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# Eco-design model of a railway: A method for comparing the energy consumption of two project variants

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ABSTRACT

In accordance with the environmental concerns that national policies still address throughout the world, railways have been extensively studied to provide quantified indicators for assessing construction/operations practices.

It is essential to take energy consumption, into account since energy can be measured worldwide, in addition to constituting a global environmental load that is time-limited as regards resource availability and known as a discriminating criterion in comparing transport infrastructure. This article introduces an innovative, generic and systemic method dedicated to determining the energy consumption of a railway line during the pre-project phase by taking into account the complete life cycle of the rail infrastructure, including construction, maintenance and operations. The method developed (called ≪PEAM ≫) focuses on assessing project variants during the design stage and therefore integrates both the geometric longitudinal constraints of the line and the thicknesses/volumes over the entire itinerary as design parameters for input into the various construction scenarios. PEAM combines methodologies stemming from life cycle assessment with a consumption model derived from physical modeling. The models associated with this method are then applied to study the energy consumption of a new high-speed line located in France that also has major implications for the European connections currently under investigation as well. Two project variants are compared in terms of total energy for a 50-year service life and a given characteristic rail traffic, including passenger and freight flows. Results obtained reveal a 30% difference between the two variants, which prior to applying PEAM were considered to be relatively similar.



## 1. Introduction

At the global scale, approximately 30% of end-user energy and 62% of end-user oil is consumed by the transport sector, according to International Energy Agency (2013). Reducing the world's fuel consumption is one of the highest priorities for all countries due to energy security, greenhouse gas and economic concerns. In this context, high-speed trains (HST) offer many advantages, with an energy consumption significantly less than either road or air transport. According to Akerman (2011), high-speed trains consume roughly 4 times less energy than road transport and 9 times less than the air sector (expressed in kilowatt-hours per passenger-kilometer – kWh/pkm). This, among others reasons, explains why the network

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of high-speed lines (HSL) is still growing at a very fast pace. According to UIC (2013), some 21,365 km of high-speed lines are in operation across the world, 13,964 km are under construction and another 16,347 km are planned. The HSL network is expected to cover 51,677 km by 2025.

Once it has been decided to link two cities via an HSL, the facility owner conducts an assessment of the project variants. Choosing among the various possible solutions entails a complex process that includes a range of actors (government, local authorities, local residents groups, ecological associations, etc.) and criteria (economic, environmental, technical). A clearer understanding of the tradeoffs requires suitable tools to compare the different assumptions. Since the 2000's, the environmental impacts of railways have been investigated using life cycle assessments (LCA), whereas the energy and greenhouse gas criteria are currently being evaluated.

Valuable research has previously been conducted to compare various modes of transportation from an environmental perspective (e.g. Chester and Horvath, 2009; Hoffrichter et al., 2012; Raghunathan et al., 2002; Janic, 2003). These works unfortunately did not take into account the impacts of infrastructure (e.g. see Janic, 2003).

Works on HST are uncommon since conventional trains are typically studied (e.g. Chester and Horvath, 2009). Recent findings by Chester and Horvath (2009) have provided specific values for HSL and other transportation modes. These results however cannot be applied to distinguish variants since only the project length is being considered. Other works compare different train types (urban transit, conventional, high-speed), such as Garcia (2010) and Lee et al. (2011), although it is impossible to compare a given alternative using the same train technology. van Wee et al. (2003) performed breakthrough research on evaluating alternatives in the Netherlands. Different rail links with dissimilar trains have been studied. Regrettably, the method adopted to estimate the indirect energy (resulting from the infrastructure impact) is only briefly described and limited to freight infrastructure. Also, the fastest conventional trains included in the study have a maximum speed of 260 km/h, whereas project speeds of 320 or 350 km/h are common today. Let's note that van Wee et al. (2003) did include the Maglev train, though this is not a conventional model. In conclusion, HSL offers a specific domain with its own constraints, and previously published works lack the precision required to distinguish different variants designed with the same train technology.

The method proposed in our paper has been developed to assess alternatives during the pre-project (or design) phase of a railway project. Moreover, our method takes into account both the infrastructure and its operations phase. The discrete approaches normally proposed for LCA products are adopted herein and combined with vehicle dynamic models. Both these approaches offer a well-to-wheel perspective so as to be comprehensive and take into account all phases (construction, maintenance, operations).

In the following sections, the acronym PEAM (Project Energy Assessment Method) will be used to describe our particular model. This paper continues with a full description of PEAM, which will then be applied to a real case study, i.e. a European HSL project whose life cycle phases (construction, maintenance, operations) will be studied separately as regards energy consumption. The final section will discuss the applicability of PEAM to other impacts and other projects, along with its limitations.

## The PEAM method for assessing project variants

### *Purpose of a variants assessment using LCA*

At the project level of a railway, the various routes (i.e. current route and variants) are examined simultaneously (Fig. 1). Application of the proposed model would thus contribute to the decision-making process by focusing on the main design parameters to obtain an objective criterion for choosing a variant. Such a model could avoid controversy, such as that illustrated by Leheis (2012), and promotes better practices at the project level.

The alignment of an HSL requires mild slopes and gentle curvature. These low flexibilities of the horizontal and vertical alignment are the main causes of environmental issues as regards territorial integration. In comparison with motorways, the

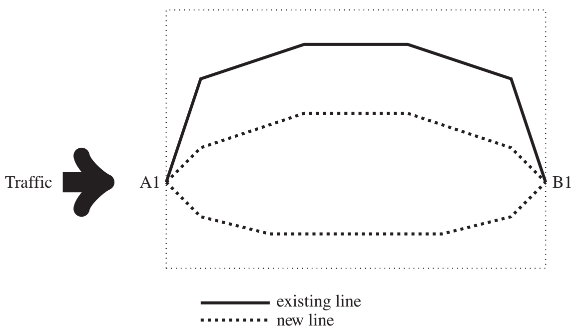


**Fig. 1.** Theoretical example of traffic flow through a territory.