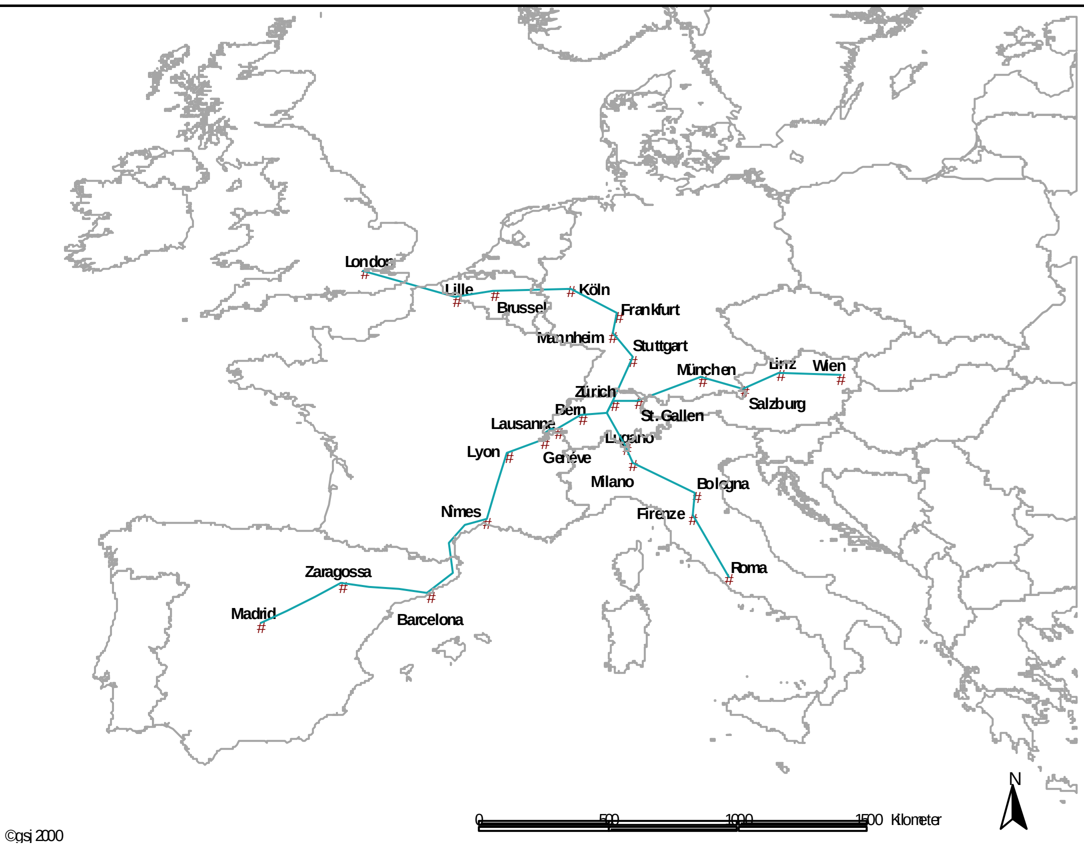

Energy- and Environmental Assessment of EUROMETRO

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Abstract

A Eurometro- system based on Swissmetro technology could provide a ecological alternative to flying over distances of about 1000 km. This is the core result of an extensive study into the energy and environmental assessment of an underground maglev in Europe.

Despite some uncertainties, the following conclusions can be made: An ecologically and energy optimised Eurometro high-speed system could achieve an efficiency gain by the factor 5 to 10 over short and medium distances in comparison with today's air traffic.

In comparison with railway systems such as ICE or TGV, half the energy for operation, and about the same amount for the infrastructure, should be achievable.

Energy demand and greenhouse gas emissions arising from the construction of the infrastructure will account for about half of the total energy demand.

The study also investigates the impact of different technical assumptions of an "Eurometro"-system: It shows the demand, the travel speed and the mix of power generation have the largest influence on the results.

Further research remains to be done to provide better understanding of the future demand depending on mode shift from car- and train- traffic and additional Mobility generated and its impact on the ecological performance of the system.

Keywords

High speed traffic – Air traffic – Eurometro – Maglev - Climate Change – Energy – Environmental Assessment – Demand – Transport Concept – Swiss Transport Research Conference – STRC 2001 – Monte Verità

1. Objectives and Concerns

"For an integrated, sustainable global transport policy of the future, further essential information is required which must be supplied by research."

M. Leuenberger, Minister of Environment, Transport, Energy and Communications, NFP41-Portrait

This research aims at dealing with an issue concerning an integrated, sustainable transport policy that previously has been only marginally discussed and evaluated in research: **High Speed Transport (HST)**. It seeks to drive the attention to the potential critical impact of high speed traffic from the energetic and ecological perspective – and provide a first input for discussions whether new and innovative technology developed in Switzerland could provide a feasible technical alternative to long distance traffic, especially to the rapidly growing air traffic.

1.1 Why assess a Eurometro System?

Europe is growing closer, politically and economically - and it's in the process of expanding, especially to the East. Powerful communications and transport infrastructures are very important elements of a development towards economic and social stability. But how can these important networks and their technologies be further developed in order to make them ecologically sustainable?

The strong growth in the areas of transport and mobility has resulted in a critically increased burden on the environment. After decades characterised by the increase in car traffic, high speed-, respectively **air- traffic** - with it's much higher rate of growth **- is rapidly gaining ecological importance**. Particularly short haul air traffic, results in high specific energy consumption as well as local air and noise pollution. Therefore, as further documented in the next section, new, ecologically more efficient high speed traffic- systems for Europe should be considered and evaluated.

Modern high-speed railway systems (such as TGV and ICE) already play a major role as an efficient alternative to short-haul air transport with journey times of approx. 3 hours. However, the switching or migration potential within Europe that might be achievable by developing the HST railway network is limited. A COST study [COST 1998] concludes that for travel times of more than 3 to 4 hours, the migration potential is significantly reduced. Furthermore new high speed ground-level rail systems can cause additional problems in the fields of noise pollution and damage to the landscape.

