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Environmental rebound effects of high-speed transport technologies: a case study of climate change rebound effects of a future underground maglev train system

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Abstract

The implementation of new high-speed transport technologies re-shapes the demand balance between transport modes and rebound effects may occur. In this paper first a definition of environmental rebound effects of high-speed transport is presented and various cases are discussed. Second, a method is developed to determine and quantify the environmental rebound effects employing life cycle assessment. The method is illustrated in a case study by investigating the greenhouse gas emissions of a frequently discussed future underground maglev train system for Switzerland.

The environmental rebound effect expresses the size of environmental impact changes due to demand corrections in relation to the plain substitution effect. The latter expresses efficiency substitution effects due to the substitution of existing transport services with a high-speed transport service; i.e. passenger-kilometre performance remains constant in a world with and without the new transport service. Demand corrections are determined employing the notion of the constant travel time budget, assuming that if travel speed increases, the time saved will be exclusively used to travel more and further.

In order to quantify the environmental rebound effect we determined the environmental efficiency – including operation, energy supply, vehicle supply and infrastructure supply – for all important transport services of the current passenger transport system as well as for the new transport technology. In addition, we generated and quantified a set of cornerstone scenarios to address possible changes in mobility patterns and technological options of passenger car transport at the time when the new high-speed transport technology would be in operation.

The results show an increase of per capita environmental impact for all considered scenarios even without accounting for additional transport demand due to time saving effects. All scenarios show additional environmental impacts due to rebound effects on top of pure substitution effects.

The case study demonstrates that taking into account demand changes, i.e. rebound effects is essential to evaluate emerging transport technologies. New technologies allowing for higher travel speed, even if energy-efficient on a passenger-kilometre basis, might lead to higher environmental impacts. This is ignored by the traditional approach of environmental transport assessment, which compares environmental efficiency of each transport mode separately. The presented approach allows to better understand the consequences of new transport services, and facilitates the assessment of future transport technologies on the level of the transport system as a whole.

Keywords: Life cycle assessment; Rebound effects; High-speed transport; Maglev technology; Sustainable consumption; Travel time budget; Swissmetro; Cornerstone scenarios; Climate change; System delimitation; Prospective life cycle assessment; Induced impacts

1. Introduction

In all industrialized countries, transport demand continues to increase [1] and roads are becoming more congested [2]. This also is the case for Switzerland [3]. Alongside the

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growing construction of new roads, often alternative transport services and the construction of new infrastructure for public transport are proposed to meet the continuously increasing demand. Public transport is often promoted as being the preferable option over the construction of new roads for individual motoring as it has a lower space demand and higher energy-efficiency per seat kilometre [4]. Therefore, new mass transport systems are being constructed in large cities [5,6]. At the regional scale Europe has seen the emergence of new high-speed train systems [7]. A frequently discussed alternative high-speed train technology is so-called maglev (magnetic levitation) trains [8,9], which cannot use existing rail systems and are based on completely new infrastructures. Examples are the German Transrapid that started first commercial service in January 2004 in Shanghai (China) [10,11] and the proposed Swissmetro [12,13].

Environmental aspects of new transport technologies are frequently addressed using life cycle assessment (LCA). LCA, a tool facilitating a ''cradle-to-grave'' analysis of the consumption of resources and emissions, is particularly useful to detect and account for trade-offs [14], e.g. the shifting of environmental burdens from vehicle use to transport infrastructure. LCA studies on transport technology compare the environmental efficiency of existing transport services with new alternatives. Such an approach is applicable for (a) an intra-modal comparison such as the introduction of new propulsion system and fuel types [15–17] and/or (b) an inter-modal comparison (e.g. bus vs. rail) [4], provided a complete substitution of one mode (e.g. rail) by another mode (e.g. bus) takes place.

As high-speed maglev trains go in hand with completely new infrastructure, they in fact constitute a new transport mode. Therefore, they re-shape the demand balance between existing transport modes.

Consequently, determining and comparing the environmental efficiency, i.e. the emissions per passenger-kilometre, of different transport modes is not sufficient. In addition, one should assess transport alternatives on a transport system level, taking into account environmental consequences of changes in the modal split induced by the introduction of a new technology. Most important is the so-called rebound effects.

Traditionally, the concept of rebound effect is associated with energy use and the question how energy-efficiency improvements affect energy consumption [18,19]. The classical rebound effect describes changes in total resource use due to increased efficiency in the use of that specific resource [20]. For example, Haas and Biermayr [21] report demand increases of 30% for heating services induced by the increased energy-efficiency of the retrofitted heating systems in eight multi-family dwellings in Austria. Rebound effects also can be expected to occur when hybrid vehicles enter the market, however, such effects could not be identified up to present [22,23].

In recent years, the discussion on rebound effects and sustainable consumption recognizes the time dimension (see Jalas [24] for a brief overview). Similar to the classical rebound effect, the rebound effect in time describes changes in total resource use due to increased efficiency in time use, which in turn influences the use of resources in general. For example, Binswanger [25] theorizes – based on the household production function approach [26,27] – that if there is a time saving innovation in transport technology (faster cars, faster public transport, etc.) people will travel longer distances, since a certain distance can be traveled at lower opportunity costs. In contrast to the classical rebound, therefore, rebound in time is ruled by the allocation of a fixed and limited resource (time), whilst the classical rebound is ruled by the elasticity of demand to changes in efficiency (not to be confused with changes in price).

The goal of this research is to define environmental rebound effects (ERE) and develop a method to investigate and quantify ERE caused by the introduction of time saving transport innovations. The method is illustrated in a case study of an intensely debated future high-speed underground maglev train system for Switzerland.

The paper is organized as follows. In Section 2, we outline the methods used and the concept to determine and quantify ERE. Section 3 describes the main characteristics of the current transport system and the possible maglev enhancement. In Section 4, we present and discuss the results. Final conclusions are drawn in Section 5.

2. Methods

2.1. Environmental rebound effect

The environmental rebound effect describes changes in the environmental performance of a transport system due to the introduction of a time saving innovation in the transport sector.

Following the concept introduced by Haas and Biermayr [21], we distinguish two types of environmental impact changes, describing the difference in mobility patterns of an average traveler's behaviour in a transport system with high-speed transport (A_1) and a transport system without high-speed transport (A_0):

- Environmental impact changes (ΔEI_{cp}) expressing exclusively the efficiency substitution effects of selected transport service with high-speed transport; i.e. whilst the average traveler substitutes existing transport services with Swissmetro the total kilometric performance of the transport system remains constant, (cp = ceteris paribus). $\Delta EI_{cp} < 0$ indicate a higher environmental efficiency of the new transport service compared with the substituted service(s).
- Environmental impact changes ΔEI_{dc} expressing efficiency substitution effects and including environmental impacts due to demand corrections (dc). The latter describes the environmental impacts of the activities that occupy the time that is saved by using a high-speed transport service instead of a conventional service. If demand does not change, then $\Delta EI_{dc} = \Delta EI_{cp}$