17th MAGLEV, Sept. 2002 in Lausanne – Call for Papers

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Energetic and Environmental Assessment of a Eurometro

Abstract

NRP 41 Project F6 and ongoing research concluded that using the ecological potentials of Swissmetro technology it is possible to develop a better ecological alternative to long distance and high speed transportation with distances around 1200 km or more. An Eurometro system could achieve effiency gains of a factor 5 or more compared to air transport. While travelling with considerably higher velocities it could use about the same amount of operating energy or even less than that of high speed railway systems such as ICE or TGV. New data allow to update the calculations and will allow more recommendations regarding environmental key factors in the ongoing development process.

Key Words

Eurometro; High Speed Transport; Sustainable Transport; Eco Balance; Energy Balance; Environmental Assessment; Swissmetro Technology; MAGLEV; Swiss National Research Program 41: Transport and Environment, Project F6

1 Long distance and High Speed Transport in a sustainable transport policy

A sustainable transport policy has become an important topic on political agendas since the demand for transport, esp. long distance and high speed transport did grow strongly and is expected continuing to so. This growth is driven by factors as deregulation, globalisation, the disappearance of borders in Europe and increased leisure time mobility.

Although conceivable, a single political approach to solve e.g. the environmental problems, such as noise pollution and exhaust emissions, by reducing demand of long distance / high speed transport sufficiently through legislative measures seems rather questionable in today's political settings. Therefore besides such legislative measures new and innovative technological approaches that contribute to a solution of these problems need to be developed and evaluated.

Modern high speed railway systems (such as TGV and ICE) already play a major role with travel times of ca. 3 hours or distances of between 300 and 600 km. An European Maglev-System «Eurometro», using the ecological potentials of the «Swissmetro» technology researched and developed at EPF Lausanne, could be one part of a long-term transport policy aiming at sustainability of transport at distances of 300 to 1200 km or more. Compared to other long-distance transport vehicles such as air traffic, high-speed trains ,e.g. TGV/ICE, Transrapid type maglev trains and cars, improvements regarding sustainability esp. in the areas of energy consumption, noise, and use of landscape could be possible.

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 technology with a high environmental performance potential is based on an underground magnetic railway system, running inside tunnels with partial vacuum. Such systems could be implemented in the foreseeable future. They could achieve speeds of 300 to 500 kilometres 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.

The presented results are a further step in an ongoing iterative research-process of developing a new technology for long distance and high speed transport.

2 Research in the NRP41 Project F6 – Update of the Results and Conclusions

2.1 Eurometro compared to high-speed transport systems

The following figure illustrates a comparison of Eurometro with air traffic on an assumed pilot route, Frankfurt-Rome, for two demand variants and different production-mixes for the operational electricity.

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 or more 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.

