Ecological effects of Eurometro

(Energie- und Umweltbilanz einer Eurometro)

Project F6 of the
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’Transport and Environment’

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Report F6 (Summary)

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Energetic and Environmental Assessment of Eurometro

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The National Research Programme "Transport and Environment - Interactions Switzerland/Europe" (NRP 41) intends to become a think-tank for sustainable transport policy. It shall supply contributions from all relevant disciplines towards the efficient and sustainable satisfaction of mobility needs.

The Swiss Science Foundation was given the task by the Federal Council of carrying out this programme. It started in 1996 and will probably last until 2000.

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S - 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."*
>
> Moritz Leuenberger, Member of Federal Parliament, in an NFP41 portrait

This research report aims at dealing with an issue concerning an integrated, sustainable transport policy that has previously been only marginally discussed – **High Speed Transport (HST)**.

It also seeks to provide a basis for decisions whether new and innovative technologies could provide a sensible technical alternative to long distance traffic, especially to the rapidly growing air traffic, keeping in mind the energetic and ecologic perspective.

S - 1.1 Why Eurometro?

Europe is growing together closer and closer regarding politics as well as economics. Powerful communications, transport and mobility infrastructures are very important elements of this development. But how are these technologies to be developed in order to make them ecologically, socially, and economically sustainable?

Strong growth in the areas of transport and mobility has resulted in a critically increased burden on the environment. In the last two decades this is especially the case for air traffic. Air traffic, and particularly short haul traffic, generally tends to result in high energy consumption and noise pollution. Furthermore, according to the latest research results [IPCC 1999] the exhaust emissions from aircraft at great heights have a higher greenhouse potential than groundlevel emissions.

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. Such "Swissmetro" or "Eurometro" systems could be implemented in the foreseeable future. They could achieve speeds of 300 to 500 kilometres (200 to 300 miles) per hour, largely without noise pollution or direct exhaust emissions, and without a negative impact on residential areas or the landscape. These speeds come close to the lower range of short-haul air traffic.

Thus "Eurometro" could be part of a long-term transport policy aiming at sustainability. It could replace in particular short-haul air traffic with its generally overproportional energy consumption and noise pollution on routes with high demand. Consequently it could significantly reduce the burden on the environment. Further improvements with regard to sustainability in the areas of energy, noise, and landscape would be possible by replacing other long-distance transport vehicles (high-speed trains such as TGV/ICE, Transrapid and cars). "Eurometro" would 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-London or Madrid-Zürich-Vienna). This network could also link Switzerland to a pan-european HST network, despite its difficult topographical conditions.

However, the first issue to be addressed must be whether high speed transport, respectively air traffic within Europe are relevant aspects for a transport policy aimed at sustainability at all and whether it would therefore be worthwhile to explore in detail Eurometro's potential for energy saving and improvement to the environment.

S - 1.2 Air traffic – A new Challenge within a sustainable transport policy?

A sustainable transport policy and connected to it **climate protection,** have become important topics on national and international political agendas over the past years and decades. Nevertheless, the Kyoto Protocol and CO_2 legislation both have **excluded** international **air traffic** from obligations for emission reductions. 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. It has even doubled since 1980 and in 1999, air fuel sales reached **approximately one quarter of the overall fuel consumption in Switzerland**.

The demand for **air transport** can be expected 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 **approx. 3 to 4 per cent**. However, despite all efforts to reduce kerosene consumption, **CO_2 emissions from air transport could double again in some 20 years.**

Studies of air traffic further indicate that, based on such growth scenarios, practically the entire **savings effect of 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**. In view of expert opinions at IPCC [IPCC 2000] and the European Commission [EU 2000], one has to expect that the **technological and operational savings potential of air traffic as foreseeable today will not be sufficient** to prevent further increases of fuel consumption and associated greenhouse-gas emissions. One also has to expect additional noise and air pollution, at least in the vicinity of airports.

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 or distances of between 300 and 500 kilometres (200 to 300 miles). The switching or migration potential within Europe that might be achievable by developing the HST railway network is, however, quite limited. A COST study estimates a migration potential of just 15 to 20 per cent for the year 2015. Furthermore the switching to ground-level railway systems could cause additional problems in the fields of noise pollution and damage to the landscape.

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.

S - 2 Concerns and Research to Date

S - 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 realised? How could it supplement the European high-speed transport systems in order 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.

S - 2.2 What has been researched so far?

The present study and its results are a further step in an iterative 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, HISTAR, 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 at time of going to press.

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 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] und 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**.

