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EU Strategy for the Alpine Region EUSALP – Action Group 4 Mobility

External costs in mountain areas

Final Report
Zurich, 16 December 2017

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Executive Summary

Background and objectives

The internalisation of external cost of transalpine transport is a major claim and challenge in the context of a coordinated modal-shift approach, mainly in the Alpine Region. An in-depth analysis of the environmental costs in the Alpine Region has been done within the research project GRACE (2006), where the differences in the environmental costs of road and rail transport costs between mountain and non-mountain areas were analysed. The study suggested so-called 'mountain factors' describing the differences in external costs between mountain areas and non-mountain areas.

Since 2006, there has been no comprehensive update study of the external costs in mountain / sensitive areas. Therefore, the present study aims to validate and update the mountain factors, mainly focussing on the methodological approach of the GRACE study (2006). To do so, all cost drivers that influence the different environmental costs are reassessed, considering the latest research results (e.g. Oekoscience 2013, Ecoplan, INFRAS 2014, HBEFA 2017, CNOSSOS-EU 2012). Furthermore, possible additional cost drivers are examined as well as additional cost categories are analysed (e.g. accident costs, costs for nature and landscape). Finally, new mountain factors for Alpine regions are suggested.

Methodology

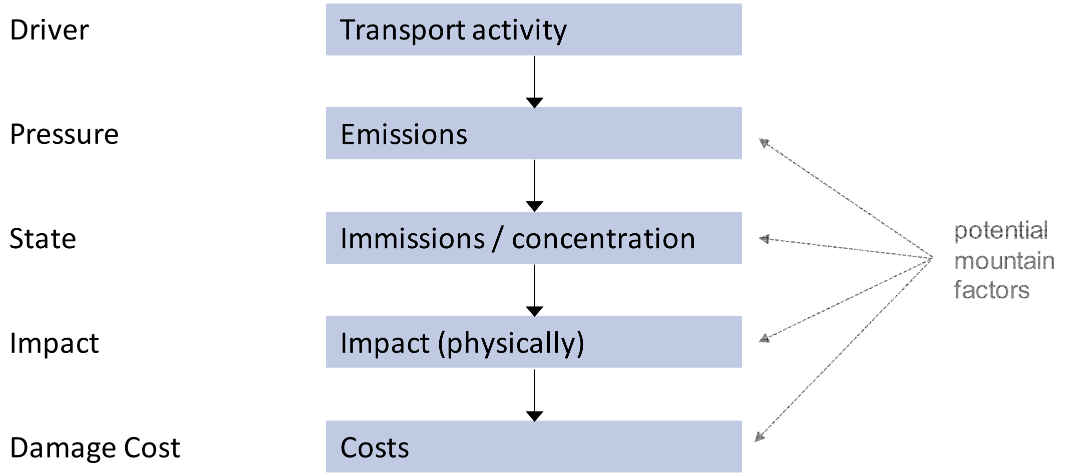
The following cost categories are investigated in the present study: air pollution, noise, nature and landscape, accidents and climate change.

The analysis to derive cost factors (mountain factors) follows a specific approach along the so-called 'impact pathway approach' (see Figure S-1), which is the main methodology to assess environmental costs based on a damage cost approach. Hence, the methodological approach used in the present study is the same as in the GRACE study (2006), which is based on cost drivers and 'cost differential factors' (mountain factors) along the impact-pathway:

- Emissions: higher emission level e.g. due to gradients and altitude.
- Concentration/immissions: higher concentration of air pollutants e.g. due to topographical and meteorological conditions.
- Impacts: different impacts based on the dose(concentration)-response evidence, e.g. due to other population density or other risk factors.
- Damage cost: different cost factors for damage costs, i.e. due to country-specific monetization factors, specific prices, etc.

In total, the mountain factors for all levels of the impact-pathway approach result in an overall factor for the cost per transport performance (vehicle-km) in mountain regions in comparison to non-mountain regions (or a country average). The result of the analysis is a 'mountain factor' for a certain category of external costs (e.g. air pollution costs, noise costs, accident costs) and transport mode (road, rail).

Figure S-1: Impact pathway approach to derive mountain factors



Source : INFRAS.

The present study focuses on rail and road freight transport. The analysis is based on a corridor approach, which means that the factors derived apply to whole corridors and not only specific infrastructure factors. The corridor specific view allows the derivation of one consistent factor for a whole transit corridor.

The focus of the analysis is on the Gotthard and Brenner corridors. An inclusion of more corridors would have been desirable, but was not possible within the present project. Still, the mountain factors can also be applied to other Alpine corridors. The mountain factors resulting from the study are always referring to possible costs per vehicle-km (or train-km), like in the GRACE study (2006). Hence, the mark-up factors could be applied on a toll per vehicle-km.

Results

The following table summarizes the main results of the present study, showing the mountain factors for the different external cost categories. Additionally, the values of the GRACE study (2006) are also represented as a comparison. Please note that the different mountain factors do not say anything about the *absolute* level of external costs, but only represent the factor between external costs in mountainous and external costs in non-mountainous areas.

Table S-1: Mountain factors for external costs of transport

	Present EUSALP study		GRACE study (2006)	
Cost category	**Road transport**	**Rail transport**	**Road transport**	**Rail transport**
Air pollution	**4.2** (1.3 – 14.2)	**2.6** (0.9 – 6.6)	5.25 (2.4 – 19.8)	3.5 (2.1 – 5.2)
Noise	**4.1** (1.3 – 14.7)	**3.0** (1.0 – 11.25)	5.0 (2.3 – 19.8)	4.15 (2.1 – 10.4)
Nature & landscape	**1.3** (1.0 – 1.6)	**1.4** (0.8 – 2.0)	n.a.*	n.a.*
Accidents	**3.9**	n.a.	n.a.	n.a.

The values in brackets indicate the sensitivity intervals (lower and upper level). n.a.: not available / no data available.
* for visual intrusion, the GRACE study suggested a factor of 10.7 for road transport and 5.3 for rail transport.

Table INFRAS.

The results of the analysis of external costs of transport in mountain areas can be summarized as following:

- For **air pollution costs**, there is substantially new information and data available for a profound update of the mountain factor. The main cost driver for the air pollution costs in the Alpine Region are the higher immissions due to inversion (factor 4.4). Other cost drivers are the higher emissions due to the higher gradients and the altitude. The resulting mountain factor for air pollution is slightly lower than in the GRACE (2006) study, which is mainly a result of the lower factor for population density, which outweighs the slightly higher value for the immission (concentration). However, the adjustment of the population density can be justified due to a more detailed analysis in the present study based on geographical information system (GIS) data.
- For **noise costs**, there is only partially new scientific evidence for deriving mountain factors. Above all, for the noise immission no update of the factor was possible. The other cost drivers have been updated and the resulting mountain factor for noise costs is also lower than in the GRACE (2006) study. Again, this is mainly a result of the lower factor for population density. The main cost driver for the noise costs in Alpine regions are the higher immissions due to topographical and meteorological conditions (inversion, amphitheatre effect).
- For **nature and landscape**, a mountain factor has been derived for the first time. Based on detailed results of the Swiss study on external costs of transport, significantly higher costs for habitat loss and habitat fragmentation in mountain areas compared to non-mountain areas can be derived. The resulting mountain factors are 1.3 for road (motorways) and 1.4 for rail transport and can be regarded as a sound basis.
- For **accident costs**, there is also evidence for higher costs in mountain areas, mainly due to higher infrastructure investments to keep the accident rate as low as possible. For the first

time, a mountain factor has been derived for accident costs. The calculation is based on an abatement cost approach taking into account additional infrastructure safety measures on roads in Alpine corridors. The resulting factor for accident cost in mountain areas is 3.9.

- For **climate change**, a mountain factor cannot be derived due to methodological reasons (global issue with global effects).

Conclusions and recommendations

- Environmental costs in mountain areas are substantially higher than in other (average) areas. It is therefore desirable to adjust toll systems in mountain areas accordingly in order to give a correct price signal to transport users. Mountain factors are an adequate and simple way to adjust tolls on corridors in mountain areas.
- For air pollution costs, noise costs, accident costs and costs for nature and landscape, the present study suggests updated mountain factors that can be applied for toll systems. The mountain factors can be applied on average cost factors for environmental costs per vehicle-km for a transalpine corridor.
- The present study had to focus on selected corridors, mainly on the Gotthard and the Brenner corridor. However, the results can also be applied to other Alpine corridors, e.g. in France or Switzerland. It is recommended to conduct additional case studies for other corridors, such as French corridors, in order to broaden the scope.
- The analysis showed some significant gaps in knowledge on specific environmental effects or cost factors. Therefore, additional research is recommended for the following fields:
  - For noise costs, there are several cost drivers where new scientific basis would be needed. Mainly for the higher noise immission (concentrations) due to inversion and the amphitheatre effect in mountain regions there have been no new research since the publication of GRACE, although this effect is very substantial. Also, for the higher noise emissions due to gradients of the infrastructures new research would be desirable.
  - Since the populations density is a very crucial factor with a high variety between different regions, it is advisable to conduct more detailed (GIS based) analysis of this factor.
  - To enhance the validity of the results for the mountain factor, analyses for additional Alpine corridors should be carried out (e.g. for French corridors).
  - For accident costs as well as cost for nature and landscape, the present study recommends mountain factors for the first time. For both cost categories, the results could be further deepened, e.g. for additional corridors or for rail in the case of accident costs. The analysis of habitat loss could be updated and deepened based on recently built road or rail infrastructures.
  - Additional research is also recommended for other environmental effects that might be relevant for Alpine areas, e.g. visual intrusion.

