Environmental Evaluation of Future Transport Technologies

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Abstract

In this paper, based on a case study of a Swissmetro Network, a procedure for the environmental evaluation of future transport systems within the framework of Technology Assessment is presented. The environmental evaluation is performed pursuing a Life Cycle Assessment (LCA) approach. In order to incorporate the future, scenario analysis has been introduced to LCA for the first time. The main goal of the case study was then to determine and evaluate the environmental impacts of the additional traffic generated by Swissmetro Network. The environmental evaluation of these induced impacts is built on two steps. First, the volume of the induced traffic is determined for different scenarios and variants, and second the environmental impacts due to an additional person kilometer are calculated by performing an LCA. The results of the case study reveal that the conditions determining the development of mobility, which have been operationalised in scenarios, seem to have a decisive influence on the environmental performance of the future transport system.

1 Introduction

Presently, environmental aspects of new transport technologies are addressed within the framework of Technology Assessment [1,2]. The Swiss Bundesrat defines Technology Assessment as "…any form of fundamental study which sets out to investigate the social effects of introducing a new technology… over as broad a scope as possible. It examines the (positive and negative) influences of technology on social, cultural, political, economic and ecological systems and processes. The aim of the studies is to shape the political process by presenting an analyzed selection of options, alternatives and consequences to the decision makers" (quoted in Kowalski, 1994, 5, cit. Ruesch and Haefeli, [3]). However, as Rohpol [4] stated, environmental assessment instruments merely address the status quo, as opposed to the requirements of a TA study, which aims to address possible future developments.
In order to overcome this drawback a Life Cycle Assessment (also referred to as eco-balances) model [5.6] is combined with scenario analysis [7,8] to allow for an estimate of the environmental impacts of a future transport system.

The objective of this research is to present a procedure that allows for an environmental evaluation of future transport systems. The procedure is developed and demonstrated by performing a real world case study aiming at an environmental evaluation of induced impacts of Swissmetro Technology.
The main intention of this research is to develop an environmental evaluation methods and not an opportunity study. Thus, the aim is to present and discuss an approach to operationalise Life Cycle Assessment in TA. The aims are not to determine whether the technology is worthwhile to be further developed or not nor to present a general framework for LCA in TA.

2 The Methods

In the following section we briefly describe the methods selected to operationalise an evaluation of future transport systems, namely Life Cycle Assessment (LCA) and Scenario Analysis (SA)

2.1 Life Cycle Assessment

Life Cycle Assessment (LCA), as it is outlined in ISO 14040, is a tool to assess the environmental aspects and potential impacts of a product or service from cradle to grave.
The great advantage of LCA is its ability to detect and account for trade-offs. Shifts of environmental burdens from one medium to another as well as from one stage of the life cycle to another stage can be identified.
In contrast to similar analytic chain management tools (e.g. MFA), much research in the LCA community has been undertaken and is still in progress to further link environmental interventions (Life Cycle Inventories (LCI)) (e.g. airborne emissions) to environmental impacts (Life Cycle Impact Asessment (LCIA)) and offer highly aggregated information [9].
Various impact categories have been determined and corresponding characterization factors have been defined for several hundred environmental interventions to calculate category endpoints. Several default lists of impact assessment have been suggested [6,10,11]. Moreover, the spectrum of impact categories have been further organized at a more general level according to the three areas of protection (human health, natural environment and natural resources) representing environmental sustainability. The ECO indicator 95/ 99 [12] allows for an aggregation of environmental data up to a single point indicator (eco indicator).
Aggregation of the modeled environmental intervention of this level of representation is able to assist the understanding of the related environmental impacts by illustrating their environmental relevance and makes the results manageable as well as easier to be communicated.