For about two decades, scientists and engineers at **EPF Lausanne,** with support from experts of other research institutes and from industry, have been engaged in the development of a new high-speed transport system. This environmentally friendly technology is based on an **underground magnetic railway system**, running **inside tunnels with partial vacuum** and should become a "Swissmetro". However, it could also be implemented as a "Eurometro" system in the foreseeable future. This technology could achieve speeds of 300 to 500 kilometres (200 to 300 miles) per hour, a speed level which comes close to the lower range of short-haul air traffic. However, this underground High Speed Transport (HST)- System could run **largely without noise pollution or direct exhaust emissions and negative impact on the landscape**.

Thus "Eurometro" could become part of a long-term transport policy aiming at higher sustainability in the high speed and long distance traffic. If well interconnected with the local, regional and international public transport system it could also become a more attractive alternative for long distance car travellers.

A Eurometro-System should therefore be implemented step-by-step, integrated as much as possible into existing and future HST infrastructures and connect major economic centres (e.g. alongside the corridors Rome-Frankfurt or Madrid-Zurich-Vienna). It could also **not only link, but integrate Switzerland to a European HST network**, despite its difficult topographical conditions.

Although conceivable, a political approach to solve the problems of noise pollution and exhaust emissions by reducing demand or performance of high-speed transport sufficiently through legislative measures, seems rather questionable in view of today's political and economic environment. Therefore, innovative approaches to a solution of these problems need to be developed and thoroughly evaluated.

1.2 Air traffic – a new Challenge to Climate Protection?

Despite the successful efforts of aircraft manufacturers and airlines to improve their environmental efficiency, fuel sales and with it **air fuel** consumption in Switzerland increased by 40 per cent between 1989 and 1999 and has doubled since 1980. In 2000, air fuel sales reached **about one quarter of the overall fuel consumption in Switzerland**.

The demand for **air transport** is expected to continue to grow strongly, driven by such factors as the deregulation of air transport, **globalisation** of industries, and increased leisure time mobility. For the next decade, forecasts from major corporations such as Airbus Industry project **annual growth rates in air traffic of approximately 5 per cent**. Taking the ongoing measures for efficiency improvements, the increase of fuel consumption, based on the Airbus forecast, can be expected to increase annually by about 3 to 4 per cent. However, despite all efforts to reduce kerosene consumption, **CO_2-emissions from air traffic could double again in some 20 years.** Furthermore, latest research results in the field of climate protection [IPCC 1999] indicate that aircraft exhaust emissions at great heights may have a 2 to 4 times higher greenhouse potential than ground-level emissions by cars.

A special study on air traffic within the NFP41-program "Air traffic: a growing environmental problem", [Kaufmann et al. 2000] shows, that the CO2 emissions by Swiss residents on regular and charter flights, and freight transport, amounted to over 6 million tons in 1999, i.e. about one ton per person and year. They account for over 13 percent of overall Swiss CO2 emissions (45 million tons in 1998). Using climate relevant Global Warming Potential (GWP) as a standard (CH 1998: ca. 54 million tons CO2 equivalents) and assigning factor 2 to climate relevant flight emissions, **air traffic accounts for** a good **22 percent of Switzerland's Global Warming Potential**. Should air traffic of residents double by 2020 air traffic volume will have passed from approximately 24% to a good 40% of overall transport volume. Ongoing evaluations further indicate that, based on this growth scenario, all or most of the expected **savings form the Swiss CO_2 legislation** (in the areas of industrial production, households and other means of transport) would be **compensated by the additional emissions from air traffic**. Nevertheless, the Kyoto Protocol and CO_2 legislation both have **excluded** international **air traffic** from obligations for emission reductions.

A sustainable transport policy as well as **climate protection** have become important topics on national and international political agendas over the past two decades. If they are meant to seriously deal with our present and future environmental and transportation problems, they will have to recognize the raising importance of high speed and air traffic.

Research efforts therefore have to try to increase the awareness of the ecological relevance of this traffic sector and evaluate the technical potential of a new HST- System to help to develop an more sustainable medium and long distance transport system in Europe – and integrate Switzerland into it.

2. Concerns and Research to Date

2.1 Is Eurometro more efficient than short-haul flights?

Within this study the following **questions** have been researched in more detail particularly:

– Can a Europe-wide high-speed railway (Eurometro), based on Swissmetro technology, be realized? How could it supplement the European high-speed transport systems in order to make them superior to today's high-speed trains and to air transport with regard to energy consumption and environmental issues?
– What are the most important factors influencing the consumption of energy and resources, and the relevant emissions into the environment?

The original concerns were expressed based on the facts available at the time of project submission in the spring of 1998. Based on new findings in the course of the research project's progress a significant shift of emphasis resulted. Therefore, research was focused on the relevant aspects regarding Eurometro's energy consumption and ecological efficiency. The intended in-depth estimation of demand, and the related evaluation of various types of networks proved to be a particular problem.

2.2 What has been researched so far?

The present study and its results are a further step in an ongoing research-process of developing a new technology for high speed transport. In a first stage of the project various studies on energy and environmental efficiency based on existing findings of the main study of Swissmetro, and the licence application for SWISSMETRO SA were carried out at the HTA Burgdorf. The study „Energiebilanz Eurometro" (Energy Assessment Eurometro) [TROTTMANN ET AL. 1998] developed an energy model for a Eurometro system relating to two model tracks and based on "Ecological Assessment Swissmetro" [MINGOT ET AL., 1997] and works from EPF Lausanne, in particular by RUDOLF [1997]. „Ökobilanz Eurometro. Vergleich Eurometro – Kurzstreckenflugzeug" (Life Cycle Assessment of a Eurometro. A Comparison of Eurometro vs. Short-Haul Aircraft) by LEUENBERGER ET AL. [1998] developed the ecological inventory for a series of operating variants based on "Ökobilanz Eurometro" and "Energiebilanz Eurometro" (see above), and compared them using several evaluation methods.

During the second project stage a study on a conceivable "Energy Supply for Eurometro" [KRÄUPL ET AL. 1999] was worked out at the HTA Burgdorf. It also examined the model for "Energy Assessment of Eurometro" within the framework of a **sensitivity analysis**. Based on these research results and the above-mentioned principles **a relevance matrix on ecological sustainability factors** for the Eurometro system [GEISEL 1999] was prepared at the HTA Biel/Bienne.