1. Introduction and objectives

1.1. Background

The EUSALP Action Group 4 Mobility gathers representatives of 13 regions, five national states, three observers and three members in advisory role, offering a platform to coordinate and harmonise the activities of Alpine regions and countries for a sustainable transport and mobility system. Its mission is to build a common understanding of transport policy and mobility, to define common objectives and to launch specific activities and projects. Three priority topics have been identified:

- Implementation of modal shift policies with a focus on toll systems;
- Infrastructure for sustainable transport;
- and interconnecting public transport systems.

The internalisation of external cost of transalpine transport remains a major claim and challenge in the context of a coordinated modal-shift approach. The partner regions of the iMONITRAF! network signed a resolution to introduce a so called TollPlus system, which adds additional and harmonized prices for transalpine HGV in order to internalize additional external cost in the Alpine Region, to provide incentives for modal shift and to gain financial means for rail transport infrastructure and/or combined transport solutions. At the moment, a study – commissioned by the Suivi de Zurich process – is being carried out to design a possible TollPlus system.

Another important current process is the ongoing revision of the Eurovignette Directive at the European level, where the factors for external costs of transport and possibly mark-up factors for sensitive areas are being revised. According to the current Eurovignette Directive (2011), the external cost of air pollution and noise can be multiplied by a factor of up to 2 in mountain areas to the extent that it is justified (by the gradient of roads, altitude, temperature inversions and/or amphitheatre effect of valleys).

An in-depth analysis of the environmental costs in Alpine areas has been done within the EU research project GRACE. The case study “Environmental costs in sensitive areas” of the GRACE project has provided a comprehensive overview on external costs in mountain areas (GRACE 2006). The GRACE case study explains and assesses the differences in the environmental costs of road and rail transport costs between sensitive and non-sensitive areas, and finally derives so-called ‘mountain factors’ describing the differences in external costs between mountain areas and non-mountain areas.

Since 2006, there has been no comprehensive update study of the external costs in mountain / sensitive areas. However, there have been several new studies on the external cost of transport in Europe, mainly the EU Handbook in external costs of transport (first version: INFRAS et al. (2007), updated version: Ricardo-AEA et al. (2014)) as well as the German 'Methodenkonvention 2.0' on the estimation of environmental costs (UBA 2013; update is in progress: UBA 2017). Additionally, some recent studies have been analyzing specific aspects of the mountain factors, for example the higher concentration (immissions) of air pollutants (Ökoscience 2013 and 2014). Also, a recent French study (CEREMA 2016) has been analyzing the external costs in mountain areas. However, they did not conduct own calculations or modellings, but did a literature review of existing studies.

In order to update the results of the GRACE study and provide more recent data on the external cost on mountain areas, the EUSALP Action Group 4 Mobility has commissioned a study to evaluate and update the scientific basis for external cost in the Alpine Region, namely the so-called mountain factors.

1.2. Objectives

The objectives of the present study can be summarized as following:

The overall goal is to validate and update the mountain factors, mainly focussing on the methodological approach of the GRACE study (2006). To reach that overall objectives, the following goals are being pursued:

- Reassessment of cost drivers that influence the different 'cost differential factors' (= mountain factors),
- Consideration of recent knowledge (research) on environmental effects in mountain areas,
- Consideration of recent knowledge on external cost, mainly on additional effects like nature and landscape in sensitive regions,
- Evaluation of the robustness of the provided figures and ideas of further research.
- Derive new mountain factors for Alpine regions.

2. Methodology and scope

2.1. Sensitive Alpine regions

The Vienna Declaration of the UNECE Conference on Transport and the Environment (Vienna 1997) defined “sensitive areas” as a field of action requiring sustainable transport development. Sensitive areas are valuable for different reasons. These areas include rare landscapes and habitats, unspoiled areas, intact cultural historic landscapes and nature protection zones. These areas are valuable because of their material advantages, such as contribution to the purification of water and air, maintain biodiversity, protection against dangers, alleviation of climatic impacts, like for example floods etc. There are also non-material benefits, for example stress reduction, leisure time recreation and enjoyment of nature, sense of identity and home, etc.) for the individual and society as a whole (T&E 2005). The alpine region and their traffic corridors of international relevance are sensitive areas regarding all kind of traffic emissions.

2.2. Methodological approach

Until now, the case study of the GRACE project “Environmental costs in sensitive areas” (2006) has provided the most comprehensive overview on external costs in mountain areas. The aim of the case study was to explain and assess the differences in the transport costs per unit of transport performance (vehicle-km or train-kilometre) between a sensitive and an “insensitive” region. It does not provide bottom-up calculations but rather assesses “cost differential factors”, which can be applied to general marginal external costs. The basis for the analysis are so-called cost drivers, i.e. influence factors that are crucial for the higher transport costs in a sensitive area. This approach derives cost differential factors (or “mountain factors”) which are considerably higher than those currently used in the Eurovignette Directive (e.g. for road GRACE suggests mountain factors of around 5 for air quality and noise while a factor of 2 has been applied by the Eurovignette Directive).

The aim of the present study is to update the mountain factor from the GRACE project and to examine whether there are other cost drivers which, in sensitive regions compared to "non-sensitive" regions, would have an increased impact and should be taken into account by means of a mountain factor.

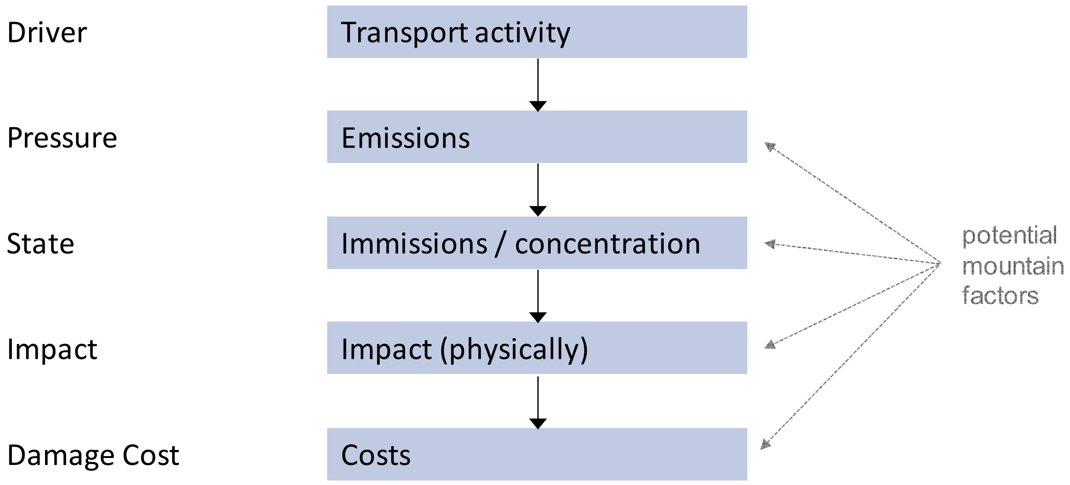
The cost categories investigated in the present study are air pollution, noise, nature and landscape, accidents and climate change.

The analysis to derive cost factors (mountain factors) follows a specific approach along the so-called ‘impact pathway approach’ (see Figure 1), which is the main methodology to assess (external) environmental costs based on a damage cost approach. Hence, the methodological approach used in the present study is the same as in the GRACE study (2006), which is based on cost drivers and 'cost differential factors' (mountain factors) along the impact-pathway:

- Emissions: higher emission level e.g. due to gradients and altitude.
- Concentration/immissions: higher concentration of air pollutants e.g. due to topographical and meteorological conditions.
- Impacts: different impacts based on the dose(concentration)-response evidence, e.g. due to other population density or other risk factors.
- Damage cost: different cost factors for damage costs, i.e. due to country-specific monetization factors, specific prices, etc.

In total, the 'differential factors' (mountain factors) for all levels of the impact-pathway approach result in an overall factor for the cost per transport performance (vehicle-km) in mountain regions in comparison to non-mountain regions (or a country average). The result of the analysis is a 'mountain factor' for a certain category of external costs (e.g. air pollution costs, noise costs, accident costs) and transport mode (road, rail).

Figure 1: Impact pathway approach to derive mountain factors



Source : INFRAS.

In general, HGV tolls are based on marginal cost (of infrastructure and environmental costs). When aiming at an efficient pricing system, the priced should be based on social marginal costs. However, there are the also pricing systems that aim to internalize the total external costs (and the infrastructure costs), like for example the Swiss HGV toll system. There, the average external costs are relevant.

In the present study, both average and marginal costs are looked at. The mountain factors derived can be applied to marginal as well as average costs. However, in some cases, the absolute level of external costs is different for average or marginal costs (e.g. noise costs or costs for nature and landscape). Still, the mountain factors are valid for moth marginal and average costs.