Formally, LCA is linear model, and can be represented by a matrix model using an inventory matrix, which results in easy calculations by matrix inversion [13]. The matrix is generated by combining a number of different unit processes. Typical unit processes presenting a transport service are: production of energy, production of vehicles, vehicle travel. Such a unit process vector (p) is split up into two parts, an economic part a (vector of economic coefficients) and an ecologic part b (vector of ecological coefficients). If we apply this distinction to the inventory matrix, it can be split up into a matrix A, specifying economic process in- and outputs and a Matrix B specifying the environmental interventions of each unit process.
For a given reference flow (r), the overall environmental interventions (x) for the total service can be calculated as follows:

$$x = B * A^{-1} * r \qquad (1)$$

where

r is the vector of reference flows or demand of certain products to fulfill the service
A is the technology matrix
B is the environmental matrix
x the vector of overall environmental interventions of a product or service.

2.2 Scenario Analysis

Developed by Herman Kahn [14] soon after the second world war, scenario technique has been widely used in business [5], environmental science [15] as well as in technology assessment [3].
A scenario can be considered as one consistent picture of a possible future state of a system. Formally a scenario can be described as a vector, which expresses a certain combination of levels of impact factors:

$$S_K = (d_1^{n_1}, \ldots.., d_i^{n_i}, \ldots., d_N^{n_N}) \qquad (2)$$

The levels of impact factors can be both, qualitative or quantitative expressions.
Due to the fact that LCA is a quantitative assessment tool scenarios must be quantified at some point in the process of research. If this condition is fulfilled a scenario analysis is applied to assess different sets of consistent assumptions of possible future states of a system. Thus model runs of the Life Cycle

Model for different sets of parameter values (levels of impact factors) are to be performed and the results compared.

3 Swissmetro Case Study

Swissmetro is promoted as a “new-generation maglev” [16]. The main difference in relation to “conventional” maglev technologies are a) to locate the entire system underground and b) to create a partial vacuum inside the tunnel to reduce resistance to the vehicle movement. An illustration of the Swissmetro Technology is given in Figure 1.

