# Greenhouse gas balance analysis of mountain rail base tunnels. A simplified model and case study from the Alps.

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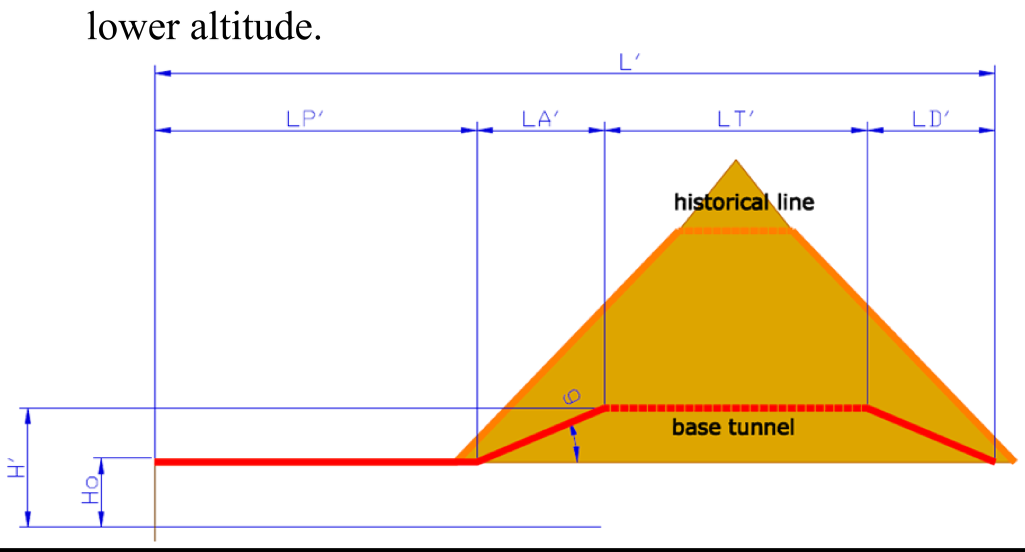
## Introduction

The environmental analysis of major transport infrastructure has been finally recently widened to include the construction stage in the last decades. However, the results of these studies mostly refer to new rail lines designed for passenger transport and in relatively easy orographic conditions. Most of the planned (and partially in construction) new Alpine railways are instead conceived as "mixed" traffic lines where freight traffic usually plays a significant role and require very important and costly engineering works, much more demanding in economic but also in energetic and environmental terms.
In this paper we build a simplified analytical model to assess the construction of a new rail base tunnel on a generic mountain transport corridor, in terms of energetic and greenhouse gas impacts. The model includes the construction and operating phases, assessing the embedded emissions of the construction and maintenance of the new infrastructure and the emission savings for both existing and mode shifting freight traffic. We also analysed the most recent sources that provide data to assess the impact of the construction and operating phases.
The model and data are then used to assess three similar new base tunnels now in construction or planned on the Alps: the Fréjus (Italy-France, projected), Gotthard (Italy-Switzerland, in construction) and Brenner (Italy-Austria, projected).

## The situation

We analyse a generic mountain (Alpine) pass, with an existing road path, an existing "historical" rail line (both with possible tunnels on top), and eventually a new rail line, with a base tunnel at a lower altitude.




## Impacts during the construction phase

In this research we refer to most of the disaggregated values indicated by Network Rail (2009). For the energy used for the tunnel excavation, we propose a more specific method based on Bieniawski et al. (2012).

Using the average Italian value of 410.3 gCO2/kWh, we obtain a value of 166.8 tonnes CO2eq per ground level rail-track km per year and 775-790.6 tonnes CO2eq per tunnel rail-track km per year.

## Impacts during the operating phase

For road transport we assessed the energy consumption as suggested by Bowyer, Ackelik & Biggs (1985), with respect to four principal resistances:

-rolling and aerodynamic (drag) resistances,

-inertia (during acceleration and deceleration), and

-weight (in slopes).

For rail transport we assessed the same resistances of road transport as suggested by Lindgreen and Sorenson (2005). An additional drag resistance in tunnels has been calculated following Yi et al. (2011).

