Région Provence-Alpes-Côte d'Azur

STUDY ON THE EXTERNAL COSTS GENERATED BY TRANSPORT IN THE ALPINE CORRIDORS

Final report

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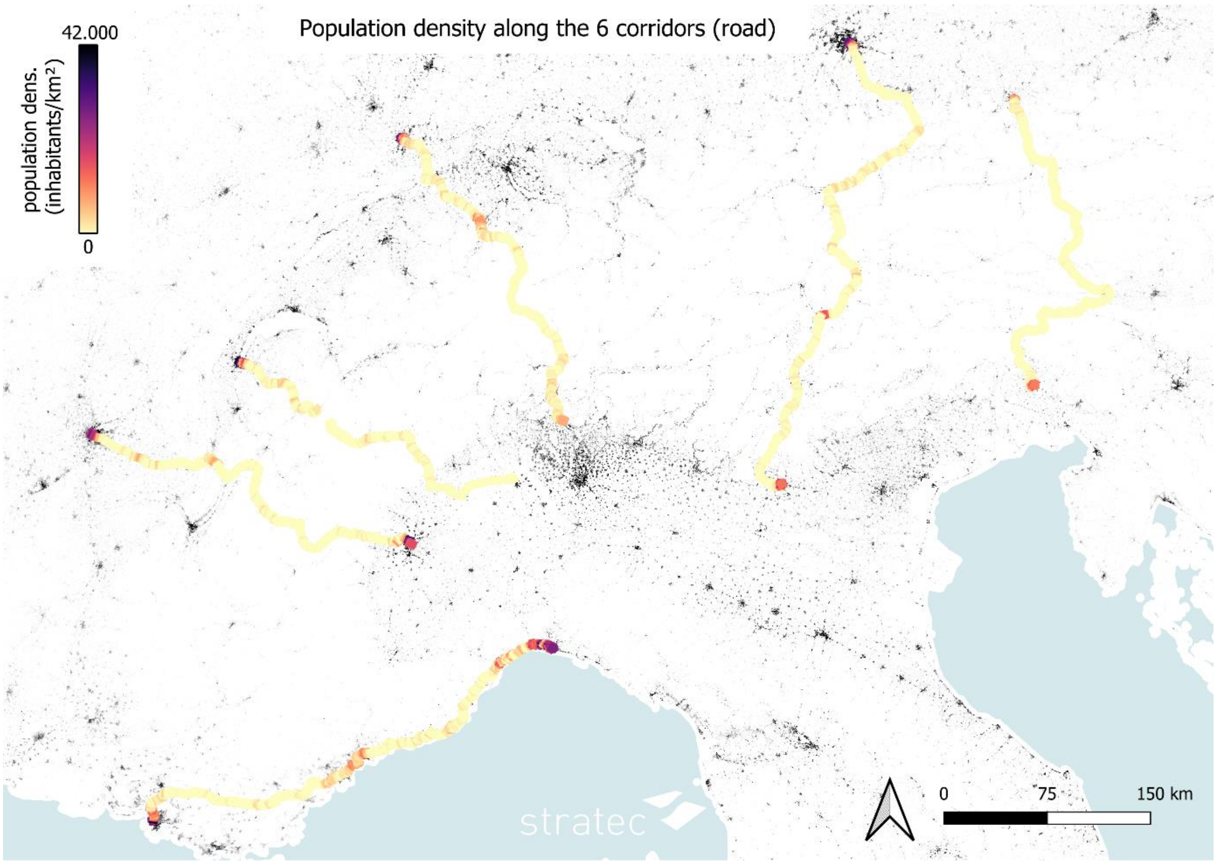
0. EXECUTIVE SUMMARY

The **aim of the study** is to **calculate the external costs of transport on the main Alpine corridors** for the various modes of transport available for both passengers and freight activities. This is carried out on 6 transalpine corridors (see map below):

- Ventimiglia (FR/IT),
- Fréjus/Mont-Cenis (FR/IT),
- Chamonix/Mont-Blanc (FR/IT), road only,
- Gotthard (CH/IT),
- Brenner (AT/IT),
- Tauern/Katschberg (AT).