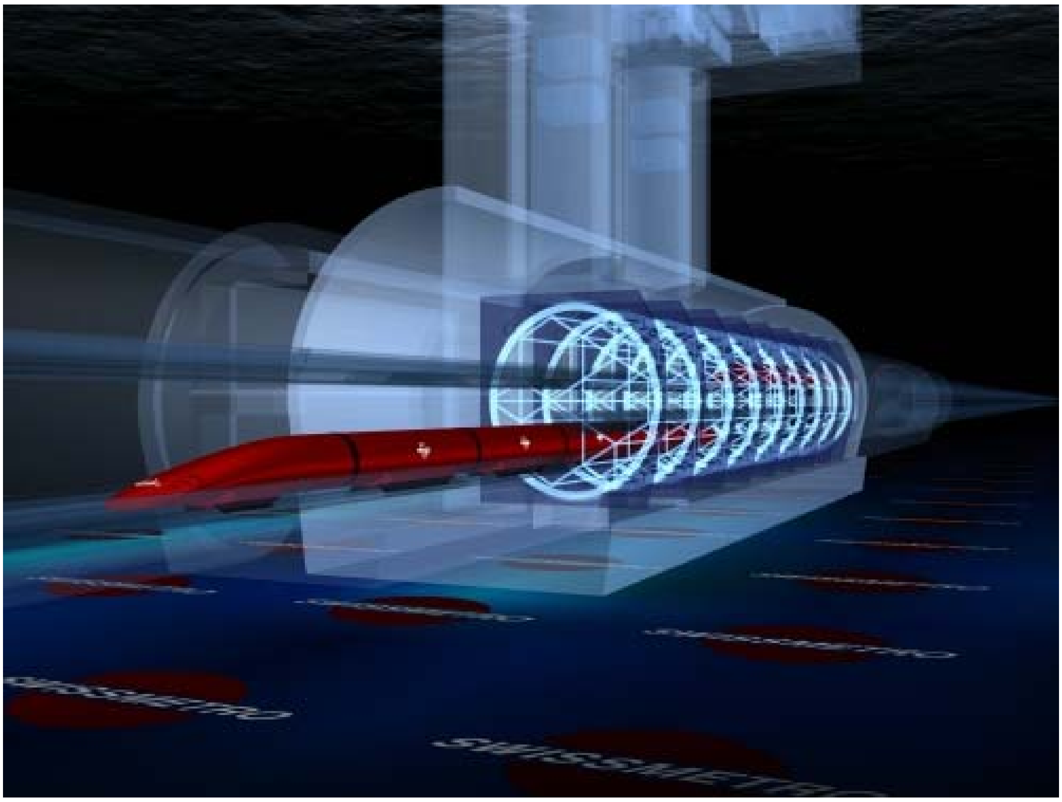

Figure 1: Visualization of Swissmetro Technology

3.1 Goal and Scope

The main goal of the case study is to investigate and evaluate the environmental impacts of the activities induced by acceleration of mobility through the introduction of Swissmetro Technology. In this paper only induced impacts of additional traffic are investigated. Detailed information on the case study presented here and additional information about induced environmental impacts due to the construction of new buildings can be found in Baumgartner et al [17].

3.1.1 System Boundaries

Among the different network options that have been discussed (quote), we have chosen the maximal network including Swissmetro stations in Chur and Sitten. In
Figure 2 the assessed network is illustrated. The planning horizons considered are 2020 (based on the optimistically assumption that the entire network will be in operation by then) and 2050 (the time Swissmetro should be established and the induced activities have been realized).

The technical details for Swissmetro were taken from the concession demand for the pilot track Geneva-Lausanne [17].
The functional unit has been determined as: “Yearly net passenger transport in Switzerland” (Pkm*yr-1).

