economic sectors (e.g. mineral oil industry).

The supply side is split into the production factors labour and capital. In addition, technological progress is considered on the supply side to integrate the technical development within the economy.

4.3.1 Demand side

The main objective of the demand side is to calculate the final demand. The final demand is determined by the development of consumption, investment, government spending and export.

The variable **consumption** represents the consumption of private households. For its calculation, we use the national income as one input. Additional inputs are the consumption spent in the transport sector like:

- mineral oil industry: the consumption of fuel for car travel,
- vehicle demand purchases: consumption of cars and motorcycles, repair,
- transport service: rail, bus and air travel.

The reason for this approach is that private households change their consumption patterns if transport prices increase. We consider that consumption in transport sectors causes impacts on consumption in non-transport sectors in a way that e.g. a decrease of consumption in transport sectors leads to a non-negligible increase of consumption in non-transport sectors. This does not mean that there will be a complete compensation because of complementarities between transport and other activities and incentive effects. For all calculations taxes and especially the mineral oil tax are taken into account.

The variable **investing sectors** represents the amount of money that is spent in investments by enterprises and government. The development of investing sectors depends on the development of consumption in the same sector.

The variable **investment sectors** means the amount of money that was paid to investment producing sectors. The total sum is equal as for investing sectors but the distribution differs.

An influence on investments depends on the freight transport sub-module. The transport models provide information about the traffic volume of road, rail and ship freight transport. These inputs are used as an indicator for investment in vehicles and buildings. Finally, the investments made by the government in infrastructure for the road and rail mode is considered. The main part of infrastructure investment is needed for the expansion of the railway network. In the EST-80% scenario a doubling of the length of the railway network is assumed to be necessary to handle the increased traffic volumes.

The variable **government** shows the expenditure of the government. We assume a yearly increase of 2%. In ESCOT the variable **export** follows a similar development as consumption, investment and government for each sector assuming that all OECD countries introduce the EST policies and experience similar impacts that are reflected by these macroeconomic variables. This means, that we add consumption, investment and government of one sector, derive the trend of this sum and link the export to this trend.

By adding consumption, investment, government and export of each sector we receive the **final demand** of each sector. Using the final demand concept we can calculate the following basic economic indicators:

- the national income,
- the gross value added and
- an input-output-table for intersectoral flows of products and resources.

4.3.2 Supply side

The main objective of the supply side is to calculate the **potential output,** which in terms of the calculation method can also be interpreted as the gross domestic output of the economy. To calculate the potential output an extended CES (constant elasticity of scale)-function is used including labour, capital, research and development (R&D), spillover effects and productivity as inputs:

$$PP[t] = c \cdot [(1-\delta) \cdot L[t]^{-\rho} + \delta \cdot K[t]^{-\rho}]^{-\frac{r}{\rho}} \cdot e^{\lambda \cdot t} \cdot (RD[t-k] + SO[t-k])^{\gamma} \qquad (1)$$

with: PP: Potential output per sector
L: Working hours per sector
K: Capital per sector
RD: R&D-Expenditure per sector
SO: Spillover effects of car manufacturing sector
c: constant
δ: distribution parameter
ρ: elasticity of input factors
r: scale elasticity
λ: exogenous technical progress
γ: endogenous technical progress
k: time delay of R&D-Expenditure

The variable **labour** stands for the yearly worked hours. It is based on employment and the number of yearly worked hours of one employee. In general, it is assumed that employment depends mainly on investment and capital[5]. Therefore the relation between employment and capital multiplies capital. Furthermore, the relation between marginal gain of labour and wages are taken into consideration.

The variable **capital stock** depends on the private and public investment, and its depreciation. We assume a fix depreciation rate of about 5%. The increase of technical progress leads to an increase of the depreciation rate. That reflects the fact that product cycles in recent years have always been shortened by the enormous technical development e.g. in the computer industry.

We treat the variable **productivity** by assuming an autonomous development of technical progress. This autonomous increase of productivity is the same for both scenarios. Besides this autonomous development of technical progress, we have to take into consideration that R&D expenditure has an impact on technical progress. Therefore R&D expenditure and spillover effects of the car manufacturing industry are treated separately. The impact of R&D expenditure is derived from historic data.