The researchers themselves, as well as experts, then queried the basic data and certain assumptions. For this reason, during the last project stage the operational energy requirements of a Eurometro system were recalculated with the assistance of EPF Lausanne, based on the updated knowledge. These new data, however, are partially derived from model simulations. However, new aerodynamic trial equipment, of the "HISTAR"-project, should significantly increase the quality of data for the calculation of the operational energy requirement. Despite assistance from EPF Lausanne, no fundamentally traceable calculation methods for the assessment of energy and ecological aspects of other HGV systems were accessible. In addition, new basic data of an updated and revised ecological assessment of Swissmetro, to be supplied by ETH Zurich, had not been available in due time.

It was then sought to recalculate the demand in an initially more simplified format, with new approaches for a primarily demand-orientated Eurometro network. It was not possible, however, to check the results of these calculations by means of additional basic data and model approaches. Also, the newly defined and examined network is only partly identical with the network used for previous research. Therefore the validity of demand data are limited to a scale. They remain parameters that need to be refined through additional future clarification.

Due to these uncertainties, and limited time and human resources, it was agreed with the NFP41 programme management to abandon an updated ecological assessment. Another reason for this decision was that, in view of the currently available data, no significant consolidation of results compared to the ecological assessments presented by MINGOT ET AL. [1997] and LEUENBERGER ET AL. [1998] could be expected.

Instead, updated results based on the latest basic data of the energy consumption and the greenhouse effect for the previously researched tracks Rome-Frankfurt were recalculated. The calculations were performed using two demand variants at the upper and lower end of the demand interval to be expected from previous and new examinations. They show that, despite the uncertainties mentioned above and some basic data remaining unchanged, the present **scope of efficiency gains to be expected with regard to energy consumption and ecology remain valid**.

3. Results and Conclusions

The following section summarises the most important findings of the research work of the NRP41 project F6: «Energy and environmental assessment of Eurometro» [Ernst et al. 2000, p. 11ff] carried out to date. They resulted from analysing impact factors within the sensitivity analysis of the energy and environmental assessment.

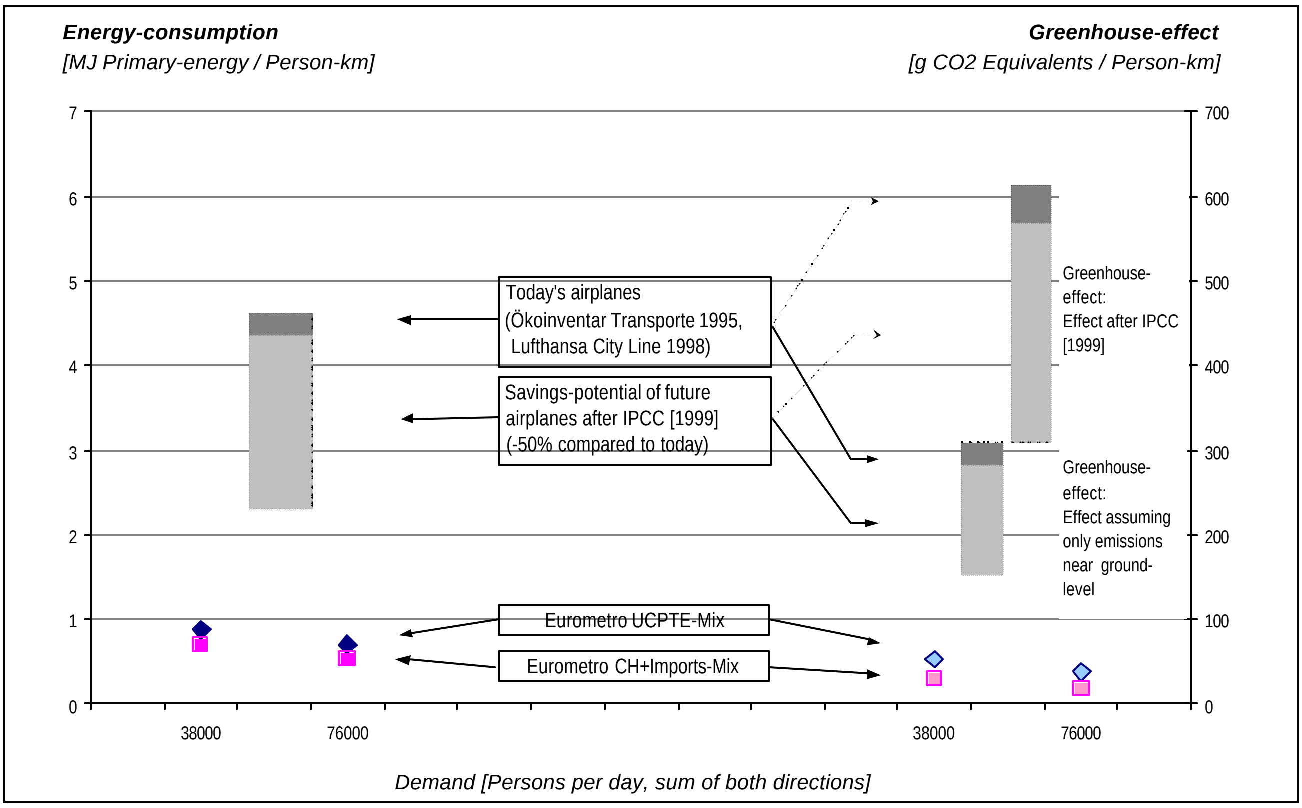
3.1 Comparison of air traffic with high-speed rail systems

Figure 1 illustrates a comparison of Eurometro with air traffic on an assumed pilot route, Frankfurt-Rome, for two demand variants, based on analyses and results that are stated further down in the text.

The graph shows that with today's state-of-the-art technologies a high-speed system with optimum energy and ecological features based on the Swissmetro technology would be feasible and enable an efficiency increase by a factor of 5 to 10 compared to today's air traffic. This is particularly true with regard to the indicated greenhouse effect, respectively the Global warming Potential (GWP) of air traffic. [IPPC 1999, S. 8,9] estimates and uses in all scenarios an "overall radiative forcing by aircraft (excluding that from changes in cirrus clouds) … a factor 2 to 4 larger than the forcing by aircraft carbon dioxide alone." Therefore the figure shows a comparison assuming only the greenhouse effect of carbon dioxide emissions by aircraft as well as assuming a total greenhouse effect by aircraft twice that amount.