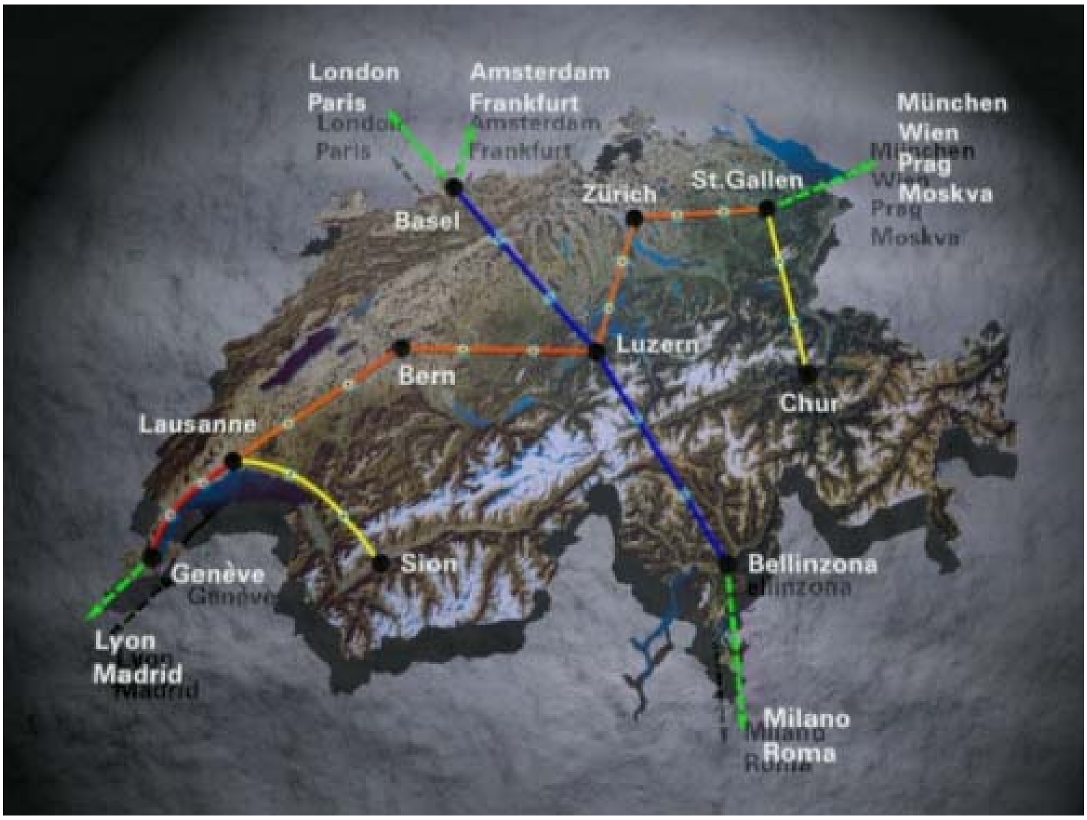

Figure 2: The Swissmetro Network. The network investigeted in this research is indicated by the red, blue and yellow links. The dashed green line represent potential connections of the European high speed network (picture taken from the homepage of the Swissmetro SA (www.swissmetro.com).

3.2 Scenario Analysis

In line with overall objective of this research, scenario analysis is performed to get insight in the environmental implications of the Swissmetro Technology rather than support a decision to implement or not implement the new technology. According to the classification of scenario analysis given in Gausemeier et al [18], the scenarios constructed here can be characterized as explorative and descriptive. Point of departure of such scenarios is a description of the current state of the system. From this point we are looking ahead and describe different possible developments of the system. Consequently, we model either planning horizon independently of each other, i.e. starting each time with the present situation.
The scope of the scenario analysis in this research is reduced to tackle uncertainties in the reference flow of the case. The reference flow, as defined in ISO 14040, referrers to the amount of product that is required to fulfill the function. Thus the reference flows considered are the total induced person kilometers (pkm) as performed by different means of transportation (Airplane, Rail, Local (Public)

Transport, Car, Pedestrians). In order to determine the reference flows a transport model is required. The process of scenario determination and the latter model are described in the following parts.

3.2.1 Determination of reference flow scenarios

In Figure 3 the framework of scenario as applied in this research is presented. According to Scholz & Tietje [8], a multilevel scenario analysis, with a further distinction between variants and shell scenarios is introduced.

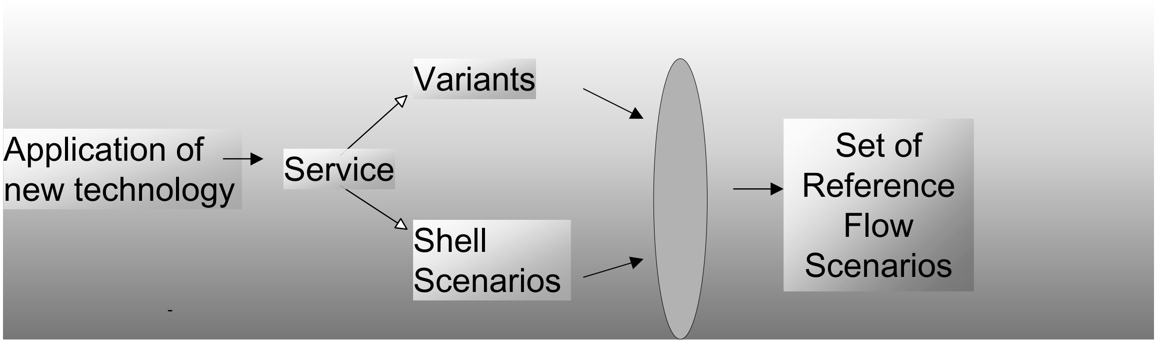

Figure 3: Framework of Multilevel Scenario Analysis

Variants are a set of possible options to fulfill the function defined. In this research we merely assess two variants:
V1: Future Swiss Transport Network with Swissmetro.
V2: Future Swiss Transport Network without Swissmetro.
Shell Scenarios are expressions of alternatives futures in which the variants „takes place", addressing the consequences of uncertainties in the socio- economic system on projections for the environmental system.
In order to determine the shell scenarios, results from a transport scenario workshop held in Zürich [19] have been taken as a point of departure. As Maggi [19] stated, the development of transportation is determined by five external impact factors: Ecological Awareness, State Regulation, Public Financing, and the transport hardware and software in future use. In Figure 4 the precision of prognosis for the introduced impact factors is illustrated.