S - 3 The Most Important Results and Conclusions

S - 3.1 Comparison of air traffic with high-speed rail systems

The following figure S - 1illustrates 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, increased by a factor of 2 (According to [IPPC 1999, S. 8,9] and depending on further climate research findings, an increase by the factor of 4 might have to be considered.)

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.

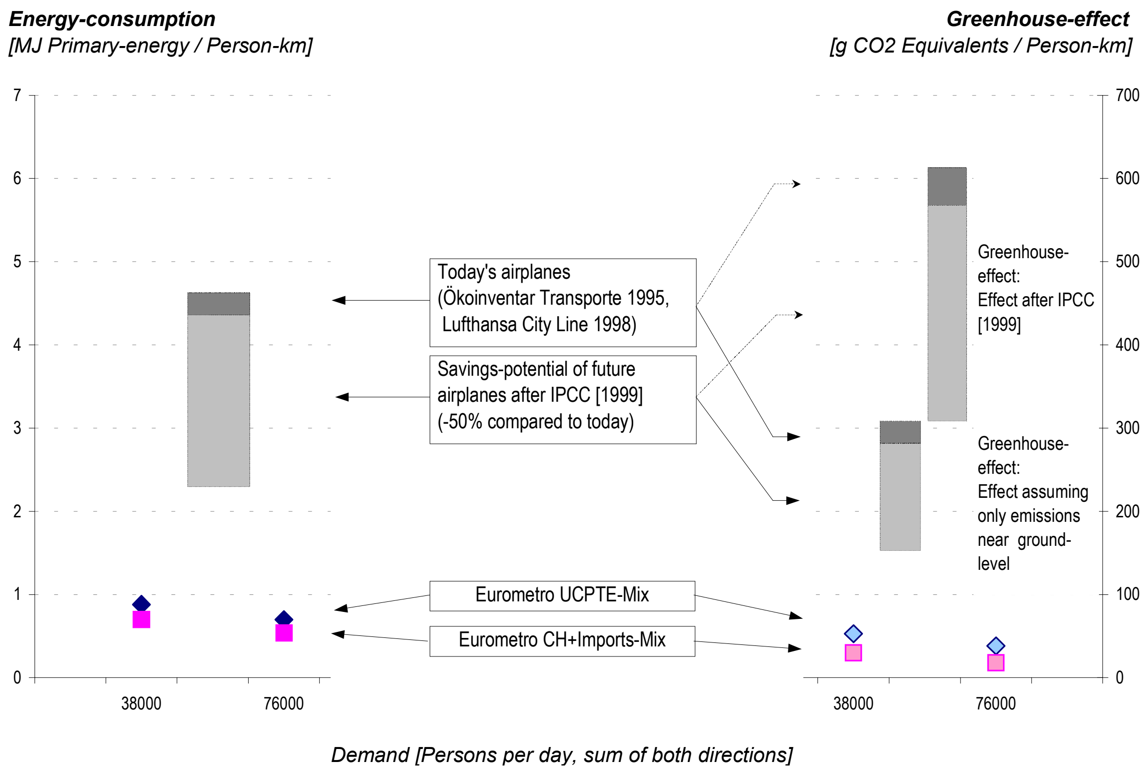

Fig. S - 1 Comparison between energy consumption and CO_2 emissions respectively potential greenhouse effects, of a Eurometro system in the expected range for 2 demand parameters versus short-haul air traffic, OWN CALCULATIONS: GREY ENERGY: [LEUENBERGER ET AL. 1998], OPERATING ELECTRIC ENERGY: CASSAT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

The following figure S - 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.

It is based on the following calculations:

	Eurometro 76000 passengers/day	**Eurometro 38000 passengers/day**
Operating energy (electricity) [MJ/pkm]	0.185	0.21
Grey primary energy for construction [MJ/pkm]	0.12	0.24
gramms CO_2 equivalents per pkm	*= 0.12*90.6 + x*0.185*	*= 0.24*90.6 + x*0.21*
UCPTE mix in 1995	38.2	52.8
CH mix and imports in 1995	18.2	30.0
Gas combination turbine in 2020	30.9	44.4
CH water power in 2020	11.1	22.0

Table S - 1 CO_2 equivalent emissions of a Eurometro system for two demand scenarios and power generation with different types of power stations; for emission factors „x" see table below; OWN CALCULATION: GRAUE ENERGIE: [LEUENBERGER ET AL. 1998], ELEKTRISCHE BETRIEBSENERGIE: CASSAT ET AL. [2000] AND LEUENBERGER [APPENDIX B] and OWN CALCULATION: based on: MINGOT ET AL. [1997], PSI [2000]