In EST-80% and EST-50% the e.g. fostering of higher emission standards of transportation for all modes leads to more investigations, innovations and new technologies. Therefore, we derive from both EST scenarios an increase of R&D expenditure and an increase of the rate of technical progress.

5 Evaluating Economic Feasibility of the Environmentally Sustainable Scenarios

5.1 Indicators

To evaluate scenarios we can consider key variables of each model or construct one or more aggregated indicators for all or a set of variables.

Usually in cost-benefit-analysis, scenarios are compared using one monetary indicator of welfare changes. Different quantities like traffic volume or CO_2-emissions are multiplied by transport costs and cost values per emitted ton of CO_2. Using this method we lose many interesting information of important variables. This is the reason why our analysis focuses on the changes of the following key indicators of each model:

- Macroeconomic Model: consumption, investment, final demand, employment, potential output.
- Regional Economic Model: regional employment, regional population.
- Transport Model: traffic volumes for personal travel (urban and non-urban), traffic volumes for freight transport (urban and non-urban).
- Environment Model: CO_2, NO_x, volatile organic compounds (VOC) and particulate matter (PM).

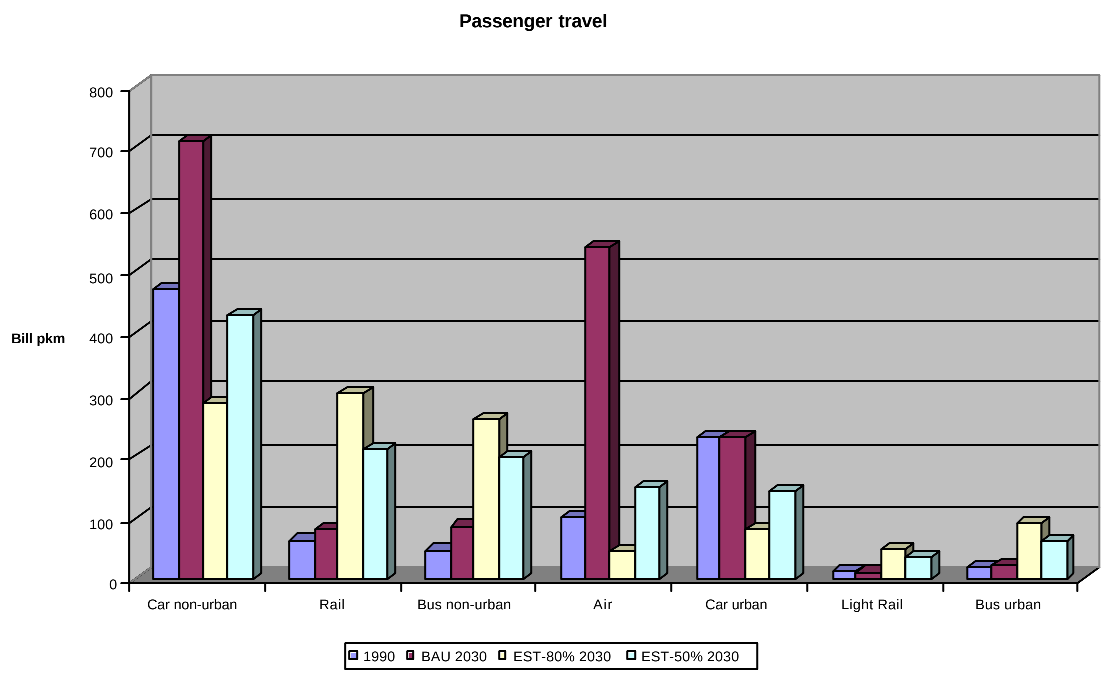
[5] See Keynes (1973), S. 98f.

One major advantage of system dynamics compared to static cost-benefit-analysis is the ability to consider the development path of the indicators instead of only one certain point of time in a scenario. For some variables there may be no dramatic change at the forecasting horizon of different scenarios. But this does not mean that these variables cannot have large differences during the whole simulation period. Because of the different starting and ending points of the policy measures this problem will be strengthened. With ESCOT we can examine all variables during the whole simulation period and can extract variables that show undesirable developments. This makes it possible to vary the magnitude and the schedule of policy measures and enables us to improve the results of EST scenarios.

