Zurich, June 15-17 2016
Sustainable Built Environment (SBE) Regional Conference

Expanding Boundaries:
Systems Thinking for the Built Environment

ENVIRONMENTAL EFFECTS OF AN ALPINE SUMMIT TUNNEL

F. Gschösser[1,2]*, W. Purrer[3], P. Sander[4]

[1] Leopold-Franzens University of Innsbruck, Unit of Project and Construction Management, Technikerstraße 13, A-6020 Innsbruck, Austria

[2] floGeco – Environmental Management, Hinteranger 61d, A-6161 Natters, Austria

[3] Construction Contract Consultant Purrer, General-Feurstein-Straße 23c, A-6020 Innsbruck, Austria

[4] RiskConsult GmbH, Technikerstraße 32, A-6020 Innsbruck, Austria

*Corresponding author; e-mail: florian.gschoesser@uibk.ac.at

Abstract

Since many years the construction of a summit tunnel on the analysed alpine pass route is discussed (*due to confidentiality reasons the name of the route cannot be disclosed). In recent years a tunnel-path study and a traffic analysis were carried out to determine the optimum position for the tunnel and its influence on the traffic situation.

This Life Cycle Assessment (LCA) study analyses construction, maintenance and operation of the optimum tunnel variant over an analysis period of 100 years. The LCA results consider the new traffic situation and the environmental savings caused by the shortened and flattened route due to the new tunnel.

The analysis of the tunnel bases on data from the path study, geological studies, comparable tunnel projects and expert knowledge. The tunnel has a total length of 1.500 m and a maximum gradient of 4 %. A rescue tunnel with a length of 600 m accompanies the main tunnel. The tunnel is constructed by applying the New Austrian Tunnelling Method (NATM).

The traffic LCA evaluates both the situations with and without tunnel for the years 2013 and 2025 (based on the traffic analysis). The existing tunnel causes a traffic load rise on the pass route, what furthermore causes more traffic jam situations on main traveling days.

The results show that the environmental impacts caused by constructing, maintaining and operating the tunnel are environmentally “amortised” within a short period due to the usage of the tunnel and the shorter route as well as the avoidance of the top of the pass (for Global Warming Potential within 10 years, for Acidification Potential within 5 years, for Non-renewable Cumulative Energy Demand within 6 years). These results show the great environmental potential of route-shortening transport infrastructures.

Due to the short “amortisation period”, the influence of future engine technologies and fuels was considered only in a qualitative form.

Keywords:

Alpine summit tunnel; Life cycle assessment; Construction; Maintenance; Operation; Traffic

1 INTRODUCTION

Since many years there was an on-going discussion regarding the construction of a summit tunnel on this alpine pass route. In recent years a tunnel-path study and a traffic study were carried out to determine the optimum position for the tunnel and its influence on the traffic situation.

Based on these two studies a Life Cycle Assessment (LCA) was carried out to demonstrate the environmental influence of a tunnel on the pass route. This LCA study analyses construction, maintenance and operation processes of the optimum tunnel variant over an analysis period of 100 years. The results of the tunnel LCA are compared to

G. Habert, A. Schlueter (eds.): Expanding Boundaries © 2016 vdf Hochschulverlag AG an der ETH Zürich
DOI 10.3218/3774-6_57, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

the new traffic situation and the environmental savings caused by the (due to the tunnel) shortened and flattened route.

Thus the core issue of this study can be expressed as:

When will the optimised route and the connected environmental savings due to less fuel consumption compensate the environmental impacts caused by the tunnel construction, maintenance and operation?

2 BACKGROUND

2.1 Tunnel-path study

The goal of the study was the development of several path variants for a tunnel undercutting the summit of the pass route. Also a rough cost overview for all developed variants and specific recommendations for further project steps are included.

Finally, the path variant with two tunnel sections connected by an open track was chosen to be the optimum solution due to its low longitudinal gradient (max. 4 %), short tunnel length (1070 m and 500 m), little safety requirements (rescue tunnel 600 m) and lower construction costs (€ 67 Mio.).

2.2 Traffic study

Within this study the traffic-influence of the tunnel was analysed for two different situations:

- Working days
- Traveling days (winter and summer)

For average working days the study determined the number of journeys over the pass route for both the situation with and without the summit tunnel. Thereby the focus was put on the traffic growth due to the new tunnel. *Table 1* shows the total number of journeys on an average working day of the year 2013.