This study is the first comprehensive estimation of external costs of land transport on Alpine corridors. It is based on the most recent data and studies available in 2025 and relies heavily on the following studies (among others):

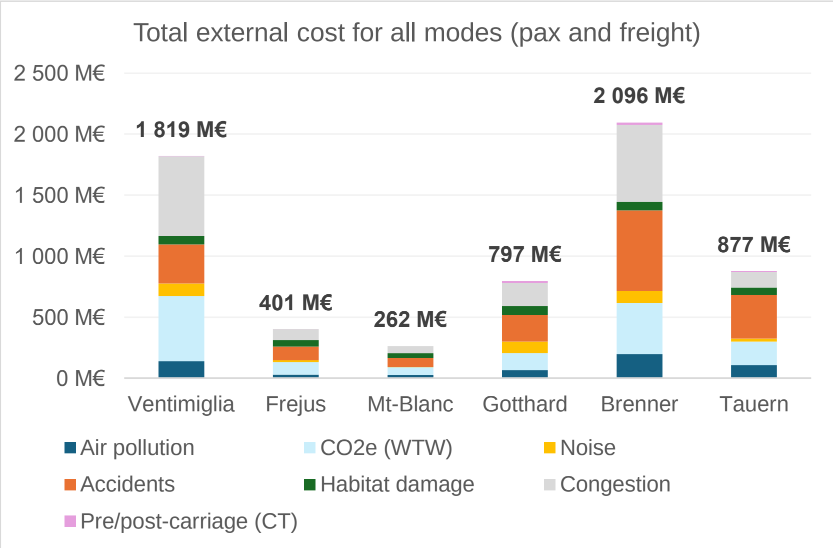
- European handbook on external costs (CE Delft 2019), which is currently being updated,
- Noise of road transport in an Alpine environment (Cerema 2018),
- The value of climate action (France Stratégie, Quinet 2025).

An extensive GIS analysis of the corridors was carried out for a finer calculation taking into account:

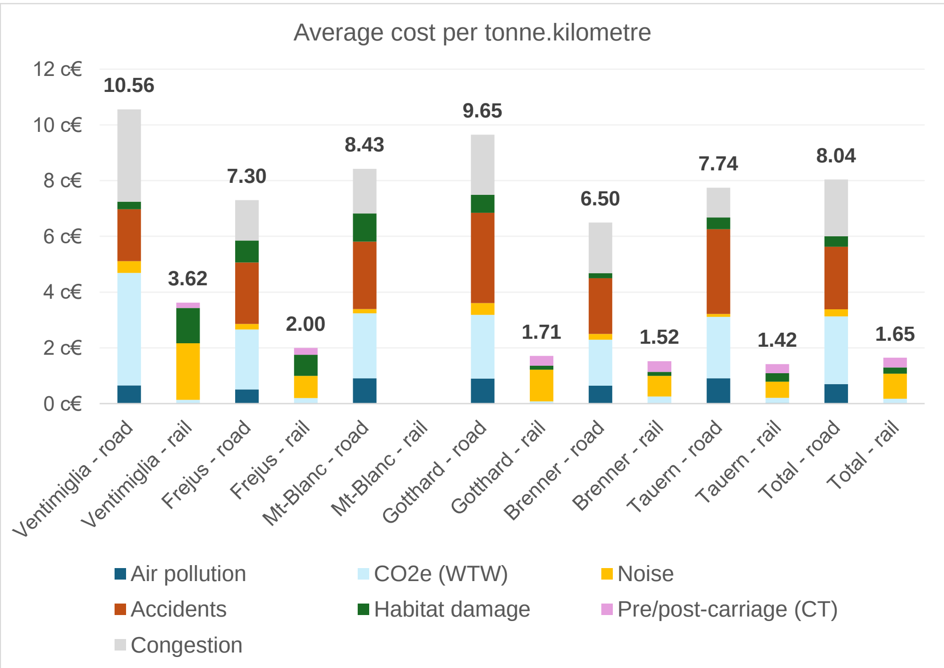
- Population density along each corridor,
- Infrastructure characteristics (speed, number of lanes, gradient, altitude),
- Distinction of type of natural environment (plain / Alpine foothills / Coastal Alpine foothills / Alpine).

The chart below presents the results in absolute values of external costs for each corridor. Variations in total external cost between corridors mainly reflect:

- Total vehicle flows, especially road traffic — with Brenner and Ventimiglia at the top,
- Corridor length (longer corridors have longer estimated external cost per vehicle crossing the Alps),
- The geographical characteristics of each corridor (population density, slopes/gradients, Alpine environment, etc.).