The calculation of the *CO_2 equivalent emissions* in the table above are based on the following emission factors "x":

Energy	**gramms CO_2 Equiv. per MJ Energy**
Grey primary energy for construction	90.6
Electricity UCPTE mix in 1995 [MINGOT ET AL. 1997]	148.0
Electricity CH mix and imports in 1995 [MINGOT ET AL. 1997]	39.5
Electricity gas combination turbine in 2020 [PSI 2000]	108.1
Electricity CH water power in 2020 [PSI 2000]	1.1

Table S - 2 Emission factors of different power generating mixes, based on: OWN CALCULATION, [MINGOT ET AL. 1997], [PSI 2000]

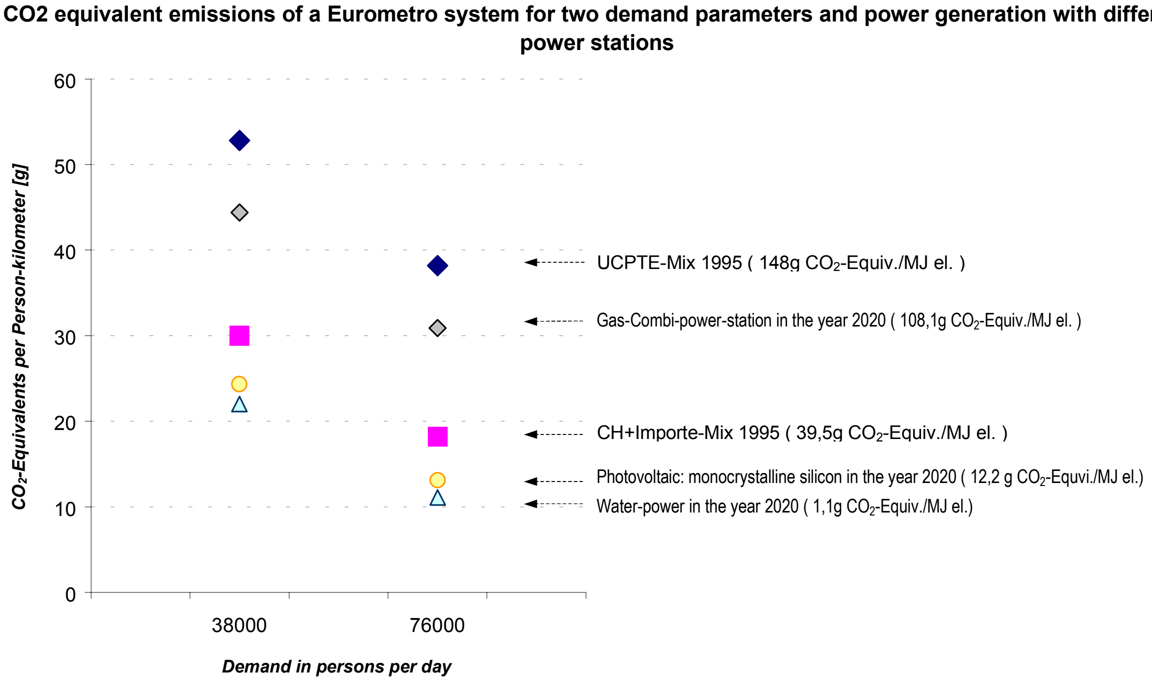

Fig. S - 2 CO_2 equivalent emissions of a Eurometro system for two demand parameters and power generation with different types of power stations, OWN CALCULATIONS: GREY ENERGY: [LEUENBERGER ET AL. 1998], ELECTRIC OPERATING ENERGY: CASSAT ET AL. [2000] AND LEUENBERGER [APPENDIX B]; PSI [2000]

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 S - 3.2.4, because of the very low operating 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.

With regard to air traffic, according to IPCC [1999, p. 10] " 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 ration 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** by new findings and additional research. 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.