2.3. Scope and system boundaries

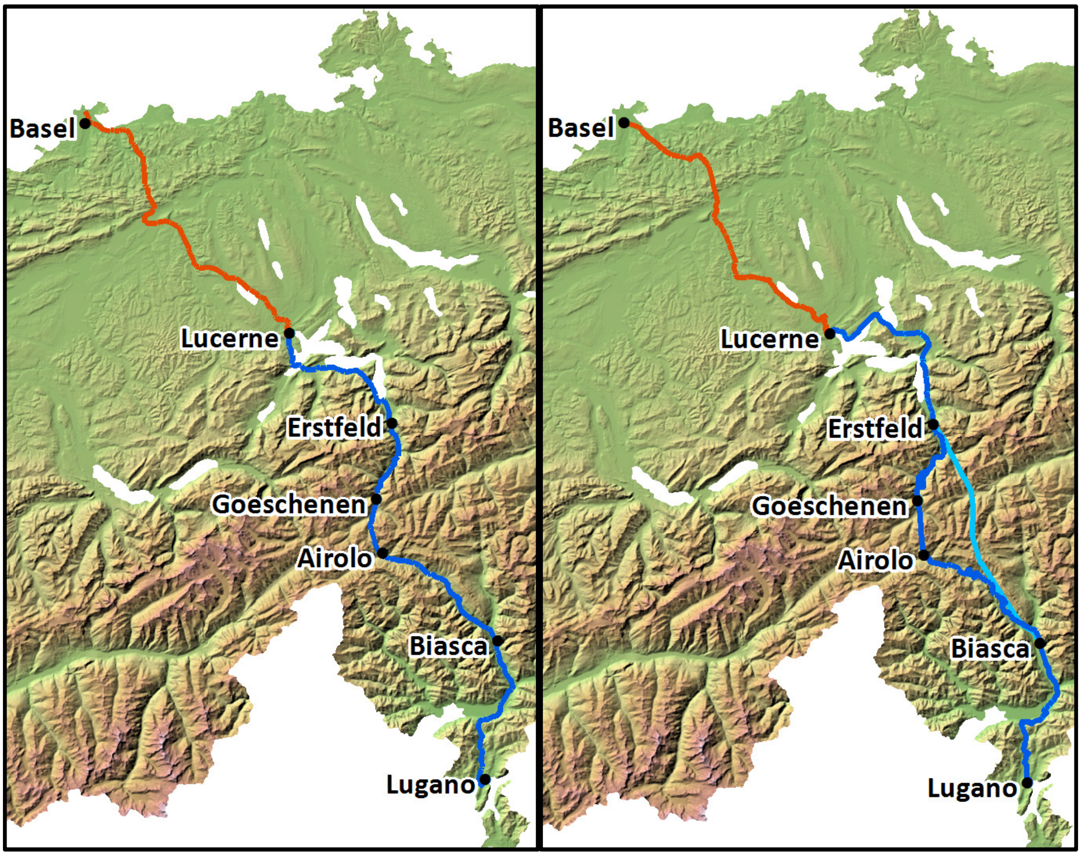
The investigations on the mountain factors only focus on rail and road freight transport. Passenger transport is not taken into account. The analysis was conducted based on a corridor approach, which means that the factors derived apply to whole corridors and not only specific infrastructure factors. This implies that new base tunnels (e.g. new Gotthard base tunnel, later Brenner) can possibly decrease some of the mountain factors of rail transport on the specific corridor, because the share of tunnel is much higher (in tunnels, the factors are lower, generally 1.0). A corridor specific view allows the derivation of one consistent factor for a whole transit corridor.

The focus of the analyses is on the Gotthard and the Brenner corridors. Some of the analyses were done for the Gotthard, some for the Brenner and some for both corridors. Figure 2 shows how the sensitive Alpine space along a corridor was defined using the Gotthard Corridor as an example. An inclusion of more corridors would have been desirable and would allow to make the analysis even more profound. However, this was not possible within the present project. Still, the resulting mountain factors can also be applied to other Alpine corridors.

The mountain factors resulting from the study are always referring to possible costs per vehicle-km (or train-km), like in the GRACE study (2006). Hence, the mark-up factors could be applied on a toll per vehicle-km (like the proposed cost factors in the Eurovignette Directive).

The geographical scope chosen for mountainous areas vs. non-mountainous areas follows the definition of the scope of the Alpine Convention, which is oriented on topographical and geographical criteria.

Figure 2: Road (left) and rail (right) transit corridors considered in this study



Left: Road corridor. Basel-Lucerne is the non-Alpine corridor (red line), Lucerne-Lugano the Alpine corridor (dark blue line). The “Gotthard Road Tunnel” is between Göschenen and Airolo.
Right: Rail corridor. Basel-Lucerne is the non-Alpine corridor (red blue line). There are two options for the Alpine corridor: the older rail tunnel “Scheiteltunnel” between Göschenen and Airolo (dark blue line) and the new “Gotthard Base Tunnel” between Erstfeld and Biasca (light blue line).

Figure INFRAS. Source: GIS data from DDPS (2016).

3. External cost analysis: mountain factors

In the following sub-chapters, the analysis of possible mountain factors for external costs of transport are analysed and (if relevant) calculated by cost category.

3.1. Air pollution

For the direct comparison of air pollution costs in Alpine and non-Alpine regions, only pollutants causing local damages are relevant. That is, the emission source and the damage resulting from that particular emission have to occur at the same location. We therefore focus on PM10 air pollutants causing damages to human health and infrastructure damage for the assessment of air pollution costs (GRACE 2006). As a first assumption, these factors can also be applied to other costs resulting from air pollution such as crop losses or biodiversity loss. In the present study, like in several other studies (e.g. Ecoplan, INFRAS 2014; GRACE 2006) the air pollution costs are analysed on the basis of PM10 as 'lead substance'. However, the results (mountain factors) can also be applied to external costs of other air pollutants such as NO_x.

3.1.1. Overview of cost drivers

As a summary of the whole chapter 3.1, the following two tables list the cost drivers for air pollution costs and their corresponding mountain factors for road and rail freight transport. More details about each cost driver are described in the subsequent sections.

Road transport

Table 1: Air pollution costs: mountain factors for road freight transport

Impact pathway	**Cost driver**	**Mountain factor**	**Short description (Source)**	**Chapter**
Pressure (emissions)	Gradient	1.03 (1.01 - 1.20)	Higher PM10 exhaust emissions from HGV due to higher gradients in Alpine regions (based on GIS elevation model and HBEFA 3.3)	3.1.2
	Altitude	1.34 (1.10 - 1.80)	Higher PM10 exhaust emissions from HGV due to higher altitudes in Alpine regions (based on Lieb et al. (2006) and Chao et al. (2011))	3.1.3
	Fleet	- *(1.0)*	*Different fleet composition could lead to different emissions. However, this should be directly covered by the HGV toll (differentiated cost factors)*	*3.1.4*
State (immissions, concentrations)	Inversion	4.36 (2.37 - 7.30)	Higher immission levels due to inversions and valley sides in Alpine regions (based on Oekoscience (2013))	3.1.5
Impact	Population density	0.7 (0.5 - 0.9)	Lower number of affected residents due to lower population density in Alpine regions (based on GIS analysis)	3.1.6
	Health risk	- *(1.0)*	*No evidence on higher health risk in mountain regions.*	*3.1.7*
Costs	*Specific damage costs*	- *(1.0)*	*Regional differences of cost factors due to different income levels not appropriate.*	*3.1.8*
Total mountain factor for air poll. costs		**4.2** **(1.3 – 14.2)**		

Mountain factors are restricted to the air pollutant PM10 and to damages to human health and infrastructure. Sensitivity intervals in brackets.

Table INFRAS.

Rail transport

Table 2: Air pollution costs: mountain factors for rail freight transport

Impact pathway	Cost driver	Mountain factor	Short description / Source	Chapter
Pressure (emissions)	Gradient	- (1.0)	No data available	3.1.2
State (immissions, concentrations)	Inversion	4.36 (2.37 - 7.30)	Higher immission levels due to inversions and valley sides in Alpine regions (based on Oekoscience (2013))	3.1.5
Impact	Population density	0.6 (0.4 - 0.9)	Lower number of affected residents due to lower population density in Alpine regions (based on GIS analysis)	3.1.6
	Health risk	- *(1.0)*	*No evidence on higher health risk in mountain regions.*	*3.1.7*
Costs	*Specific damage costs*	- *(1.0)*	*Regional differences of cost factors due to different income levels not appropriate*	*3.1.8*
Total mountain factor for air poll. costs		**2.6** **(0.9 – 6.6)**		

Mountain factors are restricted to the air pollutant PM10 and to damages to human health and infrastructure. Sensitivity intervals in brackets.

Table INFRAS.

3.1.2. Gradient

a. Causal chain and methodological issues

Road transport: Emissions from freight road transport in Alpine regions are higher than in non-Alpine regions. On non-winding motorways, which are dominating on the main freight road transit routes, this effect can be mainly attributed to steeper gradients in Alpine regions:

- The steeper the longitudinal inclination of the road, the more fuel is consumed from road vehicles for the same distance. Accordingly, the **exhaust PM10 emissions** are higher for steeper gradients as well. Descending slopes lead to lower emissions (lower fuel consumption, brake energy recovery).
- When driving on descending slopes, vehicles have to brake more, which will increase **non-exhaust PM10 emissions**. Unfortunately, there is no differentiation of different gradients in HBEFA 3.3 when it comes to non-exhaust PM10 emissions, which is why this effect cannot be included in the assessment. As a first guess, one can assume the same mountain factor for non-exhaust emissions than for exhaust emissions, which means the mountain factor can be applied to the total emissions and hence to the total health costs of air pollution.

Rail transport: For rail freight transport, exhaust PM10 emissions from electricity consumption occur at the place where the electricity is produced, depending on the energy source. That is, in an electric powered rail system, gradients do not influence the emission level of rail transport.

On the other hand, higher non-exhaust PM10 emissions from more braking on descending rail sections may be relevant (particularly with regard to the fact that non-exhaust particulate matter emissions contribute to a high and increasing share of total PM emissions (HBEFA 2017)). However, there is no quantitative evidence on the share of PM10 emissions caused from braking and from abrasion of overhead lines. It is therefore not possible to estimate a mountain factor due to gradients for railways at the current state of scientific knowledge. This topic might be an issue for further research.

According to the explanations above, we derive a mountain factor for freight road transport based on higher PM10 exhaust emissions in Alpine regions due to gradients. However, we do not estimate a mountain factor rail freight transport due to a lack of suitable data.

b. Data and methods

The following methodology only applies to the estimation of a mountain factor for road freight transport (see explanations above).