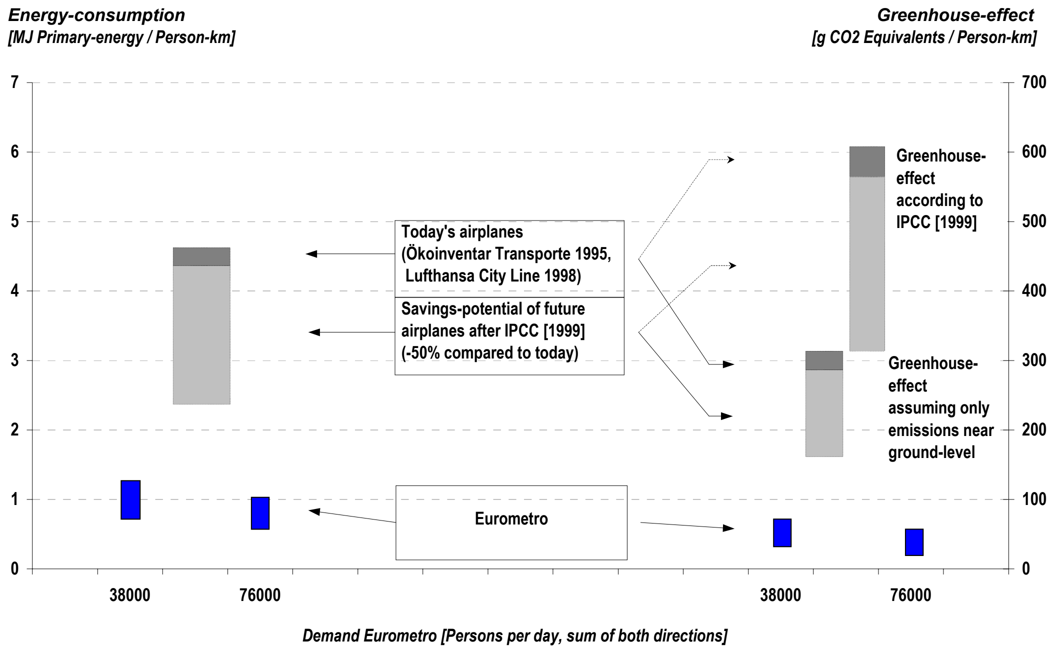

Fig. 1 Comparison between energy consumption and CO_2 emissions respectively potential greenhouse effects, of a Eurometro system in the expected range for 2 demand parameters and different production-mixes for the operational electricity versus short-haul air traffic

Comparisons with ground-level high-speed rail systems have been only basic at the present stage of research. While travelling with considerably higher velocities regarding the operating energy consumption Eurometro would use about the same amount of energy or even less than that of high speed railway systems such as ICE / TGV or Transrapid.

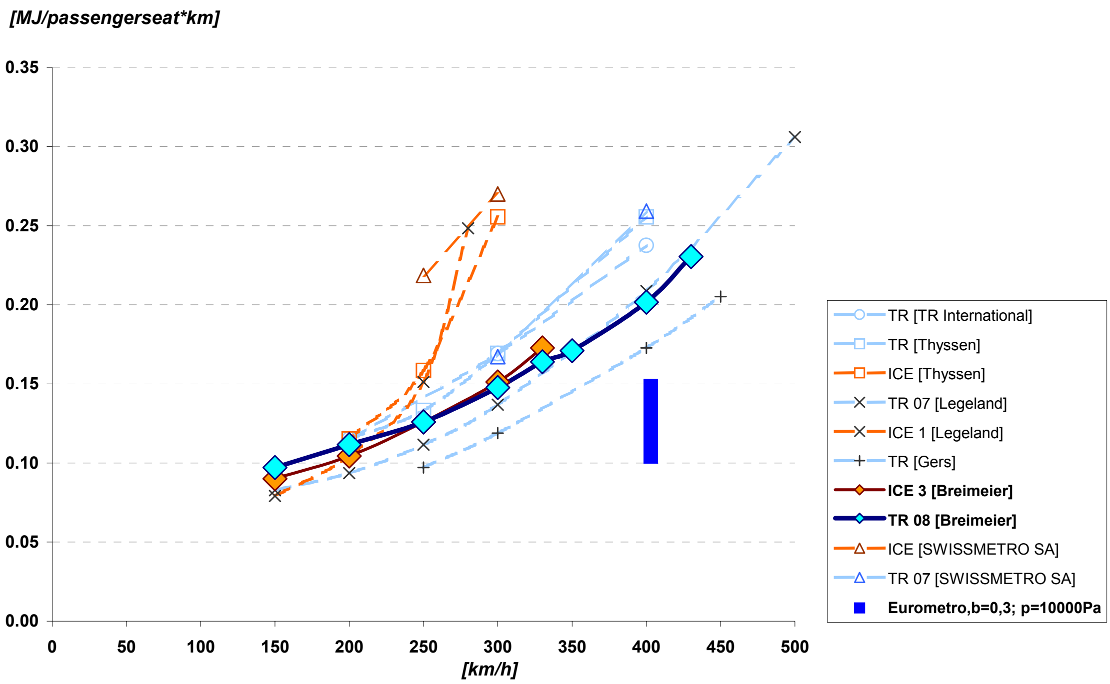

Fig. 2 Secondary (electric operation) energy consumption of different high-speed means of transport in MJ per passenger seat kilometre, i.e. a nominal capacity utilisation of 100 per cent, depending on speed

Regarding the demand for indirect, grey energy it was found that with increasing topographical difficulty, or dense population of an area, the grey energy and needed construction as well as cost of a Eurometro should not be much above or even equal that of ground-level high speed systems.