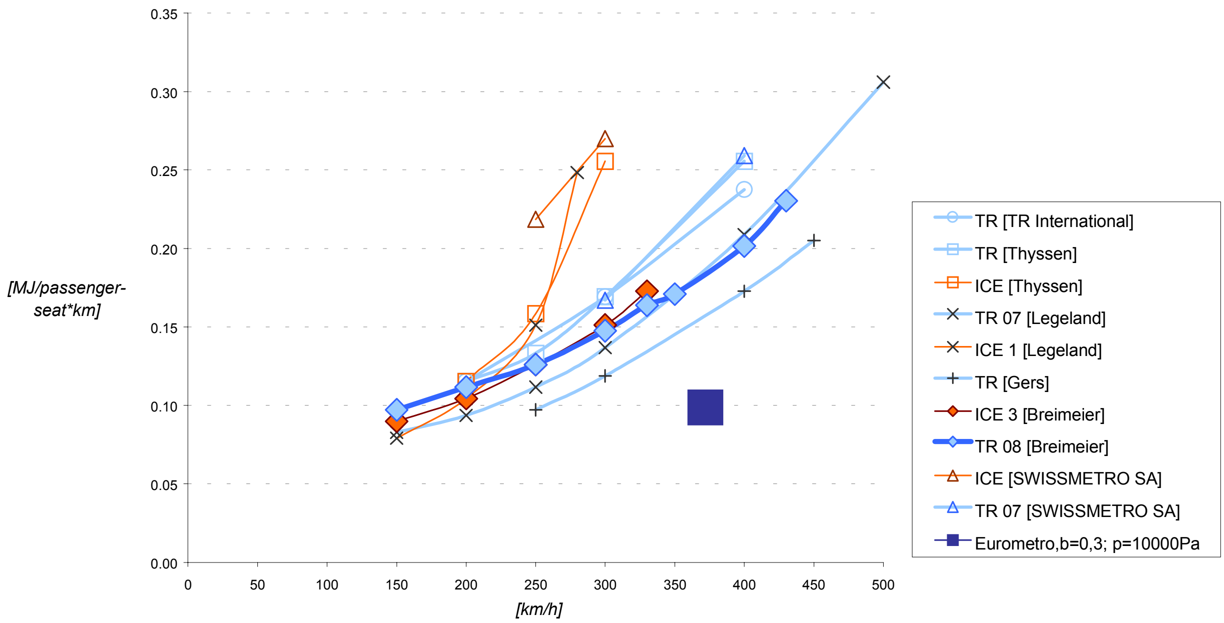

Fig. S - 3 Secondary (electric operation) energy consumption of different high-speed means of transport in MJ per passenger seat kilometre, i.e. a nominal capacity utilisation of 100 per cent, depending on speed, according to: TRANSRAPID INTERNATIONAL [2000], THYSSEN [2000], LEGELAND [1998], GERS [1997,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

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 artifical 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. Detailed information can be found in section S-3.2.5

S - 3.2 The most influential factors for energy and environmental assessment

The following section summarises the most important findings of the research work carried out to date. In particular shows those from analysing impact factors within the sensitivity analysis of the energy and environmental assessment.

S - 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. During the final phase, however, it was possible to recruit another project assistant who initiated in-depth research based on the existing and partly conflicting basic data within the framework of his dissertation (for Professor Knoflacher at TU Vienna) on high-speed transport. Among other results these studies are supposed to provide solid basic data on **today's demand**, future **demand potential,** and the associated impact on the demand for different **network and development variants**.

Work initiated during the final phase 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 approximative 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 model calculations** 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 to date (end of July, 2000) indicate 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.

S - 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.

S - 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 ressource 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. During the entire life cycle its contribution to the overall energy demand is also much less than the energy demand for the operation of the Eurometro track. Furthermore, if external costs are being taken into consideration, the overall costs for a system with larger tunnel diameters should be in the same range or might be even lower.

S - 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.

Research has pointed out that the **utilisation of environment-friendly energy generation**, e.g. through waterpower compared to the average European energy generation has a very positive effect in almost all categories of impact on the environment.

In our opinion, two variants are generally conceivable for the obtaining of 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 promille-range 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.

S - 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: it mainly runs 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.

S - 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 emtpy 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 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 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 porportion 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.

S - 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.

The assumption of a pressure level of 5,000 pa by TROTTMANN ET AL. [1998], based on energetic considerations, is not permissible by today's standards of safety analysis und technology as a minimum pressure of 8,000 pa is required to safeguard the passengers. In order to achieve this or an even lower level and with it to reduce the energy demand even further, new safety concepts would need to be investigated. This would, however, also require to take into consideration possible negative effects such as the need for stronger constructed vehicles and higher energy demands for the vacuum pumps.

S - 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. Accordingly, longer vehicle units were chosen for a Eurometro system in order to reduce the energy demand per seat or passenger respectively.

At the beginning of the year 2000, EPF Lausanne provided up-to-date results from a new simulation model that 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.