The mountain factor for higher emissions due to steeper gradients in Alpine regions has been estimated by comparing average PM10 exhaust emission factors of HGVs on flat roads in Switzerland with the analogous emission factors of the specific longitudinal inclination of the Gotthard road transit corridor. Four steps were followed to find the mountain factor:

1. The longitudinal inclination (in percentage) was calculated for each road section of the Gotthard road transit corridor according to a GIS elevation model of the region[1].
2. The resulting gradients per road section can be positive and negative (ascending/descending), which is why the absolute values were used. The gradients were weighted with the section length of the respective road section before a mean gradient was calculated. This mean value is an absolute value, which is indicated with a plus/minus sign. Obviously, the mean gradient for the Gotthard route is not representative for Alpine regions in general. Therefore, a short analysis of the mean gradient for the Brenner motorway route was carried out, in order to have a comparing value. To show the variance in gradients for different Alpine road corridors, the sensitivity analysis was made with a range of gradients (minimum: ±1%, maximum: ±6%) when calculating the mountain factor.
3. A polynomial function describing emission factors of HGVs depending on road gradients was created according to specific HGV emission factors[2] for the mean gradients of 0%, ±2%, ±4%

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[1] The GIS elevation model contains surface altitude values. Therefore, the values in tunnels had to be corrected since they are underneath the surface. The gradients in tunnels were linearly interpolated between the starting and ending point of the respective tunnel. The model was not corrected for bridges.

and ±6%. From that function, the HGV emission factor for the specific mean absolute gradient in the Gotthard road transit corridor was retrieved.

4. The PM10 exhaust emission factor of HGVs for the specific gradient in the Gotthard corridor was divided by the average Swiss PM10 exhaust emission factor for HGVs on a flat road.

The input data used in the assessment is depicted in Table 3.

Table 3: Input data (air pollution costs, gradient)

Data description	Source
GIS motorway route in the Gotthard corridor (Swiss Map Vector 500)	DDPS (2016)
GIS elevation model in the Gotthard corridor (DHM25/200m)	DDPS (2010)
PM10 exhaust emission factors of HGV differentiated for gradient levels (0%, ±2%, ±4%, ±6%)	HBEFA (2017)

Table INFRAS.

c. Results

The mean gradient in the Gotthard road transit corridor amounts to ±3%, which is considerably higher than the mean gradient on Switzerland's motorways (about ±0.96%). Accordingly, the HGV emission factor of PM10 exhaust on roads in Alpine areas is higher than the emission factor in flat areas by a factor of 1.03. This factor is smaller with a gradient of ±1% (factor 1.01) and considerably higher with a gradient of ±6% (factor 1.20). The table below gives an overview over the results. For the Brenner route, an average gradient of 2.3% has been calculated, which leads to a slightly lower mountain factor of 1.02. We suggest to use the value of 1.03 as main mountain factor, corresponding to an average gradient of 3% (as in the Gotthard route).

Table 4: Mountain factors for higher PM10 air pollution due to higher gradients in road freight transport

Gradient [%]	EF PM10 exhaust for HGVs [g/km]	Mountain factor [-]
±1.00	0.03893	1.01
±3.00	0.03959	1.03
±6.00	0.04627	1.20
Average Swiss motorway on a flat road (reference scenario for non-Alpine regions)	0.03849	1.00

The last row (grey colour) is the reference scenario for non-Alpine regions. I.e., the mountain factors are calculated by dividing the gradient-specific emission factor by the reference scenario emission factor. EF = emission factor.

Table INFRAS. Source: based on GIS elevation model and HBEFA 3.3.

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[2] The emission factors are derived from the 'Handbook on emission factors for road transport (HBEFA) 3.3' (HBEFA 2017).

3.1.3. Altitude

a. Causal chain and methodological issues

Road transport: Lieb et al. (2006) showed by means of two studies conducted in Switzerland that emissions from HGVs increase with increasing altitude. This effect occurs due to lower air pressure and oxygen contents in higher altitudes, which influence the engine performance and increase fuel consumption (Chao et al. 2011). Lieb et al. (2006) however pointed out that their mountain factor describing altitude effects is rather uncertain due to very little data availability, especially for particulate matter emissions.

Rail transport: There is no evidence for a similar altitude effect for rail transport systems, given they are powered with electricity.

b. Data and methods

The mountain factor of road freight transport for higher emissions due to higher altitudes is derived from literature. A literature research has been conducted with the aim to confirm or adapt the results found by GRACE (2006). Since 2006, one relevant study on the topic has been published by Chao et al. (2011) on emission characteristics of heavy-duty diesel engines at simulated high altitudes.

c. Results

In their experimental study, Chao et al. (2011) found that the increasing rate of smoke emissions from HGVs amounts to 35.7% between altitudes of 0-1000 m.a.s.l. and 33.2% between altitudes of 1000-2000 m.a.s.l. On average, the increase of smoke emissions per 1000 metres of altitude is about 34%. If we assume that the increasing rate of PM10 emissions is similar to smoke emissions, the mountain factor for higher emissions due to higher altitudes equals 1.34 according to the study by Chao et al. (2011).

In comparison, GRACE (2006) found a mountain factor of 1.35 for the same effect. Due to the high uncertainties, they chose to apply a broad sensitivity interval (1.1-1.6). The study by Chao et al. (2011) supports the result, provides further evidence and adds certitude to the result. However, the average difference in altitudes between Alpine and non-Alpine regions can vary depending on the transit corridor. According to the values from Chao et al. (2011) noted above, the increase rate between altitudes of 0-2000 m.a.s.l. could amount to about 80%. On the other hand, the increase rate may be close to zero for a smaller difference in altitude.

In line with the literature and results described above, we apply a mountain factor of **1.34** for higher emissions due to higher altitudes, with the broad sensitivity interval of 1.1 to 1.8.

The broad sensitivity interval is not only due to uncertainties in the estimation of the mountain factor, but also due to strong variations in altitude differences between Alpine corridors and non-Alpine regions.

3.1.4. Fleet

The truck fleet composition can vary a lot between different corridors. For example in Switzerland, the composition of the road fleet in transalpine freight traffic differs in size and technology from the average fleet composition in the country. In 2015 on transalpine routes the sum of EURO V (64%) and EURO VI (28%) vehicles is 92%. In the average Swiss truck fleet, the sum of EURO V (50%) and VI (17%) is 67% (BAV 2016, BFS 2017).

The two main reasons for these differences are the changes in regulations in Switzerland in the last 20 years and the fact, that freight forwarders use bigger trucks for long distance transports. The performance-related heavy vehicle charge (LSVA) is a federal charge that depends on the total weight, emissions level and kilometres driven in Switzerland, was introduced in 2001. In the same time the weight limit of 28 tons was increased up to 40 tons per vehicle. These two changes in regulations are mainly responsible for the renewal of the transalpine fleet composition. Bigger vehicles with a higher degree in capacity utilisation are also applied on long distance transports in the flatlands. This fact is not a reason for an increased mountain factor due to a higher average load factor.

Differences in the average load factor and differences in the average EURO class should be directly reflected in the HGV toll, since they are generally differentiated by EURO class and by weight class or number of axles.

A different composition of the fleet will of course lead to different external costs. However, this is not attributable to mountain areas but rather to transit routes in general. Therefore, it is not appropriate to introduce a mountain factor for the fleet.

3.1.5. Topographical and meteorological conditions

a. Causal chain and methodological issues

A specific emission in an Alpine valley can lead to a higher level of immissions compared to the same emission on flat regions. The reasons for that effect are meteorologically and geographically: meteorological inversions as well as valley sides can hinder the vertical and horizontal spread of air pollutant emissions and therefore lead to an enhanced concentration in mountain valleys. (Oekoscience 2013). This effect applies for road and rail transport equally.

b. Data and methods

The estimation of the mountain factor for higher immissions is based on a study specifically looking at measured immission levels in different Alpine and non-Alpine regions (Oekoscience 2013). This study is the updated version of a study published in 2006 (Oekoscience 2006), which was used for the same purpose in GRACE (2006). In the updated version, immission data from the year 2012 were used, whereas in the older study the data stem from the year 2005. Therefore, we derive the mountain factors for higher immissions with the updated study by applying the same methodology as in GRACE (2006).

One precondition for applying the same methodology as in GRACE (2006) is that the two studies from Oekoscience (2006, 2013) are conducted with the same experimental setup. However, in the new study from 2013 the authors made a crucial observation: the measuring station in Basel/Muttenz, which served as reference station for a non-Alpine region in the study from 2006, had been moved. At its new location, it was placed at nearly double the distance from the road than before (Oekoscience, 2014). Therefore, the authors of the updated study (Oekoscience 2013) chose to use the station Reiden as a new reference for non-Alpine regions because the former reference station in Basel/Muttenz was out of line. Note that there were no similarly significant issues at any of the other stations (Reiden, Erstfeld, Moleno, Camignolo or Rothenbrunnen).

For our purpose, the reference station must be the same as it was in GRACE (2006), namely Basel/Muttenz. Else, the mountain factors from GRACE (2006) and from the study at hand would not be comparable. The issue becomes clear in Table 5, which compares the results of the two Oekoscience studies. If in the newer study of 2013 the station Basel/Muttenz were chosen as a non-Alpine reference station instead of Reiden, the mountain factor for Rothenbrunnen would nearly be twice as high as it had been in the older study of 2006.

Table 5: Results from the two Oekoscience studies (2006 and 2013)

Measurement station	Mountain factor for PM10 immissions from Oekoscience 2006	Mountain factor for PM10 immissions from Oekoscience 2013
Basel/Muttenz	1.0	0.4
Reiden	1.5	1.0
Erstfeld	2.5	1.6
Moleno	3.8	2.4
Camignolo	2.0	1.3
Rothenbrunnen	4.1	3.2

The cells marked in blue are the reference stations for the respective study. The cell marked in orange is the station in Basel/Muttenz that had been moved to a new location between the two studies. Due to that circumstance, Reiden had been chosen as new reference station.

Table INFRAS. Source: Oekoscience (2006, 2013).