5.2 Results of the Transport Model

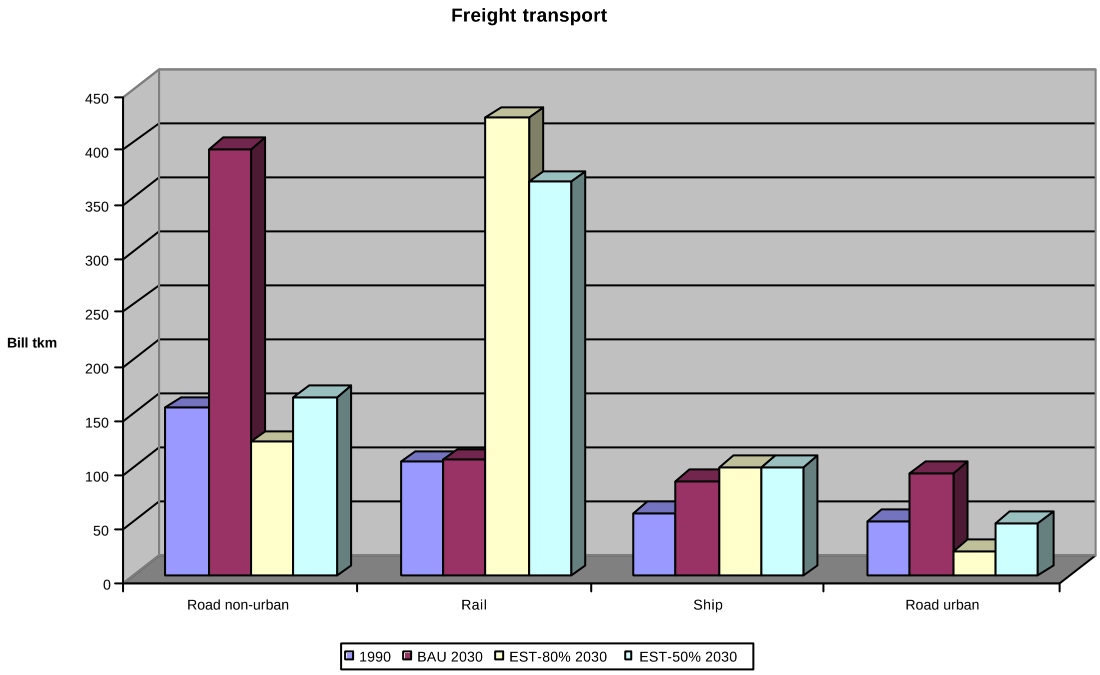
To get a clear understanding of the economic effects to be expected, it is first required to look at the changes of transportation.

Figure 5: Comparison of passenger travel in 1990 and 2030 for BAU, EST-80% and EST-50%



Drastic changes for car travel and air transport are necessary to reach EST-80%. For these two modes we derive a high decrease of passenger-km and a high increase for more environmentally friendly modes. In EST-50%, the amount of passenger-km for car travel and air transport can be held in 2030 at the same level as in the year 1990. The growth of passenger travel is absorbed by environmentally friendlier modes.

Figure 6: Comparison of freight transport for BAU, EST-80% and EST-50%



We recognise the same characteristics for freight transport. For EST-50% in 2030, the amount of ton-km of road transport remains at the same level as in 1990. The growth of freight transport is absorbed by rail and ship transport.