Emission benefits in the operating phase or the transport activity are due to:

- The reduction in emissions for existing rail transport;
- The reduction in emissions for traffic shifted from road to rail transport.

Moreover the new infrastructure will require ventilation and lightning. In very long rail tunnel ventilation is dimensioned mainly on emergency needs (control of smoke propagation in the case of fire). A smaller part of this ventilation power is used in normal conditions to lower high temperatures, to improve passenger comfort and safety equipment in technical rooms, as well as provide acceptable working conditions during maintenance. Consulted literature does not agree on the value, we used 0.12 GWh/km p.a.

## A simplified model to assess GHG emissions balance

We write the equations of the emissions of the operating phase without the new infrastructure (E1) and of the construction and operating phases with the new infrastructure (E2).
Considering constant traffic volumes, we obtain the amount of traffic shifted from road to rail needed to reach a positive balance.

$$Q_{shift} > \frac{1}{e_{road} \cdot d_{road} - e'_{rail} \cdot d'_{rail}} \cdot \left[\frac{E_{constr}}{T} + e_{O\&M} - (e_{rail} \cdot d_{rail} - e'_{rail} \cdot d'_{rail}) \cdot Q_{rail}\right]$$

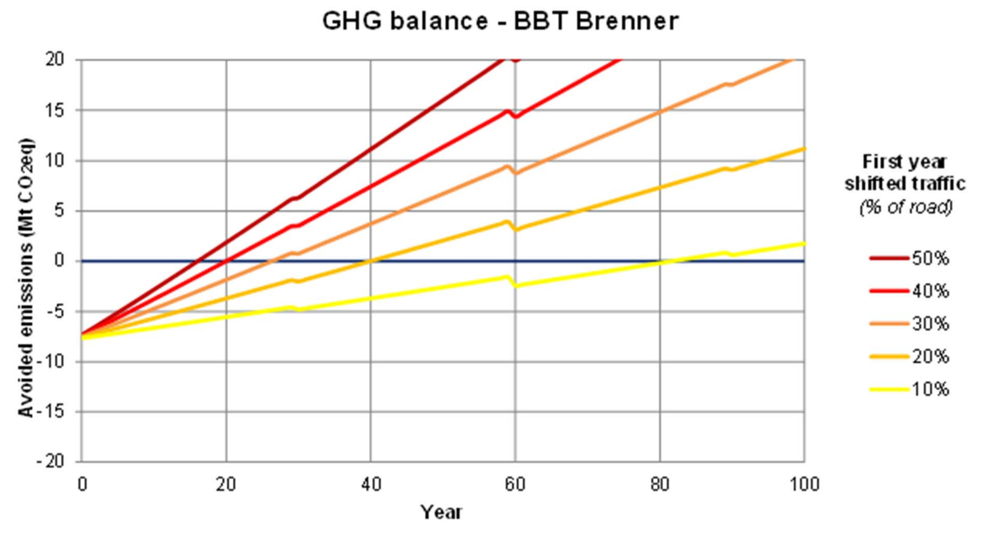
Where $Q_{shift}$ is the shifted traffic and $Q_{rail}$ the existing traffic on the rail, $E_{constr}$ the emissions of the construction, $e_{O\&M}$ the emissions of the operation of the infrastructure, $e_i$ are the unit emissions of the transport activity of the mode $i$, $d$ the average distance and $T$ the time horizon.
If we consider a logarithmic traffic growth of the form $Q_i(t) = r_i \cdot \ln(t) + Q_{i0}$, we obtain the first year needed shifted traffic.