In order to make the mountain factors of the newer study (Oekoscience 2013) comparable to the older study (2006), the factor at the station Basel/Muttenz (0.4, cell in red colour in the table above) had to be manually adjusted. We decided – after consultation with the author of the study – to replace this factor with the equivalent factor from the older study in 2006, when the station at Basel/Muttenz had not been moved yet. We then set this value as the reference for non-Alpine regions and linearly aligned the mountain factors derived for the other measurement stations in Oekoscience (2013).

A further step had to be taken to make the new mountain factors comparable to GRACE (2006). In the older study from Oekoscience (2006), a factor of 1.25 had been applied to the mountain factors of the stations in Reiden, Erstfeld, Moleno, Camignolo and Rothenbrunnen. This was done because of additional air pollution occurring at the station in Basel/Muttenz from other sources in the industrial surroundings (“background”). This factor was not applied in the newer study (Oekoscience 2013), since the station in Reiden was chosen as non-Alpine reference. When changing the reference station back to Basel/Muttenz, this factor however has to be applied again.

After adjusting the factor at the station in Basel/Muttenz and applying the factor 1.25 (“background”) to the mountain factors of all the other stations, we find the following station-specific mountain factors being the basis for the calculation of the overall mountain factor:

Table 6: Mountain factors for higher immissions at the locations of the measurement stations

Measurement station	Mountain factor for PM10 immissions
Erstfeld	2.9
Moleno	4.4
Camignolo	2.4
Rothenbrunnen	5.8
Average	*3.9*

Table INFRAS. Source: adapted from Oekoscience (2013).

In GRACE, Lieb et al. (2006) applied an additional factor of 1.125 (with a sensitivity interval between 1 and 1.25) in order to account for the fact that the immission measurements used for the assessment are conducted directly besides the motorway, but there is scientific literature suggesting that meteorology may have even higher effects on the immissions at further distances from the motorway (Kocsis 2000). Therefore, this factor is also included in the present study.

Hence, the **overall mountain factor for higher PM10 immissions in mountainous regions equals the average of the mountain factors in the mountainous regions, multiplied with the**

additional factor of 1.125 (i.e. the average factor of the 4 measurement stations as displayed in Table 6, multiplied with 1.125). The sensitivity interval is defined by the minimum factor multiplied with the additional factor 1 (i.e. the factor at the station of Camignolo displayed in Table 6 multiplied with 1) and the maximum factor multiplied with the factor 1.25 (i.e. the factor at the station of Rothenbrunnen displayed in Table 6 multiplied with 1.25).

c. Results

Applying the above-mentioned methodology, the mountain factor for higher immissions in Alpine valleys due to meteorology (inversions, valley sides) is **4.36** with a sensitivity interval of 2.37-7.30.

Note that uncertainties in this assessment are rather high due to the above-mentioned methodological difficulties and uncertainties (e.g. the moved measurement station of Basel/ Muttenz, which serves as a reference station for a non-Alpine region).

3.1.6. Population density

a. Causal chain and methodological issues

The number of residents affected from higher air pollution is typically lower in Alpine regions than in non-Alpine regions due to lower population density. This effect is equally relevant for road and rail transport.

b. Data and methods

Population densities along transit corridors in mountainous and non-mountainous regions have been analysed in GIS case studies. For the non-Alpine regions, the analysis has been conducted on the transit corridor between Basel and Lucerne, whereas the analysis of the Alpine region was conducted along the Gotthard corridor. For rail transport, two Gotthard corridors have been distinguished: the old corridor with the railway tunnel “Scheiteltunnel” between Göschenen and Airolo and the new corridor with the “Gotthard Base Tunnel” between Erstfeld and Biasca.

For each corridor, the permanent population within 500 metres from the road or railway has been summarized in order to estimate the total affected population along the respective corridor. Tunnels were spared out for this part of the analysis. In a next step, the total affected population have been divided by the total distance of the respective corridor (this time, including tunnels). The result of this division is a ratio of population per corridor kilometre, which is used for calculating the mountain factor.

The input data is depicted in Table 7.

Table 7: Input data (air pollution costs, population density)

Data description	Source
GIS motorway and rail route in the Gotthard corridor (Swiss Map Vector 500)	DDPS (2016)
GIS motorway and rail route in the corridor between Basel and Lucerne (Swiss Map Vector 500)	DDPS (2016)
GIS dataset with permanent population (STATPOP)	FSO (2016)

Table INFRAS.

Since the population density turned out to be an important cost driver and the results changed significantly since the GRACE study (2006), an additional analysis of the population density was conducted for the Brenner corridor (only road). However, no GIS data analyses were conducted, but statistical data of communities along the Brenner corridor were analysed and compared to another, non-mountain motorway in Austria: For all communities along the Brenner motorway in Austria – i.e. between Kufstein and Brenner pass – the population density was calculated (total population of the communities divided by the total area). The same was done for the motorway A1 between Salzburg and the periphery of Wien. The A1 is a typical Austrian motorway crossing urban agglomerations (e.g. region of Salzburg) as well as rural areas. By comparing the population density of the Brenner motorway and the A1, a mountain factor can be derived.

c. Results

Table 8 shows the population density per kilometre for road and rail corridors on the Gotthard route.

Table 8: Population densities along transit corridors

Transit corridor	Population density per km
Road: Gotthard corridor (Alpine)	469
Road: Basel-Lucerne corridor (non-Alpine)	766
Rail: Gotthard corridor old “Scheiteltunnel” (Alpine)	586
Rail: Gotthard corridor with new “Gotthard Base Tunnel” (Alpine)	624
Rail: Basel-Lucerne corridor (non-Alpine)	1'439

Permanent population within 500 metres from the road- or railway.

Table INFRAS.

With these population densities, the resulting mountain factors are **0.61** for the Gotthard corridor with road transport and **0.41 or 0.43** for the Gotthard rail transit corridor with the old "Scheiteltunnel" or the new "Gotthard Base Tunnel", respectively.

The derived mountain factor depends a lot on the choice of the distance from the motorway or railway that is included. A narrower analysis (e.g., 200m instead of 500m) will lead to population density factors close to one, whereas a wider analysis (e.g. 1000m) will result in even smaller population density factors towards 0.3.

The analysis of the population density along the Brenner corridor (based on statistical data of communities) shows an average value of 270 inhabitants per km^2 for the Brenner motorway on the Austrian side, compared to an average population density of 328 inhabitants per km^2 along the motorway A1. This results in a mountain factor of **0.82** for the Brenner road corridor. Since the rail corridor is more or less parallel to the road corridor, the same value can be assumed for the rail corridor.

These values are lower than the equivalent population density factors in GRACE (2006), the values for the Gotthard corridor are even considerably lower. However, the analysis in GRACE was done in less detail, i.e. without GIS analysis, only based on population densities in all communities along the Gotthard corridor, regardless of the exact distance from the corridor.

Overall, we suggest taking the average factor of the Gotthard and the Brenner corridors as a mountain factor for population density, i.e. **0.7 for road** and **0.6 for rail corridors**. Since the GIS analysis of the Gotthard corridor showed a broad range of the results depending on the width of the corridor, we suggest a broad sensitivity interval of 0.5-0.9 for road corridors and 0.4-0.9 for rail corridors.

3.1.7. Health risk

The increased health risk for certain types of illnesses due to increased concentration of air pollutants is scientifically derived based on epidemiological studies. One could assume that those risk factors (increasing risk) could differ between regions and that – for example – the cumulation of negative environmental impacts such as air pollution and noise can increase the risk disproportionately high. However, there is no scientifically sound evidence available until now about different risks in different regions. Therefore, this factor is not part of any mountain factor until now.

3.1.8. Damage cost

Damage costs of health effects due to air pollution include the following elements:

- medical treatment costs (hospital, drugs)
- production losses (due to work absence as a consequence of illness, etc.)
- employment costs (due to death or chronic disease)
- suffering, harm (monetized generally on the basis of the willingness-to-pay for avoiding an illness, lower quality of life, reduced life expectancy)

Some of the damage cost factors could differ by region, e.g. the hospital costs, the net production losses or even the suffering costs (due to different willingness-to-pay). From a cost perspective, there would be some reasons to make a regional differentiation. However, there are several reasons not to derive an Alpine factor on damage costs:

The effects described are not specific for mountain areas or the Alpine regions. Those cost effects can generally be attributed to economically weaker regions and peripheric regions. So, such factors would need to be adopted also for other regions.

The concept of the internalization of environmental externalities with the aim of increasing economic efficiency depends on the estimation of those externalities. One main aim of the internalization is to impose the true costs to the transport user (‘polluter’). If externalities are internalized in a price, e.g. by a truck toll, the toll should of course reflect the true costs, but should also be developed in a way that the primary goals (reduce negative effects for non-users) can be reached.

Of course, a toll system should take into account different population densities since this has a strong impact on the negative effects and hence the costs. In other words, it is desired that any traffic runs in less populated, rural area instead of densely populated agglomerations (i.e. idea of bypasses). However, cost differentiation due to different income level of different regions does not make sense in this respect: It cannot be the goal of an internalization that transport is performed rather in economically weaker regions with a lower average income. In this respect, the argument of double penalty for mountain regions would be obvious and problematic: The regions along transport corridors are affected strongly by the negative effects of transport, which lowers the attractivity of those regions. The derivation of lower cost factors for a toll system due to a lower income level would give a false incentive and be a double penalty for that region.

To conclude, the derivation of a mountain factor for the damage costs are for several reasons not appropriate and therefore not recommended.

3.2. Noise

3.2.1. Overview of cost drivers

As a summary of the whole chapter 3.2, the following two tables list the noise cost drivers and their corresponding mountain factors for road and rail freight transport. More details about each cost driver are described in the subsequent sections.