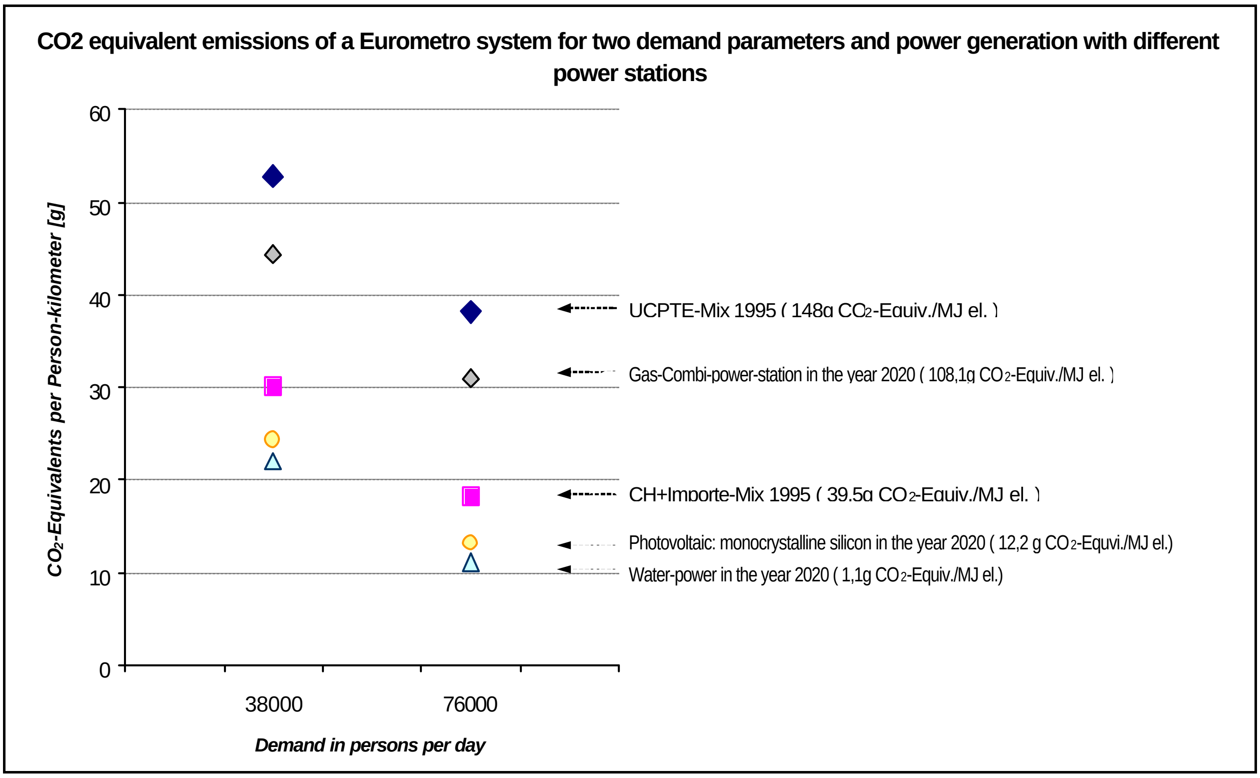
Even with noticeably increased air traffic efficiency (the graph assumes a 50 per cent reduction of the average fuel consumption of new aircraft for the year 2050 compared to today [IPPC 1999, p. 224]) or a possible increase of energy demand for Eurometro due to the above-mentioned uncertainties, significant efficiency gains should be possible.

Fig. 1 Comparison between energy consumption and CO_2 emissions respectively potential greenhouse effects, of a Eurometro system in the expected range for 2 demand parameters versus short-haul air traffic, OWN CALCULATIONS: GREY ENERGY: [LEUENBERGER ET AL. 1998], OPERATING ELECTRIC ENERGY: CASSAT ET AL. [2000] AND LEUENBERGER [ERNST ET AL. 2000, APPENDIX B], other sources: INFRAS [1995], LUFTHANSA [1999]. Source: ERNST ET AL [2000, P. 68]



The following figure 2 shows that, apart from passenger demand, the method of power generation in particular would be of critical importance for the actual energy and ecological efficiency gains in comparison with air traffic.

Fig. 2 CO_2 equivalent emissions of a Eurometro system for two demand parameters and power generation with different types of power stations, OWN CALCULATIONS: GREY ENERGY: [LEUENBERGER ET AL. 1998], ELECTRIC OPERATING ENERGY: CASSAT ET AL. [2000] AND LEUENBERGER [ERNST ET AL. 2000, APPENDIX B]; PSI [2000]. Source: ERNST ET AL [2000, P. 69]