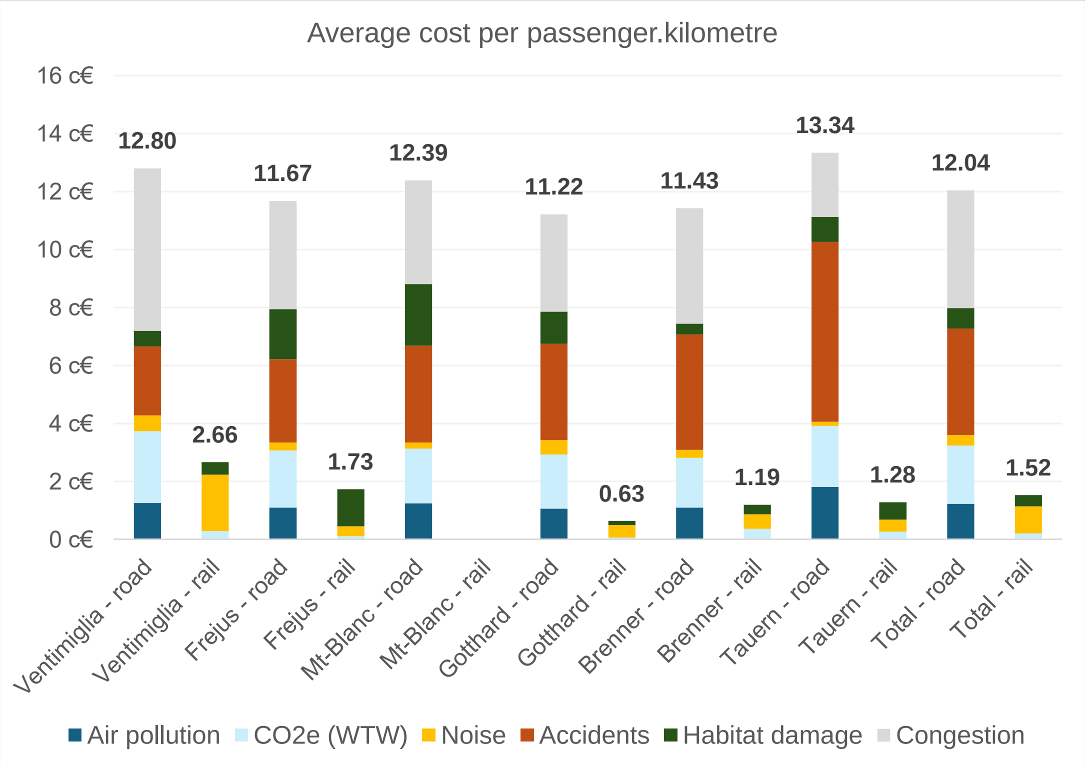


Comparing external costs per unit of demand (tonne.km or passenger.km)[1] allow us to compare the relative impact of different modes of transport between corridors. For freight, road generates 5 times more external costs per tonne.kilometre than rail, with some variations along the different corridors due to population density among others.



[1] 1 tonne.km = 1 tonne of goods carried over 1 kilometre
1 passenger.km = 1 person travelling over 1 kilometre

For passenger transport, road generates 8 times more external costs than rail per passenger.kilometre on average.



1. INTRODUCTION

1.1. Context

Historically, the Alps have been both a barrier and an interface between different European economic regions. While geography forces traffic to use a few Alpine valleys, economic development and European integration have led to a steady increase in long-distance traffic, which remains largely dependent on road transport.

The Alps contain rare and fragile ecosystems (forests, mountain pastures, lakes, high rocky mountains), but also densely populated valleys whose inhabitants suffer from the pollution and nuisances caused by transport activities (air pollution, noise, accidents, etc.). The altitude also means that more energy is consumed to cross the Alpine passes, as well as more braking power to descend back into plains.

The **concept of external transport costs** makes it possible to consider and estimate the costs generated by an actor's activities but borne by other actors. These costs are therefore not considered by the actor responsible when making a transport decision (choice of mode, choice of route, choice of travel time, etc.), since they do not have to bear the consequences.

The internalisation of external transport costs is a solution promoted by economists and a policy objective of the European Union. It aims to reintegrate the external costs of a transport activity in the form of pricing (charges, taxes, or tradable emission quotas) corresponding to the amount of external costs generated. The transport operator is then required to take these costs into account through the '**price signal**'. The aim is to improve the **well-being of the community** in terms of environmental and health issues without unduly penalising the economy through regulation (authorisation/prohibition, etc.).