Road transport

Table 9: Noise costs: mountain factors for road freight transport

Impact pathway	Cost driver	Mountain factor	Short description / Source	Chapter
Pressure (emissions)	Gradient	1.16 (1.05 – 1.31)	Higher noise emissions (rolling and motor noise) in Alpine regions (based on EMPA 1997)	3.2.2
State (immissions, concentrations)	topographical and meteorological conditions	5.0 (2.5 - 12.5)	Higher noise immission levels in Alpine regions due to inversions and the amphitheatre effect (based on GRACE 2006, Lieb et al. 2006)	3.2.3
Impact	Population density	0.7 (0.5 - 0.9)	Lower number of affected residents due to lower population density in Alpine regions (based on GIS analysis)	3.2.4
	Health risk	*-* *(1.0)*	*No evidence on higher health risk in mountain regions.*	*3.1.7*
Costs	*Specific damage costs*	*-* *(1.0)*	*Regional differences of cost factors due to different income levels not appropriate.*	*3.1.8*
Total mountain factor for noise costs		**4.1** **(1.3 – 14.7)**		

Sensitivity intervals in brackets.

Table INFRAS.

Rail transport

Table 10: Noise costs: mountain factors for rail freight transport

Impact pathway	**Cost driver**	**Mountain factor**	**Short description / Source**	**Chapter**
Pressure (emissions)	Gradient	- (1.0)	No data available	3.2.2
State (immissions, concentrations)	topographical and meteorological conditions	5.0 (2.5 - 12.5)	Higher noise immission levels in Alpine regions due to inversions and the amphitheatre effect (based on GRACE 2006, Lieb et al. 2006)	3.2.3
Impact	Population density	0.6 (0.4 - 0.9)	Lower number of affected residents due to lower population density in Alpine regions (based on GIS analysis)	3.2.4
	Health risk	*-* *(1.0)*	*No evidence on higher health risk in mountain regions.*	*3.1.7*
Costs	*Specific damage costs*	*-* *(1.0)*	*Regional differences of cost factors due to different income level not appropriate.*	*3.1.8*
Total mountain factor for noise costs		**3.0** **(1.0 – 11.25)**		

Sensitivity intervals in brackets.

Table INFRAS. Source: <please enter here>

3.2.2. Gradient

a. Causal chain and methodological issues

Road transport: A lot of work has been done in modelling road transport noise emissions, in Switzerland with the sonRoad model for calculating road noise emissions (2004), and in the European Union with the Common Noise Assessment Methods in Europe (CNOSSOS-EU, 2012). According to Kephalopoulos et al. (2012), gradients mainly have an influence on noise emissions because the steepness of the road has an effect on vehicle speed (rolling/propulsion noise) and on the engine load and engine speed (propulsion noise). Noise emissions typically increase with ascending slopes and decrease with descending slopes. The newer models can distinguish between ascending and descending slopes, whereas the model from EMPA (1997), which was used for the analyses in GRACE (2006) only look at ascending slopes.

Rail transport: For railway noise, no new scientific evidence has been found in comparison to the GRACE project. Lieb et al. (2006) and GRACE (2006) found qualitative evidence for rail noise emissions depending on gradients, but there is no quantitative data available. Therefore, no mountain factor can be estimated.

b. Data and methods

GRACE (2006) and Lieb et al. (2006) based their assessment on a road noise emission model developed by EMPA in the year 1997 (EMPA 1997). This model gives equations for specific noise emissions (rolling noise, motor noise and total noise) depending on gradients and vehicle speed (see Table 11). In the meantime, noise emission models have been further developed, for instance in the sonRoad project and in the CNOSSOS-EU project as described above. However, these new models give more complex equations that are depending on further factors besides vehicle speed and gradient (e.g. vehicle categories). Such a detailed assessment was not possible within the framework of this study, where the scope is to assess a generic freight transport situation for Alpine and non-Alpine transit corridors.

Therefore, we used the model developed by EMPA (1997) with the same method as used in GRACE (2006). We updated the input values for gradients (according to the gradients given in chapter 3.1.2) and the input values for vehicle speed (according to HBEFA 3.3). The EMPA (1997) model is not suitable for negative gradients. Therefore, the mountain factors as calculated with the EMPA (1997) model were multiplied with a factor of 0.5 in order to take into account both, ascending and descending slopes.

Table 11: Equations for noise emissions from HGVs

Rolling noise (without correction for different road surfaces)	
HGV:	$L_{HGV, roll} = 18.5 + 35 * \log (v)$
Motor noise	
HGV:	$L_{HGV, mot} = 76.9 + 10 * \log (1 + (v / 56)^{3.5} + 0.8 * g$
Total noise	
HGV:	$L_{HGV, tot} = 10 * \log (10^{L_{HGV, roll} / 10} + 10^{L_{HGV, mot} / 10})$

L = noise emissions, v = vehicle speed in km/h, g = gradient in % for g > 0%.

Table INFRAS. Source: adapted from Lieb et al. (2006), originally from EMPA (1997), p. 27, 32 and 33.

c. Results

The same mean gradients were used as described in chapter 3.1.2. HGV noise emissions on roads in Alpine areas are higher than in flat areas by a factor of **1.16**. This factor is smaller with a gradient of ±1% (factor 1.05) and considerably higher with a gradient of ±6% (factor 1.31). The table below gives an overview over the results.

Table 12: Mountain factors for higher noise emissions due to higher gradients in road freight transport

Gradient [%]	Average HGV vehicle speed [km/h]	Mountain factor for ascending roads	Mountain factor for ascending and descending roads [-]
±1.00	66.27	1.09	1.05
±3.00	65.95	1.31	**1.16**
±6.00	62.27	1.63	1.31
Average Swiss motorway on a flat road (reference scenario for non-Alpine regions)	66.28	1.00	1.00

The last row (grey colour) is the reference scenario for non-Alpine regions. I.e., the mountain factors are calculated by dividing the gradient-specific vehicle speed by the reference scenario vehicle speed. Due to the fact that the EMPA (2017) model is not suitable for negative gradients, the mountain factors have been multiplied with a factor of 0.5 in order to account for ascending and descending slopes.

Table INFRAS. Source: based on GIS elevation model, EMPA (1997) and HBEFA 3.3.

3.2.3. Topographical and meteorological conditions

Due to temperature inversions and the amphitheatre effect and reflections, the noise immission level is expected to be higher in Alpine valleys than in flat regions (GRACE 2006, Lieb et al. 2006). However, there have been no new studies since then that would allow to confirm or adapt the respective mountain factors from GRACE (2006)[3]. Accordingly, the same mountain factors are used as in GRACE (2006): **a factor of 5** with a sensitivity interval of 2.5-12.5.

3.2.4. Population density

Similar as described in the air pollution chapter on population density (see chapter 3.1.6), the number of residents affected from higher noise emissions is typically lower in the mountainous than in non-mountainous area. The same GIS model as described in the air pollution chapter was applied, see chapter 3.1.6 for further information. The resulting mountain factors are **0.61** for the Gotthard corridor with road transport and **0.41 or 0.43** for the Gotthard rail transit corridor with the old “Scheiteltunnel” or the new “Gotthard Base Tunnel”, respectively. A broad sensitivity interval of 0.3-0.9 is added to the result.

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[3] An extensive literature research has been conducted, and experts in the field of transport noise (from the Swiss research centre ‘EMPA, division of acoustics) have been questioned about the newest scientific activities concerning noise immissions in relation to inversions and the amphitheatre effect.

3.2.5. Health risk and damage cost

As for the air pollution costs, also for the noise costs no mountain factor is derived for the health risk and the damage costs. The reasons are described in chapters 3.1.7 and 3.1.8.

3.3. Nature and landscape

Overview on effects

External costs for nature and landscape due to transport activities include different negative effects, which are differently relevant in mountain areas:

- **Habitat loss:** The construction of transport infrastructures leads to a loss of ecosystems and with that a loss of natural habitats and, as a consequence, biodiversity. The corresponding damage is dependent on the type and quality of ecosystem that is lost. Ecosystems of higher quality (higher biodiversity, longer development periods) tend to have a higher value. In the Swiss studies on external costs of transport habitat loss is monetized based on a restoration cost approach (Ecoplan, INFRAS 2014; update study ongoing). Hence, some ecosystems have higher values than others. As a consequence, the cost of habitat loss differs between regions, depending on the types of ecosystems lost due to transport infrastructure.
  In mountain areas, there are different ecosystems and ecosystem patterns than in non-mountain areas. Therefore, it can be assumed, that the average value of an ecosystem is different in mountain and non-mountain areas. These again leads to different costs due to habitat loss per km infrastructure.
- **Habitat fragmentation:** Transport infrastructure and transport activity on it can lead to a fragmentation of ecosystems/habitats. The corresponding external costs can be monetized by a restoration cost approach, taking into account the necessary cost for building restauration measures (e.g. wildlife passages, amphibian passages). The extent of the habitat fragmentation depends also on the types of ecosystem and the animals affected by the fragmentation. As for habitat loss, habitat fragmentation can be different in Alpine regions than in other, non-Alpine regions.
- **Visual intrusion:** Transport infrastructure can lead to visual intrusion, mainly in regions with a landscape of high quality (as it is often the case in mountain areas). However, the corresponding ‘damage’ is very difficult to quantify and no monetization methodology has been well established until now.

It has to be mentioned that the majority of the cost of nature and landscape are dependent on the infrastructure itself (habitat loss, visual intrusion) and not on the traffic volume (only partially habitat fragmentation). Hence, the marginal costs of e.g. habitat loss are close to zero whereas the average costs are substantial. The following analysis of the mountain factor therefore mainly refers to the average costs (see also methodological explanation in chapter 2.2).

Methodology

The in-depth Swiss study on external costs of transport quantifies the costs of habitat loss and habitat fragmentation. The methodology is based on a restoration cost approach, taking into account different types of ecosystems affected by the transport infrastructure. The base study on the external costs of transport for nature and landscape (Econcept, Nateco 2004) was based on extensive analysis of aerial photos. In the analysis, today's photos were compared with photos from the 1950's and the types (and areas) of ecosystems lost or fragmented were analysed. The analysis was done differentiated by four regional types: 'Mittelland' (Swiss plateau), Jura, Pre-Alps, Alps (incl. Ticino). Since the complete quantification and monetization is executed differentiated for these four regional types, the calculations can be used as a basis for deriving a mountain factor. Also, the following update studies and the yearly update calculations are executed for these four regions. Hence, the latest results of external costs for 2015 can be taken as the basis for the calculation.