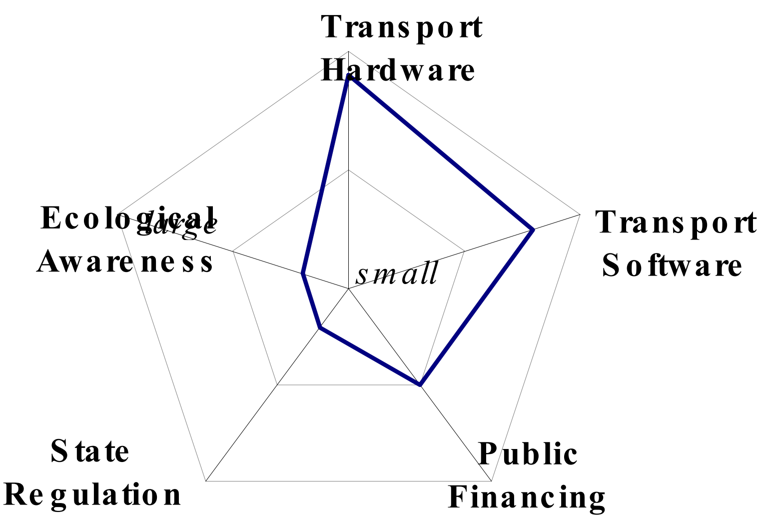

Figure 4: Precision of prognosis for proposed impact factors

Impact factors for which the certainty for future development is considered as high (Transport hardware and software), can be excluded from the scenario analysis. In turn, impact factors with low certainty about the future state of the system (Ecological Awareness, State Regulation and Public Financing) need to be further addressed in the scenario analysis. In order to further reduce the complexity we merge the two impact factors “State Regulation” and “Public Financing”. Thus, the shell scenarios consist of two impact variables. For each impact variable two levels are determined, resulting in 4 shell scenarios. In Table 1 scenarios, impact factors and their levels are presented.

Table 1: Shell Scenarios, Impact Factors and their Levels

Scenarioname	**Impact Factor**	
	State Regulation	**Ecological Awareness**
Known	Level = Low	Level = Low
Green	Level = Low	Level = High,
Regulated	Level = High	Level = Low
All Inclusive	Level = High	Level = High

For each scenario a verbal description sometimes refereed to as story line is given. The scenario “Known” corresponds to a world formed by the trends and planning orientation already dominant today. The scenario “Green” describes a society with a strong environmental awareness, which however, is not fully translated into action under conditions prevalent in this scenario. The development of the urban agglomerations and the transportation system is strongly controlled in the scenario “Regulated” In the scenario “All inclusive” we have both, a highly developed ecological awareness among the population and a system of strict state regulation.

The integration of the variants in the shell scenarios, also refereed to as a set of reference flow scenarios, is done in two steps. First a qualitative integration in form of eight story lines is performed. Each story line describes a possible state of the future Swiss Transport System. In order to gain a comparable picture, internal impact factors are defined which can have different levels in the various story lines. Second, the qualitatively described levels of impact factors are translated into quantitative measures that are used as a set of parameters for running a transport model. The list of internal impact factors comprises demographic patterns, employment figures and modal split.