For traveling days the focus was put on the number of journeys with congestion or slow moving situations and the caused delay time (*Table 2*). Due to the fact that the pass route already tends to take maximum traffic loads on traveling days, no traffic growth for the situation with the new tunnel was considered. The traffic loads were taken from traffic counts on typical traveling days (2013). However, a traffic growth of 10% for the analysed period (2013 to 2025) was considered. *Table 1* shows the total number of journeys for typical traveling days of the year 2013.

The percentage of journeys within congestion or slow moving situations was determined to be 32% of the daily traffic load for traveling days in winter and 50 % for traveling days in summer.

	Working day 2013				**Traveling day - winter 2013**		**Traveling day - summer 2013**	
Transit traffic via the pass	**Without tunnel**		**With tunnel**		**Without & with tunnel**		**Without & with tunnel**	
Direction North	Cars	Lorries	Cars	Lorries	Cars	Lorries	Cars	Lorries
A – D	821	364	966	377	4938	216	1039	62
B – D	1952	409	2177	406	4664	204	2390	143
Direction South								
D – A	900	210	1070	211	5572	222	1385	85
D – B	2492	563	2857	565	5498	219	2985	184
Originating and terminating traffic via the pass								
Direction North	Cars	Lorries	Cars	Lorries	Cars	Lorries	Cars	Lorries
C – D	291	13	297	14	1371	60	2202	132
Direction South								
D – C	571	17	592	19	1313	52	2353	145
Originating and terminating traffic via A								
Direction North	Cars	Lorries	Cars	Lorries	Cars	Lorries	Cars	Lorries
A – C	4401	80	4399	80	4738	40	3096	86
Direction South								
C – A	4505	75	4506	73	6411	76	2994	91
Originating and terminating traffic via B								
Direction North	Cars	Lorries	Cars	Lorries	Cars	Lorries	Cars	Lorries
B – C	500	16	493	15	51	2	1093	263
Direction South								
C – B	528	17	523	16	53	2	1374	17
Transit traffic A – B								
	Cars	Lorries	Cars	Lorries	Cars	Lorries	Cars	Lorries
A – B	86	11	89	11	86	11	43	6
B – A	61	5	60	5	61	5	31	3

Table 1: Total number of journeys per day for 2013.

G. Habert, A. Schlueter (eds.): Expanding Boundaries © 2016 vdf Hochschulverlag AG an der ETH Zürich
DOI 10.3218/3774-6_57, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

Traveling day - winter					
Direction north			Direction south		
A - D			D - A		
Lost time [min]	*without tunnel*	*with*	*Lost time [min]*	*without tunnel*	*with*
2013	26	31	2013	18	16
2025	40	41	2025	24	22
B - D			D - B		
Lost time [min]	*without tunnel*	*with*	*Lost time [min]*	*without tunnel*	*with*
2013	27	35	2013	16	16
2025	42	54	2025	22	22
Traveling day - summer					
Direction north			Direction south		
A - D			D - A		
Lost time [min]	*without tunnel*	*with*	*Lost time [min]*	*without tunnel*	*with*
2013	34	34	2013	18	18
2025	55	57	2025	40	32
B - D			D - B		
Lost time [min]	*without tunnel*	*with*	*Lost time [min]*	*without tunnel*	*with*
2013	35	35	2013	16	18
2025	56	74	2025	39	32

Table 2: Time loss due to congestion.

3 LIFE CYCLE ASSESSMENT (LCA)

3.1 Tunnel LCA

The goal of the tunnel LCA study is the environmental assessment of the construction processes of the tunnel as well as its maintenance and operation over 100 years [1]. The system boundaries include all construction, maintenance and operation processes over the analysis period. The functional unit of the study is defined as "one tunnel built for the traffic volume occurring on the pass route over 100 years".

It is assumed that for tunnel excavation NATM (New Austrian Tunnelling Method, drilling and blasting) is applied. The new construction processes were modelled together with experts from construction companies. Based on the geological situation based on the tunnel-path study the specific tunnel excavation and support categories were defined.

In the next step all required construction and auxiliary materials, construction equipment, energy resources as well as all transport (to construction site and landfill) and landfill processes (excavation material) were determined for each excavation and support category.