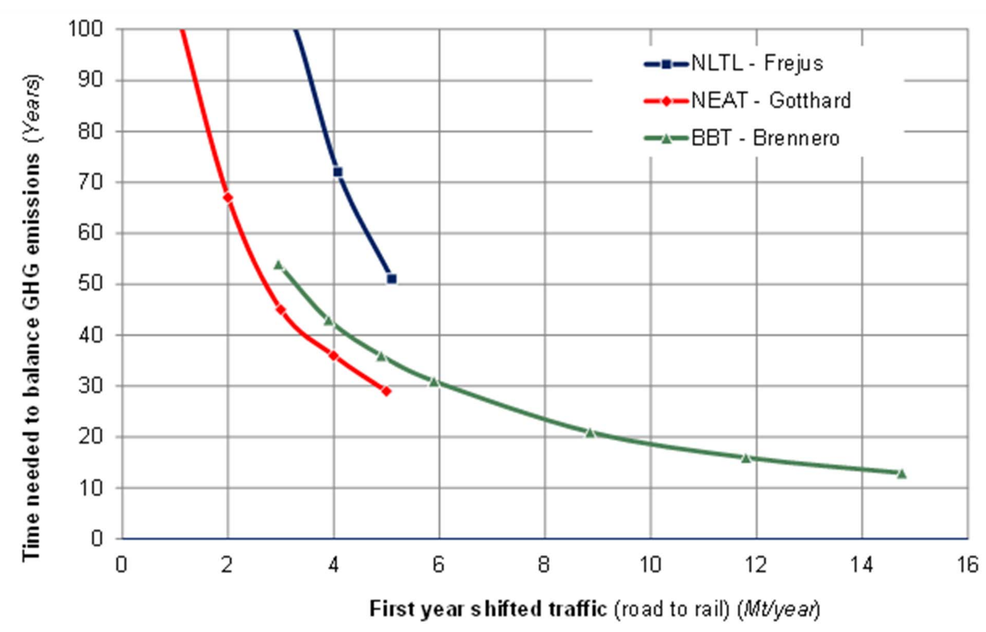
$$Q_{shift_0} > \frac{1}{e_{road} \cdot d_{road} - e'_{rail} \cdot d'_{rail}} \cdot \langle \frac{E_{constr}}{T} + e_{O\&M} - (e_{rail} \cdot d_{rail} - e'_{rail} \cdot d'_{rail}) \cdot \{Q_{rail_0} + r_{rail}[ln(T) - 1]\}\rangle + -r_{road}[ln(T) - 1]$$

## Case studies and results

The developed model is used to assess three new base tunnels now in construction or planned on the Alps: the Frejus (Italy-France, projected), Gotthard (Italy-Switzerland, in construction) and Brenner (Italy-Austria, projected).

Using the relations in the previous sections, we can plot the abaci which represent total GHG emissions on a certain time horizon with respect to a given traffic shifted from road to rail. These abaci easily allow to find breakeven years of emissions, that is how many years of operation are needed to recover the negative emissions of the construction.




## Conclusions

On the considered Alpine case studies, the parameters that seem to play a major role are those related to the volume of existing and potentially shiftable rail traffic. Other factors that play a role are: geographical factors such as altitude gap, gradient and access length; and the characteristics of the involved soil and rocks (even if preliminary results suggest that concrete production is by far the most polluting phase, and not the excavation energy).
The preliminary results for the considered case studies suggested that the sole construction of an Alpine rail base tunnel of 50-60 km generates 7-8 mCO2eq tonnes, and that a shift of some 5-6 million tonnes from road to rail transport is needed to achieve a positive GHG balance within 50 years.
It must be moreover reminded that a positive GHG balance is not sufficient to judge the convenience to invest in such infrastructure and that comprehensive cost-benefit analyses, including also the impact of the construction phase, are needed. With respect to this it is worth noticing that 7-8 mCO2eq tonnes valued at 90 €/CO2 per tonne have a social cost of 630-720 m€ (about 1/10 of the construction costs).

## Some references

Network Rail (2009). *Comparing environmental impact of conventional and high speed rail.*

Bieniawski et al. (2012). *Specific energy of excavation in detecting tunnelling conditions ahead of TBMs.*

Bowyer, Ackelik & Biggs (1985), *Guide to Fuel Consumption Anyses for Urban Traffic Management.*

Lindgreen and Sorenson (2005), *Simulation of Energy Consumption and Emissions from Rail Traffic.*

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