In most other studies or handbooks on external costs, like e.g. the German Methodenkonvention on estimating environmental costs, there are no differentiated data available on external costs for nature and landscape.

Results

The following table shows the specific cost (annualized cost per km infrastructure) for habitat loss and habitat fragmentation due to road and rail transport in Switzerland. The highest cost factors result for pre-Alpine regions, followed by the Alps (incl. Ticino). In both regions, the cost for nature and landscape are substantially higher than for the 'Mittelland'.

Table 13: Specific cost for habitat loss and habitat fragmentation

CHF/a per Meter infrastructure	Mittelland (Swiss plateau)	Jura	Pre-Alpine regions	Alpine regions (inkl. Ticino)	Total
Road: motorways	166	61	319	202	197
Rail	23.5	10.3	65.4	26.6	32.6

Table INFRAS. Source: INFRAS, Ecoplan 2017

For the transalpine mountain corridors, the road and rail infrastructure are passing the pre-mountainous regions and above all the mountainous regions. For the Gotthard corridor, where we have the main focus in the present study, the majority of the defined corridor (see ch. 2.3) is in the Alpine region, the rest in the pre-Alpine region. Therefore, the mountain factor for this corridor can be mainly derived from the average values of Alpine and pre-Alpine regions in the table above.

The following table gives an overview on possible mountain factors for road (motorways) and rail, derived from the Table 13 above.

Table 14: Mountain factors for nature and landscape costs

Base for mountain factor	Road: motorways	Rail
Alpine regions vs. Mittelland	1.21	1.13
Alpine/pre-Alpine regions (average) vs. Mittelland	1.56	1.96
Alpine regions vs. Total	1.03	0.82
Alpine/pre-Alpine regions (average) vs. Total	1.32	1.41
Proposed mountain factor for nature & landscape	**1.3** (1.03 – 1.56)	**1.4** (0.82 – 1.96)

Table INFRAS.

We suggest using the ratio in the 4th line of the table above to be the main basis for the mountain factor: the ratio between the average of Alpine and pre-Alpine regions and the total cost for Switzerland (as a reference). The other ratios of the table above can then be used as sensitivity interval. Therefore, the resulting mountain factors are **1.3** for road (motorways) and **1.4** for rail transport. If there was no pre-Alpine region along a corridor but only Alpine region, the mountain factors would be slightly lower.

3.4. Accidents

3.4.1. Introduction

Two different methodological approaches to develop mountain factors for accident costs are possible:

- *Based on accident rate comparison (motorways in and outside mountain area):*
  By analysing the accidents (number and severity) on roads (motorways) within mountainous and non-mountainous areas and matching this information with vehicles performance within Alpine region and outside Alpine region accidents rates can be calculated. This has to be done for a longer time series (at least 5 years) to reduce accident variability between years and use average accident occurrence.
  Due to the fact that specific construction and maintenance is done in Alpine region to reduce accident risk, actual accidents and accident rates are already an outcome of safety measures that have been taken by the road operators. Therefore, accident rates do not totally reflect the higher accident costs within Alpine regions.
  The comparison of accident rates leads to an underestimation of cost differences or might even show a lower accident rate in Alpine region due to safety measures set along the motorways in the Alps.
- *Based on abatement costs:*
  Construction and maintenance of motorways in the Alps have higher costs (per length or space). A high part of these higher costs is due to the mountainous terrain. But parts of the costs are due to safety measures. Based on a cost analysis, cost drivers for increasing safety on mountainous motorways to reach a safety level that is comparable to flat motorways on a lower altitude have to be identified and finally monetised.

3.4.2. Cost drivers

For the identification of cost drivers a differentiation between

- construction costs and
- maintenance costs

is necessary.

For construction costs an analysis of detailed infrastructure elements of a motorway and their relevance for safety and their potential difference in mountain and non-mountain area has been conducted. Based on this analysis the following potential cost drivers dedicated to reduce accident risk on Alpine motorways have been identified:

- 2nd tunnel tube (due to safety, not necessary due to traffic)
- Emergency exits, areas and tunnels for tunnels

- Tunnel monitoring system and centre
- Tunnel ventilation system (heat release in case of fire in the Tunnel)
- Lightning system in tunnels
- Video monitoring in tunnels
- Automatic measurement of temperature, CO, visibility condition, fire detection in tunnels
- Firefighting water provision in tunnels
- Automatic ice detection system (especially on bridges)

So, the main cost drivers are specific safety components of tunnels on the one hand and the second tube in those cases where safety and not traffic volume is the reason for constructing a second tube.

In many cases the transport volume on Alpine crossing motorways is only reaching or exceeding the capacity of the single tube tunnels on weekends during holidays when holidaymakers are going south or coming back from south. At most of the other time the capacity of single tube tunnels is sufficient. Therefore, a lot of the second tubes that have been built within the last years (at least in Austria) have been built due to safety reasons. This is also stated within the national road safety programme where the construction of second tubes is listed as one of the most important measures to increase safety.

Main cost drivers for maintenance costs on mountainous motorways (high altitude, high gradients) is winter operation including especially use of salt (ice and snow protection) and snow clearance. A comparison of salt usage and number operation hours for ice and snow clearance on motorways within and outside of mountain area gives a good base for estimating different operation and maintenance costs.

3.4.3. Estimation of mountain factor

It is necessary to find adequate (unit) costs for the different cost drivers identified and listed in the previous sub-chapter. In addition to this, it is necessary to find numbers on the existence of different infrastructure elements (length or space) within and outside of mountain area to get information on relative appearances of the cost drivers (which gives an indication of the cost weight of the cost drivers compared to total construction costs).

The situation in Austria has been chosen as case study to develop the cost factors. For Austrian motorways a good database on unit costs as well as on appearance of the respective infrastructure elements within and outside mountain areas is available.

The following table gives an overview on the Austrian motorway network and its tunnels and bridges and an estimation of the share of tunnel length with the necessity of a 2nd tube due to safety and not due to traffic volume (assumption: all tunnel with an JDTV up 20.000 vehicles need a second tube due to safety reasons but not due to traffic volume reasons).

Table 15: Share of special infrastructures (e.g. tunnels, bridges) in Alpine regions

Analysis of Austrian motorway network (2014)					
		Alpine area	Non-Alpin area	Total	share of Alpine area
total network length	km	1,666	507	2,173	77%
total tunnel length	km	318	18	336	95%
total bridge length	km	231	37	267	86%
share of tunnel length		19%	4%	15%	
share of bridge length		14%	7%	12%	
share of tunnel with 2nd tube due to safety (up to JDTV 20.000)		60%	0%		
tunnel length due to safety		190	0		

Source: ASFINAG, own calulations

The share of tunnels and bridges is significant higher in mountainous areas then in non-mountainous areas. In the non-mountainous areas, all tunnels have a second tube due to traffic volume reason. But in the mountainous area about 60% of the tunnel length has less than average 20,000 vehicles per day and have or need to have a second tube due to safety reasons only.

Beside the presented information on length of different parts of the motorway network the unit costs for the safety relevant infrastructure elements are needed to estimate an accident mountain factor. This information is taken from the estimation of the replacement value of the ASFINAG network (source: ASFINAG) and from the Austrian Audit Court (Monitoring of the investments for tunnel safety, 2010).

Table 16: Replacement values of the ASFINAG network

Cost Drivers		Replacement value EUR/meter motorway
Tunnel (construction without technical equipment) with 2 tubes		41,198
Tunnel (construction without technical equipment) with 1 tube		22,327
Emergency exits, areas and tunnels for tunnels		3,000
Technical equipment for safety in tunnels		2,950
	Tunnel monitoring system and centre	
	Tunnel ventilation system (heat release in case of fire in the Tunnel)	
	Lightning system	
	Automatic measurement of temperature, CO, visibility condition, fire detection in tunnels	
	Firefighting water provision in tunnels	
Technical equipment for safety open land		389
	Lightning system	
	Ice detection	
	emergency call system	
	traffic monitoring system	
Automatic ice detection system (especially on bridges)		47

No information per motorway section is available regarding winter operation and maintenance. Therefore, a cost distinction directly linked to sections in and outside Alpine region is not possible. But information on winter operation and maintenance is available for the nine federal countries of Austria. The countries with highest share of non-Alpine motorways are Burgenland, Lower Austria and Vienna. This fact is used to calculate different cost per motorway length for winter operation and maintenance in Alpine and non-Alpine region approximately.

For 2013 the ASFINAG reported the following information regarding winter operation and maintenance (differentiated by the 2 types of federal countries explained above):

Table 17: Winter operation and maintenance costs at ASFINAG

Winter operation ASFINAG 2013				
		Non-Alpine federal countries (Burgenland, Lower Austria, Vienna)	Alpine federal countries (all other countries))	Total Austria
salt usage	ton	20,000	103,000	123,000
winter operation	Hours	32,000	168,000	200,000
winter operation	vehicle-km	754,000	3,246,000	4,000,000
Total costs (personal, salt, machines)	Mio. EUR	14	32	46
motorway length (km)	km	691	1,501	2,192
costs / network-km	EUR/km	20,259	21,317	20,983

Source, ASFINAG, regional press information

By linking together all cost information and all network length information provided above and calculating annual costs of the infrastructure costs it is possible to estimate different costs caused to provide secure motorways for Alpine and non-Alpine motorways in Austria. For calculating the annual costs of infrastructure the annuity method is used. For this, an interest rate of 3% and an average life span of a motorway of 35 years is assumed.