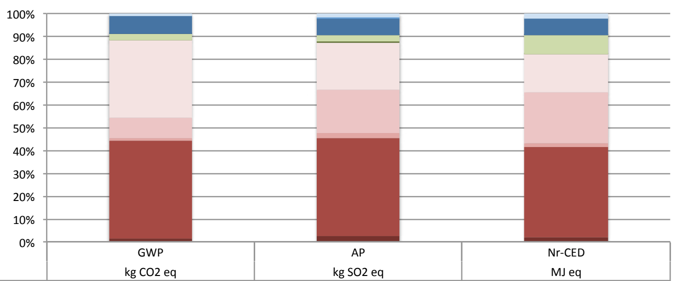
In accordance with the involved tunnelling experts it was defined that all maintenance processes occurring over the analysis period of 100 years can be considered by a surcharge of 10 % for all construction processes.

The environmental impacts of the construction processes were analysed in a very detailed manner. Due to the limited content of this paper only the overall results for construction processes (incl. maintenance surcharge, rescue tunnel and road construction) are depicted (Fig. 1).

The indicators utilized to express the environmental impacts are:

- Global Warming Potential (GWP) [kg CO_2 eq]
- Accidification Potential (AP) [kg SO_2 eq]
- Non-renewable Cumulative Energy Demand (Nr-CED) [MJ eq]

The LCA was conducted using the software SimaPro and the ecoinvent database 2.2.



	GWP kg CO2 eq	AP kg SO2 eq	Nr-CED MJ eq
Safety tunnel - excavation material landfill	0,9%	1,9%	2,2%
Safety tunnel - excavation material transports	0,1%	0,2%	0,2%
Safety tunnel - driving	7,8%	7,4%	6,9%
Safety tunnel - transports	0,1%	0,2%	0,1%
Road - pavement	2,7%	2,8%	8,2%
Road - transports	0,3%	0,6%	0,5%
Tunnel - inner shell	33,8%	20,5%	16,7%
Tunnel - excavation material landfill	9,0%	19,1%	22,0%
Tunnel - excavation material transport	1,2%	2,2%	1,7%
Tunnel - driving	42,7%	42,5%	39,6%
Tunnel - transports	1,4%	2,7%	2,0%
Sum (percentage)	100,0%	100,0%	100,0%
Sum (absolute)	2,97E+07	8,33E+04	3,38E+08

Fig. 1: LCA results tunnel new construction including maintenance.

DOI 10.3218/3774-6_57, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

The results in Fig. 1 show the great influence of tunnel excavation processes and the construction of the inner lining. These great influences are mainly caused by the shotcrete applied for the tunnel excavation and the concrete forming the inner lining.

The main components for the tunnel operation are electric lighting and ventilation. The equipment and the required electricity needed for the tunnel operation were modelled according to data of similar tunnels. Additional operation processes (e.g. for tunnel safety equipment) were considered by a surcharge of 5 % on top of electric lighting and ventilation. The comparison of the environmental impacts of the tunnel operation over 100 years and all construction processes (including maintenance surcharge) shows that operation processes cause only 20 to 40 % impact in comparison to construction and maintenance processes. Traffic LCA

For the traffic LCA in a first step the longitudinal gradients of the pass routes were modelled for the situation with and without the tunnel.

In 2013 the average fuel consumption in Austria was 6 litres per 100 km for diesel operated and 7 litres for gasoline operated passenger cars. The average fuel consumption for an average lorry was 25 litre diesel per 100 km. Fuel consumption increases with a rising longitudinal gradient. Downhill this extra fuel consumption should be theoretically compensated by the potential energy obtained when driving uphill. However, this theoretical compensation cannot be achieved in practice due to necessary braking manoeuvres. In agreement with consulted mechanical engineers, it was set that when going downwards 50 % (cars) respectively 10 % (lorries) of the extra consumption for uphill gradients is compensated. The additional fuel consumption to travel differences in height is determined by the following formula [2]:

$$F_{height}\left[\frac{l}{100\ km}\right] = mass\ [kg] * height\ difference\ [m] * \frac{1}{1000 * 3600} * \frac{100}{distance\ [km]} * \frac{1}{0{,}98}$$

$$\upsilon_{Pe}\ \left[\frac{l}{kWh}\right] \ldots consumption\ efficiency\ \left[\frac{l}{kWh}\right] \ldots 0{,}264\ for\ gasoline;\ 0{,}220\ for\ diesel \qquad (1)$$

Regarding the fuel consumption during congested conditions, it was defined (in accordance with the consultants) that the consumption within three minutes congestion corresponds with the consumption for one kilometre average ride. Based on this approach the consumption per minute of delay time during congested conditions was determined.