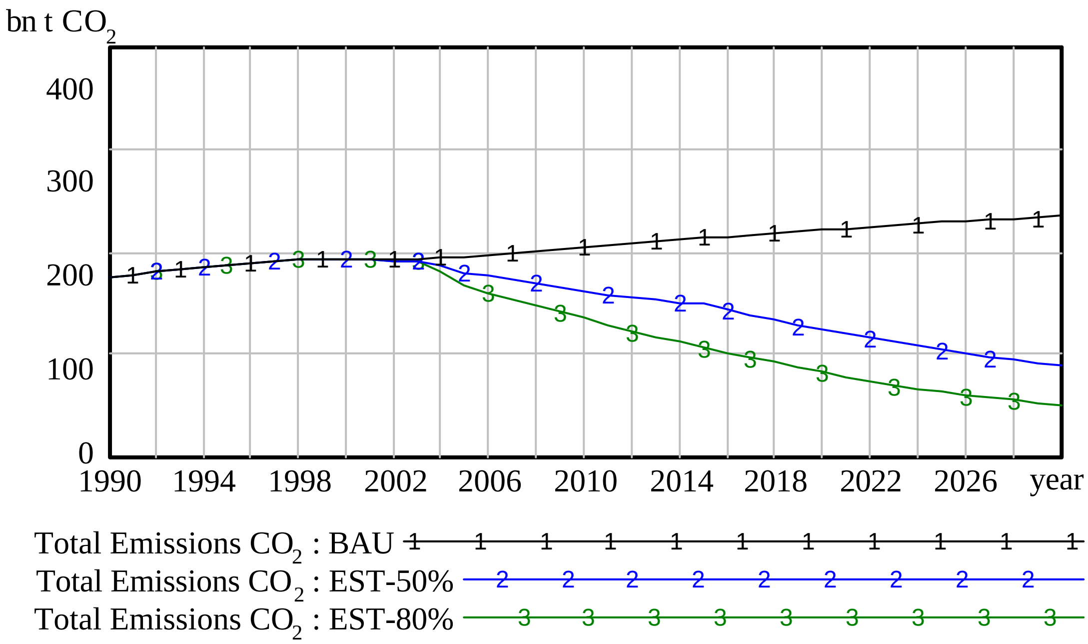
The changes for passenger travel and freight transport are much lower in EST-50% than in EST-80%. This goes further with mode shift effects towards environmentally friendlier modes as in EST-80%. But it is important that the environmentally friendlier modes have to be attractive enough to absorb the growth of transport activity.

5.3 Results of the Environmental Model

Looking at the totals of the EST-80% scenario the envisaged goal of a reduction of CO_2 emissions by 80% could not be reached completely. But with a reduction of more than 72% ESCOT is very close to this goal.

For the EST-50% ESCOT meets the reduction of CO_2 emissions by 50%. A comparison of the development of yearly emissions shows that CO_2 emissions reveal the lowest decrease of the different gaseous emissions.

Figure 7: Yearly transport CO_2 emissions of the scenarios



For NO_x, VOC and PM we observe a high decrease even in the BAU scenario. This encourages the assumption that CO_2 emissions are the most problematic gaseous emission and if the EST scenarios would fulfil the criterion for CO_2 the criteria of other gaseous emissions are also fulfilled.

Table 3: CO_2, NO_x, VOC and PM emissions in percent

Gaseous emission [%, otherwise noted]	1990 in m t	1990	BAU	EST-80%	EST-50%
CO_2	176279	100.0	133.3	50.1	28.4
NOx	1408	100.0	43.1	15.8	6.5
VOC	1447	100.0	4.6	2.2	1.7
PM	43	100.0	20.4	8.0	3.3

5.4 Results of the Macroeconomic Model

5.4.1 Demand side

The results of the simulation for the year 2030 with respect to consumption, investment, government spending, export and final demand of different scenarios are listed in table 4.

Table 4: Results on the demand side

Demand side		Consumption	Investment	Government Spending	Export	Final Demand
Value in year 2030 [bn €]	BAU	1,749	566	716	2,086	5,022
	EST-50%	1,683	575	716	1,997	4,862
	EST-80%	1,653	581	716	1,894	4,718
Difference to BAU [%]	EST-50%	-3.75	1.61	0.00	-4.28	-3.17
	EST-80%	-5.47	2.55	0.00	-9.23	-6.04

We can derive that EST leads to higher values for investment due to an increase of infrastructure investments. In EST the results for consumption and export show a decrease. With more than 5% for consumption and 9% for export the decreases are quite high for EST-80%.

For export changes in EST-50% are minor. The negative effects for exports of automotive products can not be fully compensated by the increase in other sectors. We derive a total negative effect for exports of about 4% compared to 9% for EST-80%.

Overall the results for final demand are with minus 3% for EST-50% moderate compared to 6% for EST-80%.

The development of sectors may be completely different to overall trends. Table 5 shows the development of investing and investment sectors.