3.2.2 Transport Modeling

A rough GIS -based transport model of Switzerland has been developed for this case study to estimate how the accessibility of municipalities in Switzerland can be changed with the introduction of a Swissmetro Network, assuming a constant travel budget of 85 minutes per Swiss inhabitant per day.
The model has been calibrated by adjusting the average speeds of means of transportation until we were able to reproduce in a satisfactory manner both the available trend forecast for the future mobility in Switzerland and the modal split assumed to occur in the future.
The model results present a yearly average, without taken into account seasonal, weekly and daily alterations. The model is run 8 times to calculate the total net performance of various means of transport for all variants in all shell scenarios.

3.3 Calculation of Induced Impacts

The differences in the reference flows for a certain shell scenario with and without Swissmetro, is the point of departure for the calculation of the induced environmental impacts. For instance, the induced transport impacts of Swissmetro in the scenario “Green” is determined by calculating the difference in performance for each modeled means of transport for Variant A (transport network with Swissmetro) and Variant B (transport network without Swissmetro). Figure 5 shows the induced changes in the performance of the different means of transportation for the four shell scenarios.

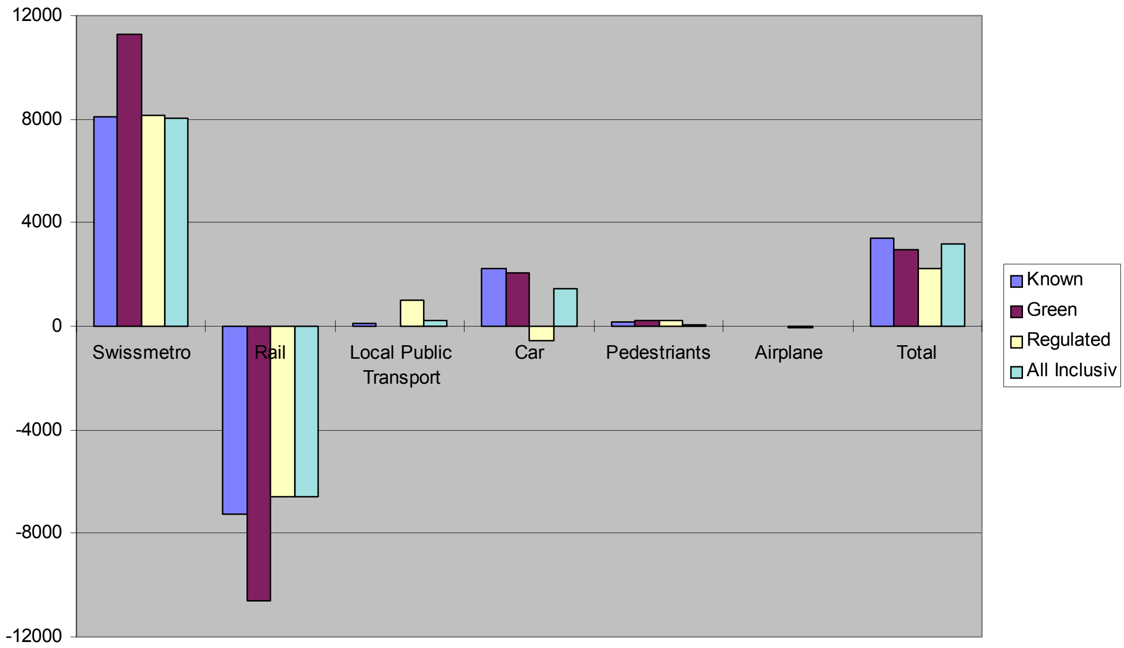

Figure 5: Changes in the performance of different means of transportation (reference flows) in a comparison of the situations without and with Swissmetro; planning horizon is 2050; in millions of passenger kilometers in 2050