With the different fuel consumptions (average, height differences, congestion), the daily number of journeys (2013 and 2015) and the percentage of journeys affected by congestion the total fuel use on average working days and traveling days was calculated for the scenario with and without the tunnel. The number of traveling days was determined within the traffic study (17 winter, 24 summer). For the remaining days of the year the fuel usage of an average working day was applied. As a next step the average fuel use for 2013 and 2025 was calculated and utilized for the comparison between the scenario with and without the tunnel.

4 TUNNEL VS. TRAFFIC

The last part of the LCA study compares the results of the tunnel LCA with the environmental savings generated by the reduction of fuel consumption due to the tunnel. Fig. 2 to Fig. 4 demonstrate the environmental effects of the summit tunnel. The impacts caused by the construction occur over a period of two and a half years (these impacts already include the 10% surcharge for all maintenance processes). The environmental savings due to the reduced fuel consumption were determined for the years 2013 and 2025. Thus, the recovery of the construction impacts is determined separately for the savings of both years and with a linear approach. The impacts caused per year of tunnel operation counter the yearly savings caused by the fuel reduction.

Although the tunnel causes a higher traffic load on the pass route, the results show that the environmental impacts, caused by the tunnel construction, maintenance and operation, are environmentally “amortised” within a short period. This amortisation is cause by the usage of the tunnel and the shorter route as well as the avoidance of the top of the pass (for Global Warming Potential within 10 years, for Acidification Potential within 5 years, for Non-renewable Cumulative Energy Demand within 6 years). Since the analysis period was set to 100 years, future developments regarding engine technologies and fuels should be considered within the study. However, due to the short “amortisation period” the influence of these future technologies was taken into account only in a qualitative form (Fig. 2 to Fig. 4).

G. Habert, A. Schlueter (eds.): Expanding Boundaries © 2016 vdf Hochschulverlag AG an der ETH Zürich
DOI 10.3218/3774-6_57, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