The **aim of the study** is therefore to **calculate the external costs of transport on the main Alpine corridors** for the various modes of transport available for both passengers and freight activities.

1.2. Scope and perimeter

1.2.1. Corridors

6 corridors were selected for analysis from the 8 corridors defined in the iMONITRAF! annual report, from West to East:

- **Ventimiglia (FR/IT)** with road and rail infrastructure along the Mediterranean Sea connecting the cities of Marseille (France) and Genoa (Italy). This is the main road corridor between France and Italy (see map below).
- **Fréjus/Mont-Cenis (FR/IT)** between Lyon and Turin, with both rail (Mont-Cenis tunnel) and road (Fréjus tunnel). This is the main corridor for rail between France and Italy.
- **Chamonix/Mont-Blanc (FR/IT)** from Geneva (Switzerland) to the Po valley at Ivrea (Italy) between Milan and Turin. With the Mont-Blanc road tunnel but no rail infrastructure, this is the smallest of the corridors in terms of traffic, but it is at the heart of the Alpine environment.
- **Gotthard (CH/IT)**, from Basel to Chiasso at the Swiss-Italian border, is the main transport corridor through the Swiss Alps, connecting the Swiss plateau to the canton of Ticino and further on to Milan (Italy) with rail (base tunnel and the older Alpine tunnel) and road tunnels.
- **Brenner (AT/IT)** this mountain pass at 1'370m above sea level is the most important transalpine corridor as it connects Germany (Munich) to Italy (Verona) with rail and road.
- **Tauern/Katschberg (AT)** is an important transport corridor in the Eastern Alps with somewhat lower topography. It leads from Austria to Italy or Slovenia and includes both road (Katschberg tunnel to the East) and rail infrastructure (Tauern tunnel to the West).

Other Austrian corridors further East (Schoberpass, Semmering, Wechsel) are also important in terms of traffic flows and have been considered but could not be included due to budget limitations.

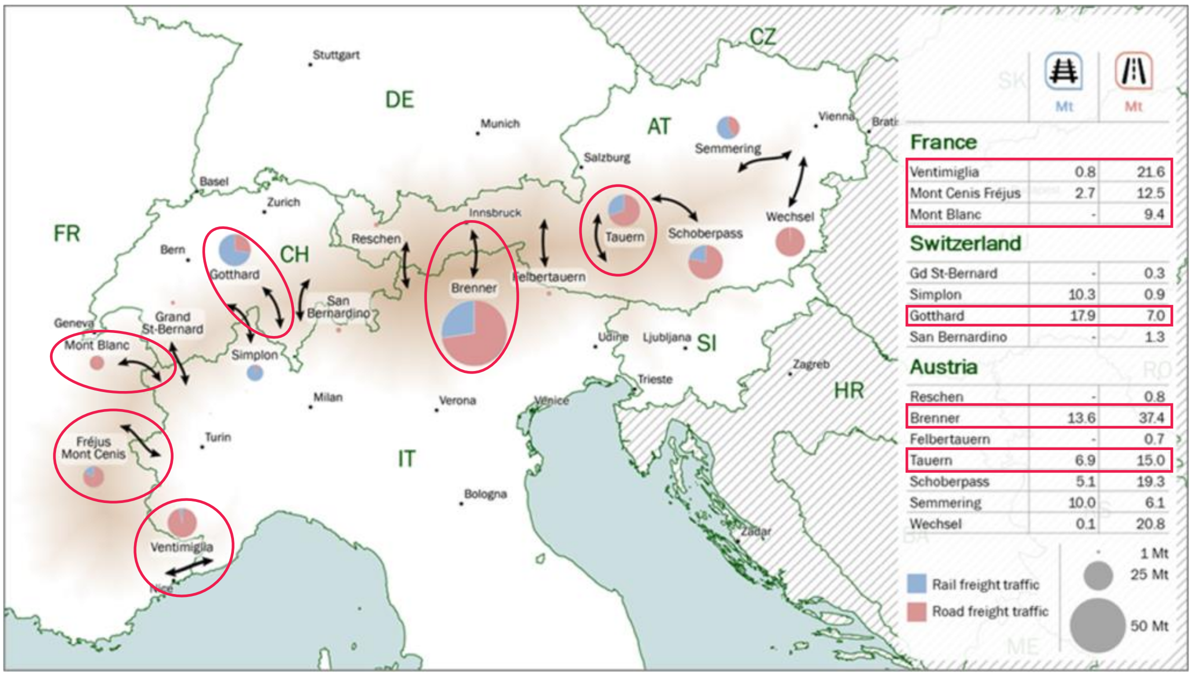


Figure 1: Transalpine Observatory - Goods flows through the Alps (TRT 2019)

1.2.2. Modes of transport and types of vehicles

For freight, we the following categories are analysed:

- **Road**:
  - Heavy goods vehicles (HGVs)
  - Light commercial vehicles (LCVs), although they are only used marginally for long-distance transport.
- **Rail**:
  - Whole trains (conventional)
  - Combined (sea containers or swap bodies) and unaccompanied rail motorway (semi-trailers only),
  - Accompanied rail motorway (semi + tractor + driver).