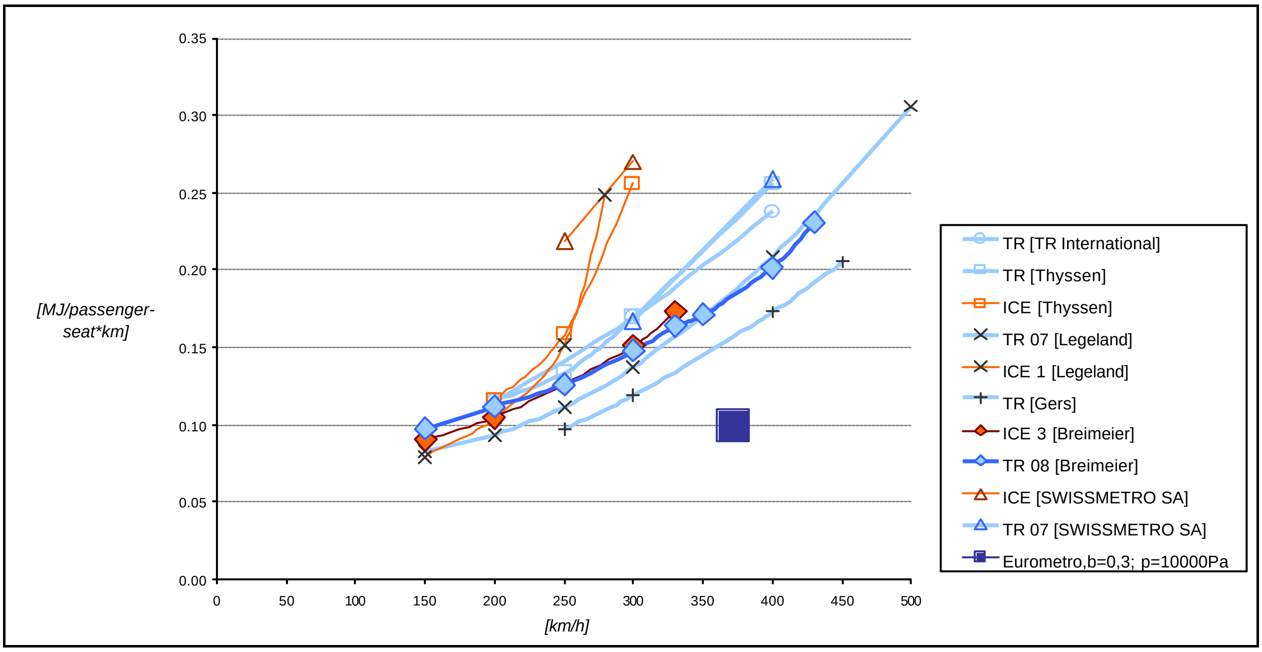
The possibility of the direct supply of electrical energy generated by environment-friendly power stations, in combination with energy efficient underground operation in tunnels with partial vacuum, would give Eurometro, respectively all electrified rail systems, another critical technical advantage. As explained in more detail in Section 3.2.4, because of the very low operating electrical energy demand of ca. 0.2 MJ per passenger kilometre (pkm) it should be possible to purchase energy generated in environment-friendly power stations on a deregulated European electrical power market.

Regarding air traffic IPCC [1999, p. 10] states that "There would not appear to be any practical alternatives to kerosene-based fuels for commercial aircraft for the next several decades." Even using fuel derived from sustainable energy sources the overall efficiency ratio would be significantly lower. In addition to that, it has to be considered that fuel is a major part of the take-off weight of aircraft.

Further ongoing research efforts should continuously put these results on a better foundation. It can be expected, for example, that in the foreseeable future the number of uncertainty factors for calculating energy demands for rolling stock can be reduced through current empirical investigations at EPF Lausanne. The new test equipment "HISTAR" is expected to deliver first empirically derived data for the validation and improvement of existing simulation models in 2001.

Due to the lack of secure basic data, comparisons with ground-level high-speed rail systems have been only marginal. German Rail also pointed out this problem in its publication 'Mobilitätsbilanz für Personen und Güter" (Mobility Assessment for Passengers and Goods) [DEUTSCHE BAHN 1999, p. 299]: "… to date no assessment based on scientific data about the impact of transport infrastructure on the environment is available in Germany." Despite this, previous research has shown that regarding the operating energy consumption compared to ground-level high-speed railways an efficiency gain of about a factor 2 or more should be possible.

Fig. 3 Secondary (electric operation) energy consumption of different high-speed means of transport in MJ per passenger seat kilometre, i.e. a nominal capacity utilisation of 100 per cent, depending on speed, according to: TRANSRAPID INTERNATIONAL [2000], THYSSEN [2000], LEGELAND [1998], GERS [1997, p. 9], BREIMEIER [1998], CASSAT ET AL. [2000] AND LEUENBERGER [ERNST ET AL. 2000, APPENDIX B]. Source: ERNST ET AL [2000, P. 40]



With regard to the demand for indirect, grey energy it was found that modern high-speed railways in topographically difficult or densely populated areas besides tunnels require much energy and resource-intensive construction of artificial buildings such as bridges or dams. Because of the smaller tunnel diameter of the Eurometro technology the required excavation volume of a tunnel section could be reduced by a factor of 3 to 4 compared to ground-level high speed transport technologies. With increasing topographical difficulty, or dense population of an area, the grey energy and construction demand as well as cost of a Eurometro should not be much above or even equal that of ground-level systems.

3.2 The most influential factors for the energy and environmental assessment

3.2.1 Demand, network and development variants

Research in this area proved to be very demanding and complex. It showed that hardly any basic data and calculation models on a Europe-wide high-speed transport system are available that could be used in an applied sciences approach. Furthermore, with today's simulation models, the demand for a new transport carrier at a European level cannot be demonstrated. Work initiated during the final phase of the F6-project provided important results for future research work with regard to basic data and the application of different model approaches. Despite assistance from transport experts involved in the NFP41 programme, the work carried out so far has only provided approximate simulation results. These need to be validated in further research work by means of better data on actual traffic volumes. The existing results of initial and greatly simplified models show, for example, less demand than determined by in-depth research within the NFP41 project F1: "Nachfrageabschätzung für Swissmetro" (Demand Estimates for Swissmetro) [Abay, 1999].

Consolidation and investigations indicated that:

– Basic data available today on border-crossing traffic in Europe are very heterogeneous, with partial deviations of a factor above 2. No uniform method of data capturing (standardisation) exists on a European or global scale.

– Forecasts extrapolated up to the year 2020 for the increase of traffic volumes to be expected, the development of travelling costs and the impact of migration between transport carriers as well as the induced new transport systems, suffer from major uncertainties.
– In addition to important technical aspects such as network development, integration into existing networks, travelling speed and comfort, non-technical factors such as economic development, political decisions (e.g. concerning climate and noise protection) and the consideration of so-called “external costs” can be expected to become highly relevant.
– The up to now rather conservative estimate of the demand indicated that average values should at least reach the lower limit of the estimated demand assumed by the energy assessment.

3.2.2 Speed

According to various research work carried out by the COST 318 study, the average travelling speed would be a critical factor with regard to the “migration range” of Eurometro. The migration range is the maximum distance where passengers are prepared to migrate from airplane to a new high-speed train.

At the same time, travelling and top speeds determine the operating energy consumption and the required driving power of the system as well as, due to the impact on travel time, the energy required for the hovering and guiding of the vehicles.