Table 5: Results for investing and investment sectors

Sector	BAU 2030 [m €]		EST-50% 2030 [m €]		Difference between EST-50% and BAU [%]	
	Investing Sectors	Investment Sectors	Investing Sectors	Investment Sectors	Investing Sectors	Investment Sectors
Agriculture	20,227	6,913	19,811	6,902	-2.05	-0.17
Coal	3,791	692	3,518	660	-7.20	-4.55
Food	11,370	0	11,295	0	-0.67	-
Textil	2,971	801	2,964	796	-0.23	-0.52
Paper	2,674	4,406	2,603	4,435	-2.63	0.66
Oil	8,909	0	8,490	0	-4.71	-
Pharma	6,398	0	6,300	0	-1.52	-
Chemistry	1,879	0	1,871	0	-0.43	-
Man-made-material	5,303	1,282	5,039	1,253	-4.97	-2.27
Stones	1,191	785	1,191	795	-0.01	1.20
Steel Products	4,711	22,988	4,702	24,479	-0.19	6.48
Machinery	11,973	85,195	11,949	84,460	-0.20	-0.86
Office Equip	321	26,823	321	26,725	-0.08	-0.36
Electric Equip	8,121	22,345	8,224	25,489	1.26	14.07
Information Tech	612	25,529	612	25,111	0.00	-1.64
Measurement Tech	14,056	23,610	13,977	23,577	-0.57	-0.14
Automotive Prod	19,500	55,886	18,584	52,714	-4.69	-5.68
Other Vehicle	4,519	23,391	4,438	20,203	-1.81	-13.63
Other Prod	252	6,573	230	6,565	-8.68	-0.13
Public utility	17,451	20,227	17,892	31,431	2.53	55.39
Building	7,592	149,589	7,578	150,671	-0.19	0.72
Trade	34,462	28,642	32,635	28,230	-5.30	-1.44
Rail Transport Service	8,068	248	32,520	579	303.08	133.00
Road Transport Serv	16,088	8,407	11,817	8,219	-26.55	-2.24
Water Transport Serv	1,326	0	1,519	0	14.56	-
Air Transport Service	10,047	0	2,637	0	-73.75	-
Other Transport Serv	38,896	0	35,404	0	-8.98	-
Information Service	16,439	0	16,014	0	-2.58	-
Banking	22,388	0	22,192	0	-0.87	-
Housing	142,932	3,784	142,256	3,762	-0.47	-0.56
Company Service	29,836	42,771	29,830	42,908	-0.02	0.32
Public Service	90,613	5,442	95,752	5,461	5.67	0.35

The most important investing and investment sectors are coloured light grey. Agriculture, automotive sector and service sectors are the investing sectors with the highest investments. With respect to the investment sectors the manufacturing sectors and company services are the most important ones.

In EST-50% the developments compared to BAU are quite different. We derive a decrease for coal, oil, automotive products, other vehicles, road and air transport services. These sectors loss because of higher transport prices.

On the other hand we derive gains for electric equipments, public utility's, rail transport services, waterway transport services and public services. The investments of these sectors are significant higher than in BAU.

With respect to the investment producing sectors ESCOT generates a slightly different picture. Besides rail transport services and public utility's the steel and electricity equipment sector increase. This increase is caused by orders of the rail transport services.

5.4.2 Supply side

The results on the supply side are listed in Table 6. In EST capital reaches a slightly higher level than BAU. The simulation shows a plus of more than 1%. For capital stock the higher amount of investment balances out the abridged depreciation of capital in the vehicle production sectors.

In EST employment reaches nearly the same level than in BAU at the end of the simulation period (EST-50% with plus 64 000 jobs in the year 2030). The same can be said for potential output. The best scenario is the EST-50% with an increase of 0.68%.

Table 6: Results of the supply side

Supply side		Capital [bn €]	Employment [Tsd Pers.]	R&D [m €]	Potential output [bn €]
Value in year 2030	BAU	10,191	39,850	55,221	6,313
	EST-50%	10,293	39,914	57,974	6,356
	EST-80%	10,377	39,952	56,658	6,339
Difference to BAU [%]	EST-50%	1.01	0.16	4.99	0.68
	EST-80%	1.83	0.25	2.60	0.41

In general these positive results on the supply side depend on the increase of productivity. The productivity increases in the EST-50% scenario by nearly 5% (2.6% for EST-80%). This increase of productivity depends itself on the enforced emission regulation that encourages research and development in the vehicle production industries and the energy supply industries. For non-transport sectors the productivity depends on the potential output.