Table 18: Mountain factor for accident costs

Comparison of safety relevant infrastructure costs and corresponding Alpine factor			
		Alpine Area	non-Alpine Area
Average replacement value due to safety relevant infrastructure per network length	Mio. EUR/km	3,600	600
Average annual replacement value (3% interest rate, 35 years life span)	EUR/km	167,500	27,500
Average winter operation and maintenance costs relevant for safety	EUR/km	21,300	20,300
Total annual infrastructure costs due to safety reasons	EUR/km	188,800	47,800
Derived Alpine factor		**3.9**	

Based on the described data, assumptions and calculations for the Austrian situation a **mountain factor for accident costs of 3.9** is suggested.

3.5. Climate change

Due to the long-lasting and worldwide effect of climate change, the economic costs due to greenhouse gas emissions cannot be regarded from a limited, geographically differentiated perspective. However, vulnerability of mountain regions to climate change is clearly higher. For example, in Alpine regions there is a higher risk for extreme weather events and there are higher costs for adaptation etc.

Therefore, in the first phase of the present study, the development of a mountain factor for climate change costs of transport were examined. Generally speaking, we see two possible approaches to develop mountain factors for climate change costs of transport:

i. 'Adaptation costs' due to vulnerability of transport infrastructure:

- Rationale: Climate change increases the risk of extreme weather events and therefore the vulnerability of the infrastructure, including transport infrastructure.
- Possible approach: It could be analysed which specific infrastructure elements are needed in Alpine regions in order to reduce the vulnerability of roads (or rails) to extreme weather events. Such elements can be walls (e.g. as a protection against rockfall), tunnels, galleries etc. After the identification of these elements, the cost of those infrastructures compared to non-Alpine infrastructures could be quantified.
- Conclusion: The analysis will identify higher infrastructure costs on Alpine areas due to climate change. However, this can be only very partially attributed to the greenhouse gas emissions occurring there (e.g. the same measures are needed regardless whether there are no greenhouse gas emissions at place e.g. thanks to electric vehicles or there is a high emission level due to a large number of Diesel trucks).
  Secondly, the corresponding costs are rather direct infrastructure costs, which should be (maybe) covered in a mountain factor for the infrastructure costs, but not the environmental costs.

ii. 'Damage costs' due to higher climate change impacts:

- Rationale: Alpine regions are more affected by climate change than other (average) regions in the middle of Europe. Some of the issues / impacts of climate change in Alpine areas are: glacier loss, higher risks of extreme weather events and natural disaster risk, fragile ecosystems, impact on (winter) tourism etc.
- Possible approach: Many studies on climate change damage (costs) identify regional differences and highlight the areas where specific impacts in Alpine regions are to be expected. However, there are no studies that explicitly quantify and compare the climate change costs

in Alpine/mountain regions and other regions. Hence, until now, we do not see any possibility to derive a ‘factor’ for climate change damage costs in Alpine regions.

Conclusion:

Climate change is a global issue with global effects due to local emissions. Therefore, transport related emissions in Alpine regions have not a higher impact on Alpine regions than other emissions. As a consequence, we recommend not to consider a mountain factor for climate change costs, since this would be methodologically not appropriate.

The only (small) effect that can be attributed to mountain areas is the fact that greenhouse gas emissions of road transport are slightly higher on roads with a gradient (see also section 3.1.2 for air pollution). However, this gradient effect is not very large (below 10%) and can therefore be neglected.

4. Conclusions

Summary of the main results

The following table summarizes the main results of the present study, showing the mountain factors for the different external cost categories. Additionally, the values of the GRACE study (2006) are also represented as a comparison. Please note that the different mountain factors do not say anything about the absolute level of external costs, but only represent the factor between external costs in mountainous and external costs in non-mountainous areas.[4]

Table 19: Mountain factors for external costs of transport

	Present EUSALP study		GRACE study (2006)	
Cost category	**Road transport**	**Rail transport**	**Road transport**	**Rail transport**
Air pollution	**4.2** (1.3 – 14.2)	**2.6** (0.9 – 6.6)	5.25 (2.4 – 19.8)	3.5 (2.1 – 5.2)
Noise	**4.1** (1.3 – 14.7)	**3.0** (1.0 – 11.25)	5.0 (2.3 – 19.8)	4.15 (2.1 – 10.4)
Nature & landscape	**1.3** (1.0 – 1.6)	**1.4** (0.8 – 2.0)	n.a.*	n.a.*
Accidents	**3.9**	n.a.	n.a.	n.a.

The values in brackets indicate the sensitivity intervals (lower and upper level). n.a.: not available / no data available.
* for visual intrusion, the GRACE study suggested a factor of 10.7 for road transport and 5.3 for rail transport.

Table INFRAS.

The results of the analysis of external costs of transport in mountain areas can be summarized as following:

- For **air pollution costs**, there is substantially new information and data available for a profound update of the mountain factor. The main cost driver for the air pollution costs in Alpine regions are the higher immissions due to inversion (factor 4.4). Other cost drivers are the higher emissions due to the higher gradients and the altitude. The resulting mountain factor for air pollution is slightly lower than in the GRACE (2006) study, which is mainly a result of the lower factor for population density, which outweighs the slightly higher value for the immission (concentration). However, the adjustment of the population density can be justified due to a more detailed analysis in the present study based on geographical information system (GIS) data. Still, the mountain factor for population density is very sensitive on how wide the corridor is chosen.

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[4] Hence, even if the mountain factor for air pollution is similar for road and rail transport, the absolute level of external costs differs a lot: air pollution costs per tkm are much higher for road transport than for rail transport.

- For **noise costs**, there is only partially new scientific evidence for deriving mountain factors. Above all, for the noise immission no update of the factor was possible. The other cost drivers have been updated and the resulting mountain factor for noise costs is also lower than in the GRACE (2006) study. Again, this is mainly a result of the lower factor for population density. The main cost driver for the noise costs in Alpine regions are the higher immissions due to topographical and meteorological conditions (inversion, amphitheatre effect).
- For **nature and landscape**, a mountain factor has been derived for the first time. Based on detailed results of the Swiss study on external costs of transport, significantly higher costs for habitat loss and fragmentation in mountain areas compared to non-mountain areas can be derived. The resulting mountain factors are 1.3 for road (motorways) and 1.4 for rail transport and can be regarded as a sound basis.
- For **accident costs**, there is also evidence for higher costs in mountain areas, mainly due to higher infrastructure investments to keep the accident rate as low as possible. For the first time, a mountain factor has been derived for accident costs. The calculation is based on an abatement cost approach taking into account additional infrastructure safety measures on roads in Alpine corridors. The resulting mountain factor for accident cost in mountain areas is 3.9.
- For **climate change**, a mountain factor cannot be derived due to methodological reasons (global issue with global effects).

Conclusions and recommendations

- Environmental costs in mountain areas are substantially higher than in other (average) areas. It is therefore desirable to adjust toll systems in mountain areas accordingly in order to give a correct price signal to transport users.
- Mountain factors are an adequate and simple way to adjust tolls on corridors in mountain areas.
- For air pollution costs, noise costs, accident costs and costs for nature and landscape, the present study suggests updated mountain factors that can be applied for toll systems. The mountain factors can be applied on average cost factors for environmental costs per vehicle-km for a corridor in an Alpine region.
- The present study had to focus on selected corridors, mainly on the Gotthard and the Brenner corridor. Due to limited resources and studies available, an extension to other corridors was not possible. However, the results can also be applied to other Alpine corridors, e.g. in France or Switzerland.

  It is recommended to conduct additional case studies for other corridors, such as French corridors, in order to broaden the scope.

- A differentiation of the mountain factor between the inner Alpine area and the 'pre-Alpine' region is not possible on the basis of the present study. Although the analysis gives some indication that differences might be substantial, we recommend using the mountain factor for a whole Alpine corridor. The corridor should be defined based on a geographic consistent area, i.e. for an area with a clear mountainous character with a valley structure and/or some gradient.
- The analysis showed some significant gaps in knowledge on specific environmental effects or cost factors. Therefore, additional research is recommended for the following fields:
  - For noise costs, there are several cost drivers where new scientific basis would be needed. Mainly for the higher noise immission (concentrations) due to inversion and the amphitheatre effect in mountain regions there have been no new research since the publication of GRACE, although this effect is very substantial. Also, for the higher noise emissions due to gradients of the infrastructures new research would be desirable.
  - Since the populations density is a very crucial factor with a high variety between different regions, it is advisable to conduct more detailed (GIS based) analysis of this factor.
  - To enhance the validity of the results for the mountain factor, analyses for additional Alpine corridors should be carried out (e.g. for French corridors).
  - For accident costs as well as cost for nature and landscape, the present study recommends mountain factors for the first time. For both cost categories, the results could be further deepened, e.g. for additional corridors or for rail in the case of accident costs. The analysis of habitat loss could be updated and deepened based on recently built road or rail infrastructures.
  - Additional research is also recommended for other environmental effects that might be relevant for Alpine areas, e.g. visual intrusion.

Glossary and abbreviations

EF	Emission factor
EUSALP	EU Strategy for the Alpine Region
Exhaust emissions	Direct emissions from vehicle fuel combustion
GRACE	Generalisation of Research on Accounts and Cost Estimation (European research study)
HGV	Heavy Goods Vehicle(s)
Inversion	Weather condition in which the vertical temperature gradients are reversed
LGV	Light Goods Vehicle(s)
Mountain factor	Cost differential factor. Indicates the magnitude of higher damages / higher external costs compared to a flat (non-mountain), insensitive area. Is applicable to existing, average external cost factors estimated in non-sensitive areas.
NGO	Non-governmental organisation
Non-exhaust emissions	Indirect emissions, other than exhaust, from vehicles (e.g., tire or brake abrasion)
PM	Particulate matter

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