The required driving energy is indirectly linked to the speed by factors such as free tunnel space respectively tunnel diameter, number of cross vents, tunnel and vehicle surface or vehicle shape. The same applies to the energy demand for hovering and guiding, which is proportional to the operating time of vehicles. Operating times depend not only on speed but also on the distance between stations and the time vehicles stop at stations.

As already stated, there are still a number of uncertainties present in these areas that will have to be explored empirically and determined by means of the planned HISTAR experiments.

3.2.3 Tunnel diameter

The tunnel diameter has a major direct and indirect impact on energy and ecological assessments: a larger diameter increases grey energy and other resource demands for the tunnel infrastructure. At the same time though it reduces the blocking factor β and therefore the aerodynamic drag of the vehicles and the energy demand for the propulsion of the vehicles.

The sensitivity analysis for the sample route Rome-Frankfurt showed that the sum of the overall energy demand for constructing and operating the system has its lowest value at the largest tunnel diameter. The most important reasons for this result are:

– Changing the blocking factor β has (according to present calculation models) an impact to the power of 3 on the energy demand for a Eurometro or SWISSMETRO vehicle.
– The energy demand curve for the construction of larger or smaller tunnel diameters, on the other hand, changes less steep.

3.2.4 Generation of operating power

So far, research has shown that the process for generating the operating energy for SWISSMETRO/Eurometro has a very strong impact on the ecological assessment respectively the environmental effects.

Two variants could generally be conceivable to obtain environmentally-friendly generated energy for Eurometro:

1. The operator of Eurometro focuses on purchasing of environment-friendly and resource-saving generated energy from the deregulated electricity market. The European market should be capable of supplying sufficient amounts of energy, since the demand of a Eurometro system, even after further extensions, would be in the range of some thousandth of Europe’s total energy consumption.
2. The operator of Eurometro constructs not only the magnetic-rail infrastructure, but also power plants for generating environment-friendly and resource-saving electricity.

Besides the direct, positive impact on the energy and ecological efficiency of a Eurometro system, both variants would also have positive effects on the generation-mix of electricity in the European market.

3.2.5 Ground-level and underground tracks

Currently no reliable data are available for a detailed comparison of the consumption of energy and resources between a Eurometro system and modern high-speed trains, in particular with regard to indirect, grey energy consumption. Research has shown so far that a magnetic rail system at ground level, such as the German Transrapid or the Japanese MAGLEV, would presumably achieve gradients of ca. 4 per cent with an intended speed of above 400 km/hr (250 miles/hr), as is the case with today's high speed tracks either in operation or under construction. Therefore constructing the tracks for magnetic-rail systems should result in similar landscape changes, bridge and tunnel construction as with the equivalent new tracks for modern rail systems such as TGV or ICE. This applies to track sections in topographically demanding areas as well as in densely populated areas. This assumption has been confirmed by the Japanese MAGLEV test track operated in a densely populated and mountainous area: more than 80% run through tunnels.

In comparison with the cross section of existing HST tunnel tracks, a Eurometro system operated at 400 km/h has a significantly lower tunnel cross section than ground-level HST systems without partial vacuum. Therefore, the excavation volume per unit of tunnel length for a Eurometro system should be three to four times lower than that for the required tunnels of ground-level HST systems. If an HST or Transrapid system requires 30 per cent tunnelling over a given distance the construction requirements for a Eurometro system should be in the same range as for a ground-level HST system. This should especially be the case if additional construction work for bridges and embankments is required for a ground-level HST system over longer stretches of the track as it is the case at the new French TGV Méditerranée line opening in 2001.

3.2.6 Weight of vehicles

Besides aerodynamic parameters the weight respectively the mass of the vehicles also has an impact on the energy demand and in particular on the power consumption of a Eurometro system. The following values increase in proportion with the vehicle mass:

– the vehicles' kinetic energy. It can only partly be fed back into the electric grid during the deceleration before the stations;
– the energy needed for hovering and guiding the vehicles;
– the energy and vehicle power needed for accelerating the vehicles.

From today's viewpoint, SWISSMETRO's assumption of a vehicle's empty weight of 150 kgs per passenger seat appears to be very optimistic, since today's high-speed magnetic-rail systems in Germany and Japan have three to four times that weight. On the other though, the empty weight of modern passenger aircraft of 225 to 300 kg per passenger seat is only one and a half or twice that of SWISSMETRO's intended weight ratio of 150kg.

However, it appears to be sensible to clarify whether a Eurometro system with significantly longer travelling times compared to Swissmetro would not have to provide higher standards of comfort such as more seating and luggage space, restaurants and working compartments. The relevant adaptations are likely to increase the average empty weight ratio per passenger seat.

In addition, possibilities should be investigated on how to reduce the energy demand for hovering and guiding, which is, among other effects, directly proportional to the weight. Current simulations of Eurometro vehicles' aerodynamic drag at EPF Lausanne, show that the proportion of the energy demand required for hovering and guiding is similar or even higher than that for propelling the vehicles. One approach to reduce this demand could be the employment of permanent magnets that could lead to a reduction in the number of electromagnets for hovering and guiding.

3.2.7 Partial vacuum

According to currently available sources [SWISSMETRO, 1997-C3, p. 10] the aerodynamic drag of SWISSMETRO/Eurometro vehicles is directly proportional to the pressure level within the tunnels, keeping blocking factors and speeds at a fixed value. The energy calculations carried out by CASSAT [1997] are based on a value of 10,000 pa. Reducing this value to the intended level of 8,000 pa in the licence application the aerodynamic drag and with it the propelling energy demand could be reduced by 20 per cent.

3.2.8 Length of rolling stock

First research results provided by RUDOLF [1997] on the impact of the vehicles' length on aerodynamic drag showed a slightly under-proportional increase of energy consumption with increased vehicle length.

At the beginning of the year 2000 up-to-date results from a new simulation model of the EPF Lausanne now show a rather more linear relation between vehicle length and aerodynamic drag. These results prove once more the importance of empirical aerodynamic tests with the HISTAR equipment for the consolidation and validation of reference values as well as for the optimum technical design of a Eurometro system.