Table 7 shows the results for capital and employment on the sector level. We can identify a similar picture compared to the demand side. We find an increase for the sectors railway and waterway transport services. But also the other vehicle sector that construct rail vehicles shows a better development than in BAU.

Table 7: Sector capital and sector employment in BAU and EST-50%

Sector	BAU 2030		EST-50% 2030		Difference between EST-50% and BAU	
	Capital [m €]	Employment [Tsd Pers.]	Capital [m €]	Employment [Tsd Pers.]	Capital [%]	Employment [%]
Agriculture	378,025	706	374,415	701	-0.95	-0.72
Coal	69,853	14	67,585	14	-3.25	-1.86
Food	209,728	199	209,201	199	-0.25	-0.22
Textil	59,934	564	59,885	564	-0.08	0.00
Paper	67,018	152	66,514	152	-0.75	-0.27
Oil	120,452	13	118,065	13	-1.98	-1.64
Pharma	80,882	590	80,015	584	-1.07	-0.98
Chemistry	57,154	67	57,090	66	-0.11	-0.96
Man-made-material	84,267	326	81,330	315	-3.48	-3.43
Stones	38,027	58	38,027	58	0.00	-0.03
Steel Products	110,304	528	110,231	527	-0.07	-0.33
Machinery	227,596	489	227,409	487	-0.08	-0.49
Office Equip	17,655	41	17,654	41	-0.01	-0.38
Electric Equip	133,598	530	134,169	527	0.43	-0.44
Information Tech	14,810	31	14,810	31	0.00	-0.18
Measurement Tech	207,795	266	207,180	266	-0.30	-0.10
Automotive Prod	313,375	301	214,682	237	-31.49	-21.15
Other Vehicle	78,178	60	129,152	102	65.20	70.52
Other Prod	8,437	15	8,276	15	-1.90	-2.13
Public utility	321,714	582	324,281	583	0.80	0.13
Building	172,171	3,343	172,065	3,344	-0.06	0.02
Trade	600,085	7,173	584,780	7,104	-2.55	-0.96
Rail Transport Service	173,677	496	576,656	660	232.03	33.08
Road Transport Serv	333,810	548	168,995	507	-49.37	-7.47
Water Transport Serv	26,622	74	28,278	77	6.22	4.84
Air Transport Service	125,991	34	59,852	18	-52.50	-47.84
Other Transport Serv	566,941	335	534,424	334	-5.74	-0.49
Information Service	288,719	600	286,028	600	-0.93	-0.07
Banking	374,112	1,216	372,832	1,215	-0.34	0.00
Housing	2,792,578	732	2,785,578	729	-0.25	-0.45
Company Service	499,209	3,890	498,287	3,884	-0.18	-0.16
Public Service	1,637,810	15,875	1,685,743	15,960	2.93	0.54

Altogether, the EST-50% scenario shows that environmental policy can have positive impacts on the economy if it actively makes use of flexible market adjustments without overstressing them. In order to develop such environmental policies the weight between technical policy measures and pricing policy measures and of course the positive economic effects caused by fostered productivity must be taken into consideration.

6 Conclusions

For EST-80% the results of the System Dynamics Model ESCOT clearly show that the departure from car and road freight orientated transport policy is far away from leading to an economic breakdown. The effects concerning economic indices are rather minor, even though the measures proposed in the EST-80% scenario designate distinct changes compared to today's transport policy. The impact on consumption and export, however, is clearly negative because of decreasing output in selected economic sectors.

For the EST-50% scenario that expanded the time period for changes in order to decrease the speed of change and to give more room to compensating mechanisms we observed more encouraging results. Although consumption and export level are still lower than expected in BAU, this effect is fully compensated by increased productivity, and the total of potential output is slightly positive. So the EST-50% scenario shows that environmental policy can have positive impacts on the economy if it actively makes use of flexible market adjustments without overstressing them. In order to develop such environmental policies the trade-off between technical policy measures and pricing policy measures and of course the positive economic effects caused by higher productivity of production activities must be taken into account.