For the passenger segment, we selected the following categories:

- **Road**:
  - Private car (PC), distinguishing between diesel, petrol or electric (hybrids being treated as combustion engines),
  - Coach (diesel),
- **Rail**:
  - High-speed train (TGV, Frecciarossa, ICE, etc.),
  - Regional train (TER, IR, etc.),
  - Intercity train (IC) or night train (conventional long distance).

1.2.3. Types of external costs

The study considers a comprehensive range of external cost categories relevant to Alpine transport:

- **Climate change** due to greenhouse gas emissions expressed in monetary terms.
- **Air pollution**: health and environmental costs from tailpipe emissions and brake/tyre wear.
- **Well-to-tank emissions**: upstream emissions from energy production and delivery.

- **Noise**: impacts on human health and well-being, particularly acute in narrow valleys.
- **Accidents**: costs related to road and rail safety, injuries and fatalities.
- **Biodiversity and ecosystem impacts**: degradation of habitats and landscapes due to the infrastructure.
- **Road congestion**: productivity and time losses due to traffic bottlenecks. This last is a cost external to individuals, but internal to the mode of transport as it does not impact neighbours or the rest of the world.

1.2.4. Geographical analysis of the corridors

1.1.1.a. • Population density along the corridors

Population density along the corridors is a major driver of external costs as local residents are impacted by noise and air pollution. It was estimated for each corridor section by identifying population in a buffer of 500 meters on each side of the road and rail infrastructure. Population data is taken from Global Human Settlement Layer (GHSL) Data Package for 2023 published by the Joint Research Centre of the European Commission.[2]