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, gives all electrified rail systems another important technical advantage. This is especially the case for Eurometro with its very low operating energy demand of ca. 0,1 to 0,15 MJ per passenger seat kilometre (pkm). It should be possible to purchase energy generated in environment-friendly power stations on a deregulated European electrical power market. This is important since apart from passenger demand, the method of power generation is of critical importance for the actual energy and ecological efficiency gains with influencing factors of 2 and more.

2.2 The most influential factors for the energetic and environmental assessment

At today's state of knowledge the following factors are considered to very influential for the energetic and environmental assessment:

2.2.1 Demand, network and development variants

Research in this area 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. Nevertheless, 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 approximate simulation results. These need to be validated in further research work by means of better data on actual traffic volumes.

Consolidation and investigations to 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.

An update concerning research in the field of demand for a future Eurometro is presented at the MAGLEV 2002 by Daniel Schöbi with *“Energy and Environmental Assessment of a Eurometro, Demand and Network: Influential Factors“*

2.2.2 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.

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 at the EPF Lausanne.

2.2.3 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 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.

Since the tunnel diameter is of such importance concerning the consumption of operating energy, the decision of the diameter has to be made carefully since it is practically impossible to change later on during the lifespan of the tunnels of a century or more.

2.2.4 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.

2.2.5 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 (TGV Méditerranée) or ICE (Kassel-Fulda or Frankfurt-Cologne tracks). 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.

2.2.6 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, the assumption of a vehicle's empty weight of 150 kgs per passenger seat appears using new construction technologies and materials seems 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 hand 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 the intended weight ratio of 150kg. In the year 2001 a redesigned vehicle using available modern aircraft construction technology and materials calculates a weight of 325 kg per passenger seat [CASSAT 2002]. While the vehicle construction costs will very likely be significantly lower the increased vehicle weight leads to a considerably higher operational energy consumption. The next vehicle generations used within the lifespan of the system will very likely have considerably lower weight and therefore operational energy consumption.

Nevertheless, the above-mentioned changes in design point strongly to more research of possibilities on how to to reduce the energy demand for hovering and guiding, which is, among other effects, directly proportional to the weight. 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.

2.2.7 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 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.

2.2.8 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 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.

2.2.9 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.

2.2.10 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.

2.2.11 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.

2.3 Conclusions

- The consumption of primary energy and the global warming potential of an Eurometro system, i.e. a long-distance high-speed transport system in a partial vacuum with magnetic driving forces, could be significantly lower per passenger kilometre than with other transport systems operating in the distance range of about 300 to 12000 km.
- 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 regarding the demand will have to be a main focus of future research.
- As an Eurometro system would be operated mainly with electric power, the technology used for generating electricity is a major impact factor regarding the climatic and environmental efficiency. Further research in this field is therfore necessary.
- Aerodynamic parameters such the tunnel diameter and its corresponding blockage ratio as well as the travelling speed and tunnel pressure but also the weight of the vehicle have a high impact on the amount of operational energy.
- Other relevant issues are the tunnel construction's and other infrastructure's energy demand, potential impact on the climate and the general burden on the environment caused by. Construction technology and the type of power generation and supply for the construction process should therefore be investigated more extensively.
- Demand forecasts need to take into account not only general transport growth rates, but also other important factors such as migration effects from other transport systems (high speed as well as road and traditional rail transport), induced new traffic volumes, and potential spatial effects.
- Other accompanying control measures, besides internalizing 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 sustainable 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, which will therefore have to be a focus of future research work.