For the assessment of such large system changes we have to consider the development of population, the way of living and housing, consumption and other macroeconomic data. In addition, the period of time for the scenarios covers 40 years. This long period of time and the complexity of the scenarios cause many difficulties for assessment. System Dynamics models like ESCOT are constructed to describe complex social and economic systems. They do not only stick with the first round effects that are in case of a path towards sustainability mostly governed by negative influences like higher prices and restrictions on the demand side. ESCOT offers the opportunity to postulate the macroeconomic development, considering also structural changes, including secondary effects that occur only in the long run. Secondary effects arise because transport is highly interrelated with other social systems such that a policy measure like charges for one mode causes a first round effect, that is a decrease in demand for this mode, but also secondary effects e.g. technological changes for other modes because of increased demand for these modes, changes in state revenues or private consumption. This ability makes ESCOT a powerful instrument for the assessment of such large ecological and economic changes.

7 References

Forrester, J. W. (1968): Principles of Systems, Cambridge, Massachusetts.

Forrester, J. W. (1972): Grundzüge der Systemtheorie, Wiesbaden.

Milling, P. (1984): System Dynamics: Konzeption und Anwendung einer Systemtheorie paper in economical sciences at the University of Osnabrück, Osnabrück.

Kuchenbecker, K. (1998): Strategische Prognose und Bewertung von Verkehrsentwicklungen mit System Dynamics, Universität Karlsruhe, Karlsruhe.

OECD (1996): Environmental Criteria for Sustainable Transport: Report on Phase 1 of the Project on Environmentally Sustainable Transport (EST), Paris.

OECD (1998): Scenarios for Environmentally Sustainable Transport: Report on Phase 2 of the Project on Environmentally Sustainable Transport (EST), Paris.

Oum, T.H.; Waters, W.G.; Young, J-S. (1992): Concepts of Price Elasticities of Transport Demand and Recent Empirical Estimates, Journal of Transport Economics and Policy, pp. 139-154.

Renes G.; Schade W.; Burgess A.; Tavasszy L.A.; Rustenburg M. (2004): "Consolidated results of case studies in transport project assessment", Deliverable D8 of IASON (Integrated Appraisal of Spatial economic and Network effects of transport investments and policies) project funded by the European Commission 5th RTD framework, Delft, Karlsruhe.

Schade, B.; Rothengatter, W. und Schade, W. (2002): Strategien und Maßnahmen für eine dauerhaft umweltgerechte Verkehrsentwicklung. Bewertung der Strategien und Maßnahmen für eine dauerhaft umweltgerechte Verkehrsentwicklung mit dem System Dynamic Modell ESCOT (Economic assessment of Sustainability poliCies Of Transport). F + E Vorhaben im Auftrag des Umweltbundesamtes FKZ 298 96 108. Umweltbundesamt, Berlin.

Schade, B.; Rothengatter, W. (2004): The Economic Impact of Environmentally Sustainable Transport in Germany. European Journal of Transport and Infrastructure Research, 4, no. 1, pp. 147-172.

Schade, W. (2004): "Assessing direct or indirect benefits of transport? - Comparing benefits of transport policies within the transport market versus within other markets with the ASTRA model", paper presented at the 10th World Conference on Transport Research 2004 (WCTR 2004), Istanbul.

Schade, W.; Rothengatter, W. (1999): Long-term Assessment of Transport Policies to Achieve Sustainability, paper presented at the 4th European System Science Conference in Valencia, Proceedings, Valencia.

Sterman J.D. (2000): "Systems Thinking and Modeling for a Complex World", Irwin McGraw-Hill, Boston.Umweltbundesamt (1994): Verminderung der Luft- und Lärmbelastungen im Güterfernverkehr 2010, Umweltbundesamt, Berlin.

Umweltbundesamt; Wuppertal Institute (1997): OECD Project on Environmentally Sustainable Transport (EST) Phase 2, German Case-Study, Berlin.

Umweltbundesamt; IWW (2000): OECD Project on Environmentally Sustainable Transport (EST) Phase 3, German Case-Study, Berlin.

Wardman (1997): Disaggregate Inter-Urban Mode Choice, Institute for Transport Studies, Leeds.