S - 3.2.9 Operating infrastructure

According to the presently 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 twice to three 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. Despite a significantly higher passenger volume, the lift movements per station, that according to Mingot et al. [1997, S. 77] consume just under 80 per cent of the energy demand of the entire infrastructure, would stay in the same range as only a certain number of passengers would leave or board the vehicles at the intermediate stops.
- 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 for 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.

S - 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, although the energy demand for the boring-process through loose rock is 60 per cent higher than that for boring through firm Molasse rock, the overall energy demand for tunnel construction would increase by ca. 6 per cent only. According to [MINGOT ET AL. 1997, p. 63,91 ; TROTTMAN ET AL. 1998, p. 46ca.] the proportion of energy demand for the tunnel construction would again be only about 10 per cent (Swissmetro) and 13 per cent (Eurometro) of the total energy consumption. 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.

S - 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 for rocks of the swiss Molasse in the cement and concrete industries show that natural raw material could be substituted and landfill space saved.

S - 3.2.12 Tunnel cladding

The life cycle 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. This publication already discusses various different options for tunnel cladding. Other options aiming at the reduction of energy and resources consumption, as well as burden on the environment, could open up considering new types of concrete and reinforcement materials and additives, e.g. reinforcement-elements made out of carbon fibre reinforced plastics.

S - 4 Conclusions and Perspective

S - 4.1 Findings

The present study has contributed the following significant or new findings:

- In the future, the rank of the issues energy demand, greenhouse gas emissions and their associated impact on climatic change caused by high-speed transport systems will increase. Therfore the optimisation of energy consumption and the corresponding power generation will be of growing importance.
- The consumption of primary energy and the global warming potential of a Eurometro system, i.e. a high-speed transport system in a partial vacuum with magnetic driving forces, is expected to be significantly lower per passenger kilometre than 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 method or the technology used for generating electricity is a major impact factor regarding the climatic and environmental efficiency. Therefore it should be considered accordingly for further optimisation of the overall system.
- Other relevant issues are energy demand, potential impact on the climate and the general burden on the environment caused by tunnel construction and other infrastructure. 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 life cycle of 100 years. Therefore, the issues of construction technology and the type of power generation and supply for the construction process should be investigated more extensively in future research studies.
- The specific proportion of grey energy and of indirect burdens on the environment per passenger kilometre, depends strongly on the passenger demand and its development over the system's intended life cycle. Further investigations with regard to the demand for such transport systems will have to be a main focus of future research studies in this area.
- Demand forecasts need to 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), induced new traffic volumes, and potential spacial effects.
- Important factors in the development of the demand of HST-systems are travel fares and speed as well as integration into the existing network. Connected to the latter are the travelling times from door to door, the level of comfort and other factors such as environmental planning and social trends.
- Other accompanying control measures, besides internalising external costs within the field of transport, have to be developed and evaluated. This is necessary in order to achieve the desired migration to a more energy-efficient and environment-friendly transport system as well as to limit induced new travel to an ecologically justifiable level.
- Economic and financial aspects of constructing and operating a Eurometro system also influence the sustainability of a high-speed system very strongly. The present study only touched upon these aspects, which will therefore have to be the focus of future research work.

S - 4.2 Perspective: Contribution to Sustainable Transport through New Technologies?

As stated at the beginning, the potential of established technical and political measures in the area of high-speed transport will likely not be sufficient to achieve the goals of protecting the climate and the environment. Therefore it seems necessary to **investigate and thoroughly evalaute new approaches to innovative solutions**.

This study aims to make a contribution by analysing a new approach to a potential solution in a constructive way: the design of a Eurometro system as a possible **alternative to short-haul air traffic** and other means of transport within the distance range of 1000 kilometres (600 miles). It's underground tracks and energy-efficient technologies should result in noticeable gains compared to today's means of transport in the areas of energy consumption, protection of climate and landscape as well as noise pollution.

Therefore, the **step-by-step development** of a Eurometro network between the major European population centres could become a kind of "backbone" of an energy-efficient and environment-friendly European high-speed transport system, having therefore the potential to last well into the future. In the foreseeable future, it could provide a transport system with state-of-the-art technology and speeds and travelling times comparable with air travel. Because of its **high efficiency, safety and reliability** it would provide noticeable progress with regard to **ecological efficiency** as well as **short travelling times** over distances up to 1000 kilometres. It could close a **"technological gap"** between national and international **ground-level railway systems** with their limitations regarding speed and track design due to various factors on the one hand, and **intra- and intercontinental air transport on the other hand**.

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