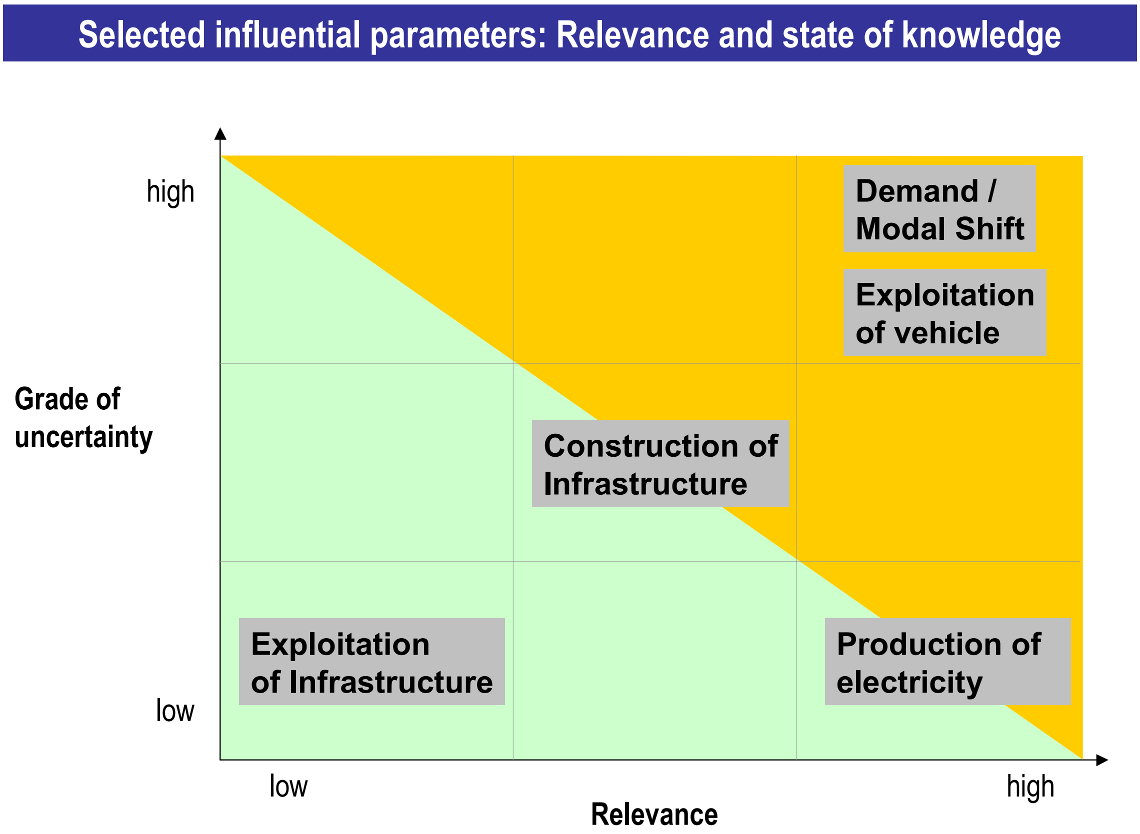

Fig. 3 Selected influential parameters for the energetic and environmental assessment of a Eurometro stating relevance and state of knowlege and therefore pointing out possible future key-research topics

3 Perspective: Contribution to Sustainable Transport through New Technologies?

The NRP41 F6 study and the ongoing research are steps in an iterative research-process of developing and evaluating possible new technologies that could be part of a sustainable long distance and high speed transport policy.

The F6 researchers and today's research team themselves, as well as experts, queried the basic data and certain assumptions from different sources, mainly the Swiss ETH/EPF. The energetic and ecological assessments of an Eurometro system were calculated as far as possible based on the available knowledge at the time. Further ongoing research efforts will continuously put these results on a better foundation, e.g. the number of uncertainty factors for calculating energy demands for the rolling stock can be reduced through investigations at EPF Lausanne with a new test equipment "HISTAR" that will deliver empirically derived data for the validation and improvement of existing simulation models.

This and other data, e.g. concerning a revision of the ecological assessment of Swissmetro by ETHZ, have and will allow it to update the calculations of the PNR41 F6 project on a more solid basis reducing the range of uncertainties.

The results of this update as well as further results of the ongoing research in the area of the energetic and environmental assessment are presented at the conference. With these results the evaluation of the Swissmetro- / Eurometro-Technology as part of a sustainable transport policy of the 21st century will be possible on a broader and sounder data base.

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