Swissmetro acquires in all four cases a significant part of the passengers of traditional rail and induces an increase in car transportation. Car transportation is reduced only in the shell scenario "Regulated". Thus, as demonstrated above, Swissmero will generate additional traffic, a conclusion likely to hold for many condition as defined in the various shell scenarios.
If these hypothetical changes in the performance of the different means of transportation have a negative or positive effect on the LCA of the induced activities depends of course on the relative size of the environmental impacts generated by them.
According ISO 14040 environmental impacts are calculated in a two step procedure. First the overall environmental interventions (e.g. CO2, Nox) for the service under investigation are determined. Second, environmental interventions are classified in impact categories and multiplied with characterization factors in order to quantify the contribution of the interventions to selected environmental impacts.
The environmental interventions per person kilometer are calculated employing the below equation (3) modified from equation (1):

$$\Delta x = B * A^{-1} * \Delta r^{Si} \qquad (3)$$

where

Δr	is the vector of induced reference flow or demand of certain transport units: $\Delta r = \Delta r^{V1} - \Delta r^{V2}$
V1	Swiss Transport Network with Swissmetro
V2	Swiss Transport Network without Swissmetro
S_i	Shell Scenario (i : Known, Green, Regulated, All Inclusive)
A	is the technology matrix
B	is the environmental matrix
x	the vector of overall environmental interventions of a product or service.

The reference flow vector is adjusted for each scenario and represents the induced transport performance calculated above.

For the technology matrix A and the environmental B the same data is employed when calculating the overall environmental interventions for the Swiss Transport Network for each of the four shell scenarios.
The environmental interventions for each means of conventional transportation are obtained from Maibach [20]. In case of Swissmetro Technology, the data has been taken from one of our previous studies, where we determined the direct environmental interventions due to operation and construction.
In order to evaluate the calculated environmental interventions we use the Eco-Indicator 95 approach and calculate ECOINDICATOR 95 points. (see 2.1). The results are presented in the next section.

3.4 Results and Discussion

In Figure 6 the results of the induced environmental interventions expressed in Ecoindicator points are illustrated.

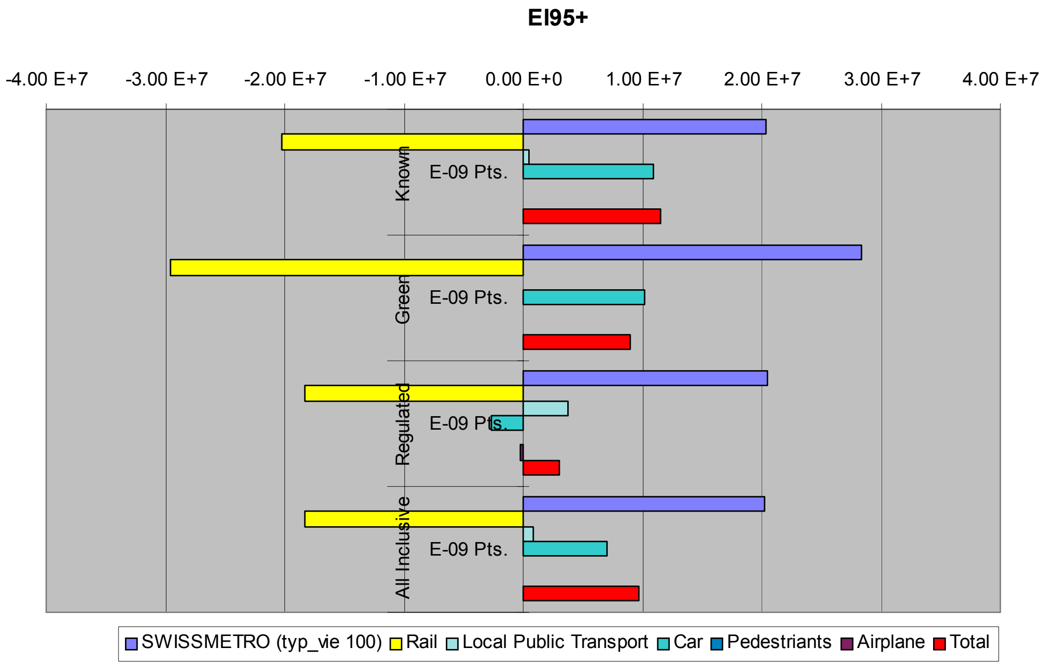

Figure 6: Results of the Environmental Evaluation of Induced Impacts for the year 2050 expressed in Ecoindicator 95 points.