3.2.9 Operating infrastructure

According to the up to now calculated energy and ecological assessments, the operation of the infrastructure would have about a quarter of the energy demand for the overall operation.For a Eurometro system, presumably lower values in comparison with the SWISSMETRO pilot track could be expected:

– Distances between stations are 2 to 3 times longer than the SWISSMETRO pilot track. This results in a lower proportion of operating energy consumption per station and per track kilometre.
– Average travelling distances of Eurometro passengers are also significantly longer, since the majority of passengers would travel over more than one track section between two stations.
– At the SWISSMETRO pilot track, a complete change of passengers takes place at each station and the vehicle revolves into the second tunnel tube. In a Eurometro system this would only be necessary at the respective terminal stations.

As no more accurate data on passenger travelling distances or the changeover ratio per station are available at the present planning stage, it has not been possible to define these factors more accurately. For this reason, clear network and operating variants with their respective number of stations should be defined in order to recalculate energy assessments. The same applies to the revision of energy consumption values with regard to the infrastructure since the relevant literature provides clearly differing data on the energy demand for the construction and the operation of the infrastructure.

3.2.10 Geology

For the construction of the Eurometro-network, tunnels would have to be built in regions with prevailing solid rock formations, e.g. Molasse, as well as loose rock, for example in the regions of the Limmat and Aare valleys, but also in the Po Plane or in the Upper Rhine Valley between Basle and Frankfurt.

Estimates by MINGOT ET AL. [1997] on the energy demand for tunnelling through various types of geological rock formations show that the overall energy demand for tunnel construction would increase by ca. 6 per cent only. Therefore the total energy demand of a Eurometro system tunnelled entirely through loose rock formation should increase by just 1 to 2 percent.

This indicates a relatively small sensitivity of the type of rock formation to be bored trough on the total energy consumption. Nevertheless, more accurate and wider research should be carried out on energy and resources demand for tunnel construction with different methods and rock formations. In particular, potential new, energy-saving and cost-effective alternative solutions should be investigated and evaluated.

3.2.11 Use of excavation material

According to the research to date, transport and disposal of tunnelling excavation material would have minor impact on the overall energy consumption. It would be important, however, to ensure recycling rather than disposal of excavated materials. First results of research work on recycling opportunities on the example of rocks of the Swiss Molasse formation in the cement and concrete industries show that natural raw material could be substituted and landfill space saved.

3.2.12 Tunnel cladding

The lifecycle assessment of SWISSMETRO by MINGOT ET AL. [1997, P. 44/45 AND 65FF] lists the types and quantities of materials used for securing, sealing and cladding the tunnel vaults.. Options aiming at the reduction of energy and resources consumption could open up considering new types of concrete and reinforcement materials and additives, e.g. reinforcement-elements made out of carbon fibre reinforced plastics.

4. Conclusions and Perspective

4.1 Findings

The research within the NFP41 program has contributed the following significant or new findings:

- Air traffic as the major means of High Speed Traffic (HST) has become a relevant factor in the field of energy consumption, climate protection and other environmental aspects. In the future, it's ecological relevance will further increase. Therefore the potential of new HST systems as a Eurometro-system should be evaluated. A Eurometro system, i.e. a high-speed transport system in a partial vacuum with magnetic driving forces, is expected to have a significantly lower energy demand and global warming potential per passenger kilometre in comparison with other transport systems operating in the distance range of about 300 to 1000 kilometres (200 to 600 miles). As a Eurometro system would be operated mainly with electric power, the technology used for generating the electricity is a major impact factor regarding the climatic and environmental efficiency. The indirect impacts on energy demand, climate and the general burden on the environment caused by tunnel construction and other infrastructure is another relevant aspect. Taking the present construction practise, greenhouse gas emissions caused by the construction of infrastructure, for example, can reach a similar scale as those for the system's exploitation, assuming an operational lifecycle of 100 years. Therefore, construction technologies as well as the type of power generation and supply for the construction process should be investigated more extensively in future research studies.
- The specific proportion of indirect energy and burdens on the environment per passenger kilometre depends strongly on the passenger demand and its development over the system's lifecycle. It is therefore important that demand forecasts take into account not only general transport growth rates, but also other important factors such as migration effects from other high-speed transport systems and from slower transport systems (road, traditional rail transport) as well as induced new traffic volumes
- Important factors in the development of the demand of HST-systems are travel fares, travel speed, the level of comfort and the integration into the existing transport network.

4.2 Perspective: Sustainable Transport through New Technologies?

As stated at the beginning, the potential of today's technical and political measures in the area of high-speed transport will not be sufficient to achieve the goals of protecting the climate and the environment. Therefore it seems necessary to investigate and thoroughly evaluate new approaches and innovative solutions concerning the development of new technologies to improve efficiency on the supply side as well as new measures to control mobility on the demand side.

Looking back though, one can observe that the introduction of new technologies like the wide spread and use of the car in western societies or the decreasing air travel fares following liberalisation of the market led to big increases in mobility. What will be the effects of the introduction of a new technology in the future? Will it's technical potential at least offset the induced mobility or will it lead to an even faster increase of mobility and it's critical impact on the environment?

From 1960 to 1990 the motorised mobility from the world population has risen by a factor greater than 4. Even more important though is that today no saturation of traffic volume is evident. Demand for transport continues to rise at a rate of around 4% annually in the developed world and at rates almost twice as high in the developing world. Such dramatic rises in transport demand increase the concerns over transport systems impact on the environment even more.

Therefore one question will be in the centre of future research: Can a new technology like Swiss-/ Eurometro help to make mobility in Europe more sustainable?

Presently **further research** is under way to help to answer this question:

EPFL LMF: Aerodynamic Test Facility HISTAR

The flow around a vehicle travelling through a tunnel at high speed is characterised by complex aerodynamic phenomena. To study these effects, the detailed design of a highly flexible and multi-purpose test facility (HISTAR) is being undertaken at LMF with strong industrial and scientific support. Once built, HISTAR will contribute to the development of Swissmetro and other high-speed transportation systems. The experimental scale will be about 1/20. The main element of HISTAR is a rope-towed carriage sliding along two guide rods. The propulsion is the key element of the system for reaching a maximum cruising speed of around 430 km/h.