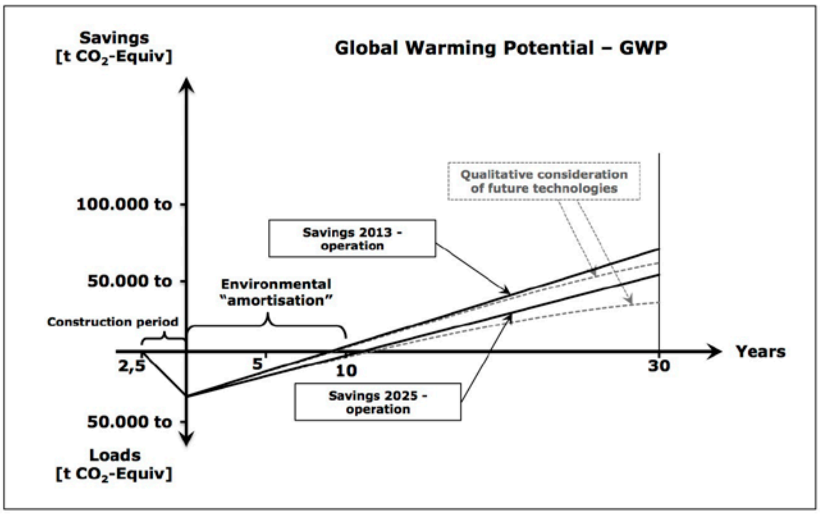


Fig. 2: Environmental effect of the tunnel – GWP

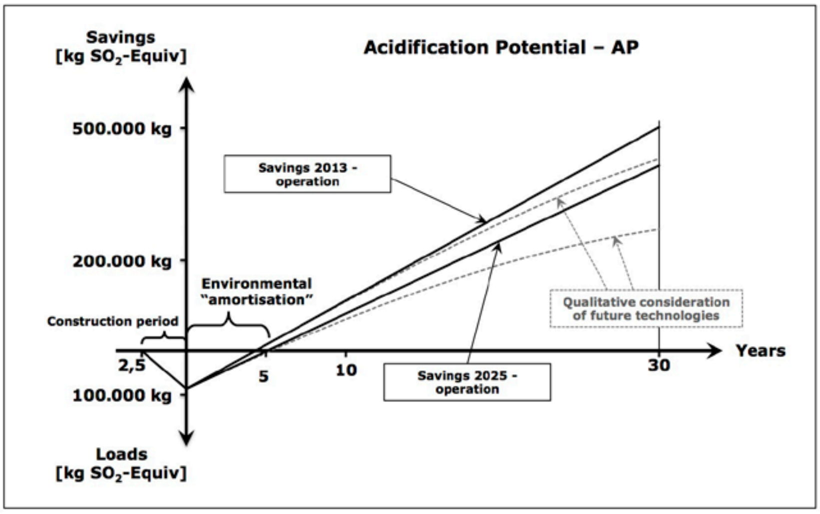


Fig. 3: Environmental effect of the tunnel – AP.

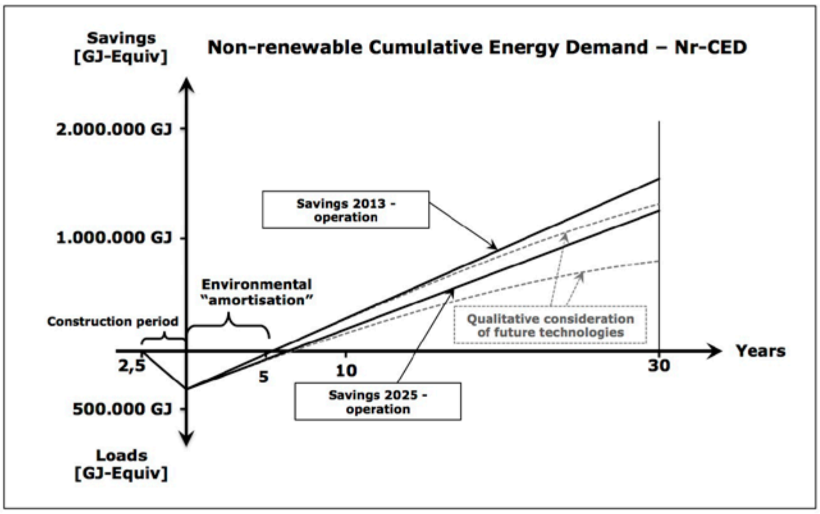


Fig. 4: Environmental effect of the tunnel – Nr-CED.

G. Habert, A. Schlueter (eds.): Expanding Boundaries © 2016 vdf Hochschulverlag AG an der ETH Zürich
DOI 10.3218/3774-6_57, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

5 DISCUSSION AND CONCLUSIONS

The results of this LCA study underline the great environmental potential of route-shortening transport infrastructures such as tunnels and bridges.

However, the study does not include further aspects, which need to be considered for an overall sustainability assessment of a transport infrastructure (e.g. noise generation, disturbances for residents, economic aspects, etc.) [3]. At the moment the working group 6 of the CEN/TC/350 develops standardisation documents for the sustainability assessment of civil engineering works aiming to include all necessary aspects and indicators [4]. These standardisation documents can then be the base for future (overall) assessments of transport infrastructures.

6 REFERENCES

1. ISO, *ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework*. 2006, International Standard Office: Geneva.

2. Liebl, J., et al., *Energiemanagement im Kraftfahrzeug*. 2014: Wiesbaden.

3. Gschösser, F. and H. Wallbaum, *Life Cycle Assessment of Representative Swiss Road Pavements for National Roads with an Accompanying Life Cycle Cost Analysis.* Environmental Science and Technology, 2013. **47**(15): p. 8453–8461.

4. CEN. *Overview of CEN/TC 350*. 2015 [cited 15.01.2015 15.01.2015]; Available from: http://portailgroupe.afnor.fr/public_espacenormalisation/centc350/chairman_remark.html.

G. Habert, A. Schlueter (eds.): Expanding Boundaries © 2016 vdf Hochschulverlag AG an der ETH Zürich
DOI 10.3218/3774-6_57, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html