The induced environmental interventions vary significantly for the considered means of transportation in all scenarios and reflect the result of the induced transport performance. In terms of total environmental impacts, the scenario "Regulated" shows the best environmental performance. Its induced impacts are characterized by environmental impacts that are just one fourth as important as those in the other extreme case, the scenario "Known". These findings indicate that the conditions determining the development of mobility, which have been operationalised in the four shell scenarios, seem to have a decisive influence on the environmental performance of the future transport system. The impacts from local public transportation induced by Swissmetro are small. This has two reasons, first the actual induced local public transport is low and second environmental interventions associated with local public transport are low.
It is finally noteworthy that Swissmetro induces additional environmental impacts due to car traffic in all scenarios bar one, the scenario "Regulated".

The individual results of the case study reveal that the transport of passengers is unlikely to be made sustainable by only introducing new means of transportation with a lower specific impact on the environment. As demonstrated, induced environmental impacts occur under a wide range of scenario conditions, which turn potential benefits due to increased environmental efficiency of a new transport technology in disadvantages on a system level.
However, the results presented here should be interpreted carefully, since the environmental data merely represents the current environmental interventions of conventional transport systems and current up-and down stream processes. Technology improvements or the substitution of current technologies with new technologies has not been considered in the environmental data. For instance, conventional car propulsion system may be substituted with new systems, such as fuel cells.
In addition, it should be bared in mind that the chosen evaluation method Ecoindicator 95, does not address two important environmental impacts of transportation, namely land use and noise. An inclusion of these two categories might result into different picture, since the noise and land use efficiency of Swissmetro as an underground system is far better than the efficiency of the compared transport systems.

4 Conclusions and Future Work

This paper has presented an operational method combination for the environmental evaluation of future transport systems. The multi level scenario analysis approach (distinction between shell scenarios and variants) allows for a structured integration of future aspects within the framework of LCA. It also allows for investigating comprehensive questions such as the induced environmental impacts of future transport systems. In the Swissmetro Case Study, it has proven its application successfully to a real world problem. It is a first step towards the application of LCA in Technology Assessment for new transport technologies.
Although the approach itself is operational, the case study has revealed some drawbacks:

1. Current Life Cycle Assessment approaches do not address the environmental impact of noise and land use sufficiently. In turn, these two categories are important sustainable indicators in the transport sector. In order to use LCA for the environmental evaluation of transport systems, noise and land use need to be integrated in the framework of LCA.
2. Current LCA databases lack environmental data on future technologies. Due to the fact that both, future market share of technologies and the environmental performance of new technologies may be rather uncertain, the scenario analysis as presented here should be enhanced and tackle these uncertainties as well.
3. The operationalisation of the scenario construction is predominately performed by the study team. From an epistemological point of view the scenarios can be considered as experts estimates. However, in particular for the quantification of the scenarios, for both, the selection of internal impact factors as well as for the determination of their possible levels, more formal method are suggested, e.g. Delphi Method.

Following the last point, one major enhancement of the proposed approach would be to have a systematically involvement of experts and stakeholders within the entire assessment and evaluation process, which may be split into a three step process.
The first step would characterize the case with respect to the areas of concern and identifies the relevant agents. This step would supply the system definition and structures the Life Cycle model. In the second step a formative scenario analysis, comprising mic-mac analysis and consistency checks, would be conducted The third step would define the evaluation criteria and provide the environmental evaluation. Each step would consist of a participatory process, in which the research team first creates a first draft study. In a subsequent step individual experts' and stakeholders' knowledge and opinions would systematically be incorporated. From this usually results a multitude of models or views. These models or views then would become subject to a group decision and consensus building process.

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