ETHZ UNS: *A decision tool for sustainable environmental technology assessment – case study "Swissmetro Zurich – Basle"*

This **dissertation by Michael Spielmann** seeks to develop a participatory method which integrates expert knowledge on the system properties, dynamics and stakeholder values. The project will thus critically examine the impact of quantitative and qualitative arguments to address different time frames (e.g. the limits and potential of LCA and of other evaluation methods for a 20 vs. 50 year time horizon) and different types of uncertainty (e.g. in environmental system or societal demand change).

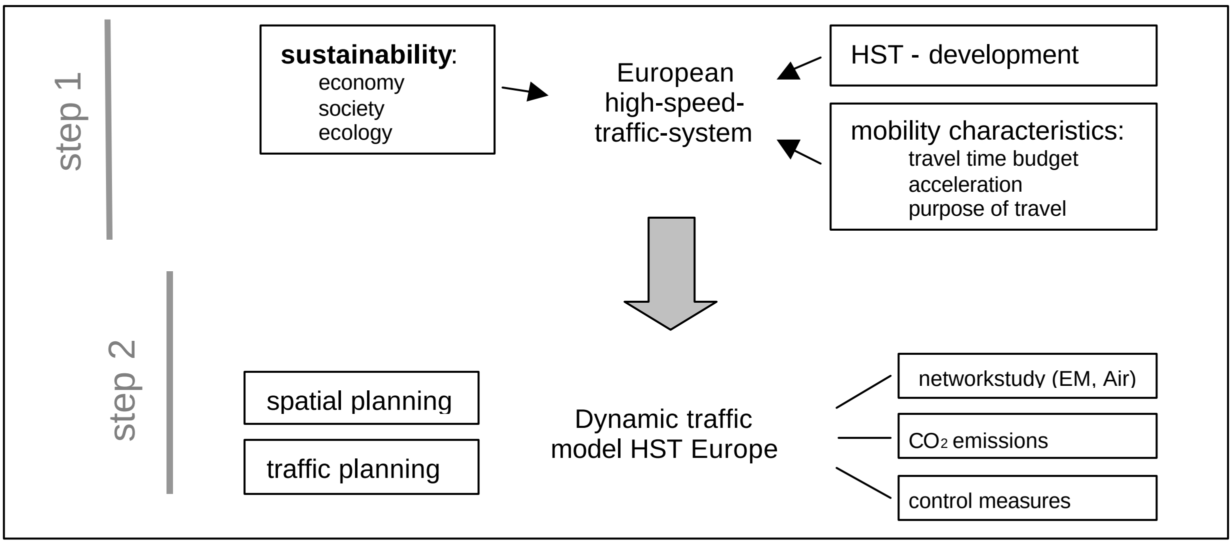
TU Vienna - PSI ETHZ: *A sustainable European HST system in the future?*

The **dissertation by *Daniel Schöbi*** aims at optimising the European HST system by introducing a Eurometro system and focussing on the example indicator CO_2-emissions. The underground tracks and energy-efficient technologies of a Eurometro- System could result in noticeable gains compared to today's means of transport in the areas of energy and climate protection.

The main questions to investigate are: :

- What effects will result from the introduction of a new technology into the European High speed traffic system such as a Eurometro system?
- Which additional control measures have to be introduced to successfully launch a Eurometro as a convincing alternative to short-haul air traffic and other means of transport within the distance range of around 1000 kilometres (600 miles) with noticeable gains compared to today's means of transport in the areas of energy consumption and climate protection?

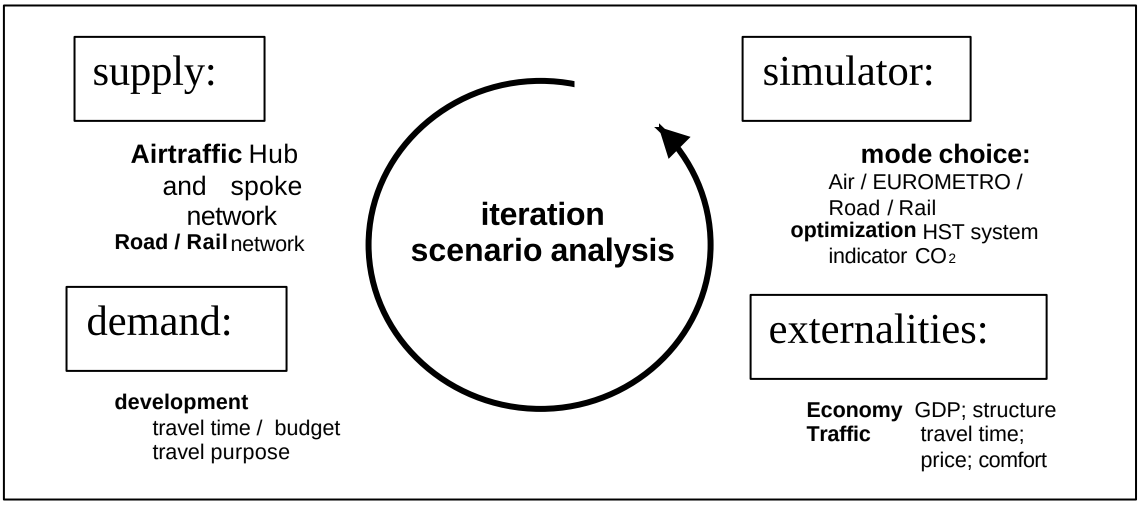
Fig. 4: The project structure consists of 2 steps



Step 1 describes today's and past situation of the European High–Speed–Traffic-system and its characteristics (e.g. travel time budget, acceleration, purpose of travel, ...). In addition to that, the effects of the HST-System on the sustainability of transport will be studied.

Focus of step 2 will be a dynamic traffic model as a tool for strategic planning. It is planned to expand and calibrate an existing intermodal traffic model for the use in the dissertation. The proposed approach is the extension of the basic dynamic analysis to the long time horizon by allowing the origin – destination - matrices to depend on the exogenously given spatial distribution of business and human activities. This method will be an attempt to describe a large network, that could be used as an aggregated reduced form for the evaluation of transportation policies (e.g. impact of induced demand, introduction of a new technology, capacity limits, pricing, ...).

Fig. 5: The European High – Speed – Traffic (HST) Simulation



The simulation should predict the CO_2 emissions of different scenarios – based on different supply-, demand- and externalities inputs. The “back-casting” method shall be applied to determine additional control measures to achieve the desired modal split.

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