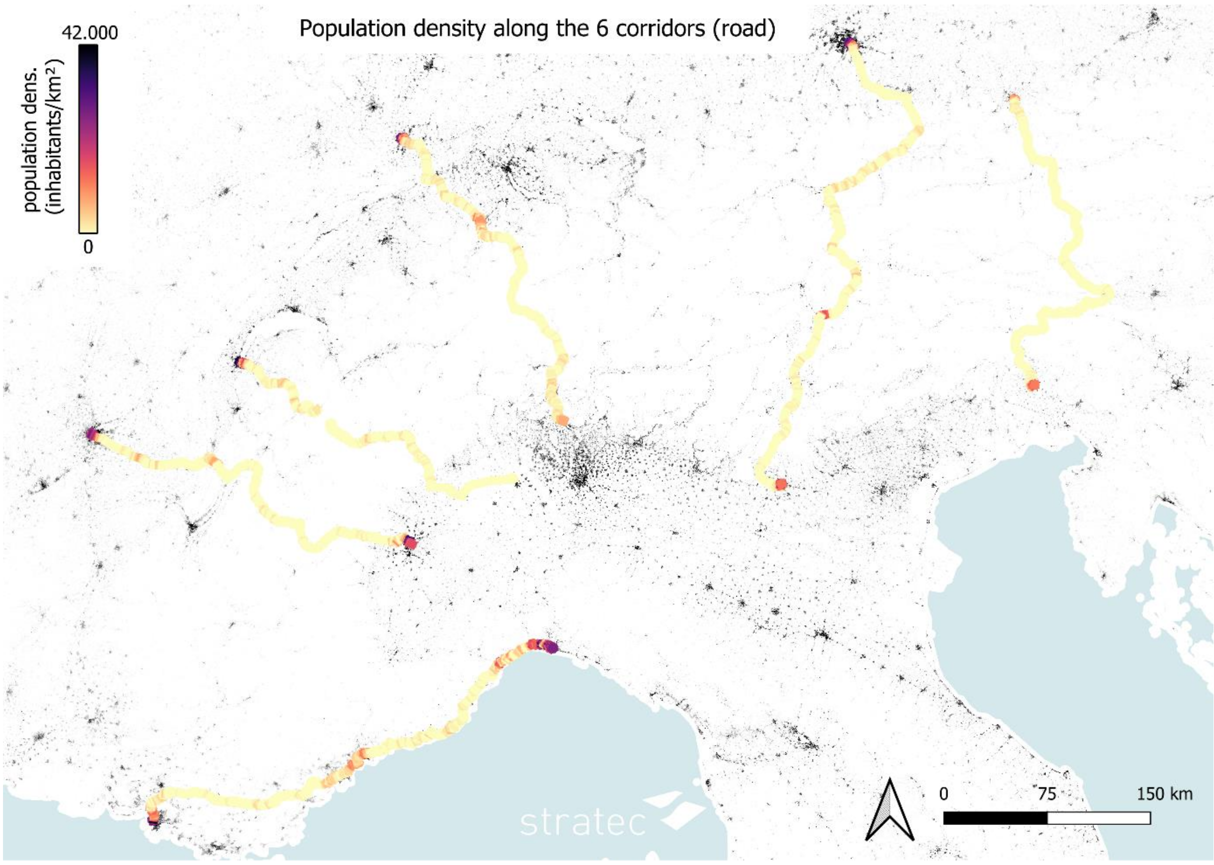


Figure 2: Population density along the 6 corridors (500m radius along road infrastructure)

The 6 corridors display notable differences in population density. The Ventimiglia corridor (Marseille – Genoa), along the Mediterranean coast, crosses the most densely populated areas with cities such as

[2] Carioli, Alessandra; Schiavina, Marcello; MacManus, Kytt J; Freire, Sergio (2023): GHS-POP R2023A - GHS population grid multitemporal (1975-2030). European Commission, Joint Research Centre (JRC) [Dataset] doi: 10.2905/2FF68A52-5B5B-4A22-8F40-C41DA8332CFE
PID: http://data.europa.eu/89h/2ff68a52-5b5b-4a22-8f40-c41da8332cfe

Cannes and Nice and an almost constant urbanisation. Fréjus (Lyon – Turin) comes next with secondary cities such as Chambery and Susa. It is followed by Gotthard (Basel – Chiasso) which crosses the densely populated Swiss plateau. Mont-Blanc (Geneva – Ivrea) and Brenner (Munich – Verona) come next, whereas Tauern (Salzburg – Udine) is the least populated corridor.

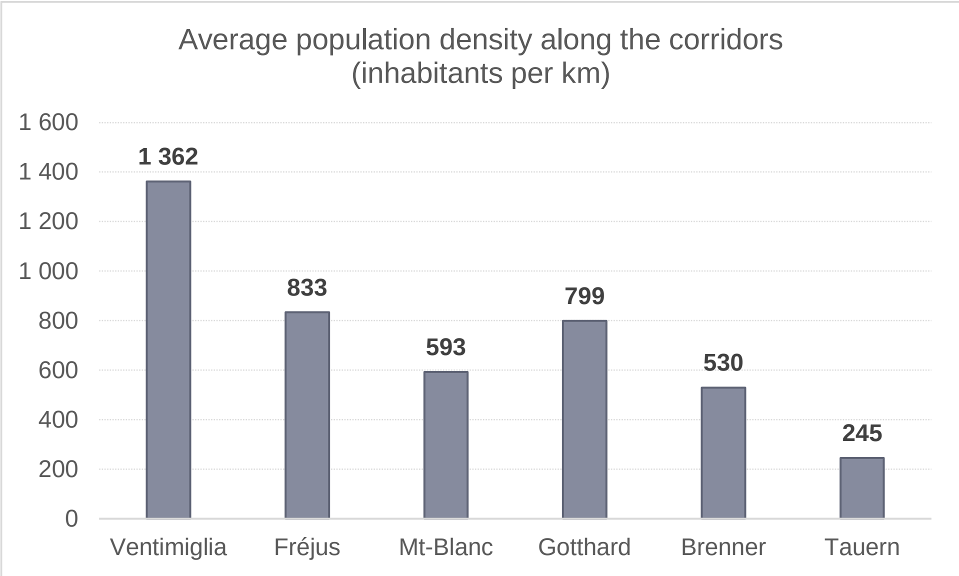


Figure 3: Average population density along the 6 corridors

By using a threshold of 250 inhabitants per square kilometre as the limit between rural and urban (and suburban) areas, this data can be summarised in the split between urbanised environment along each corridor (see chart below). This distinction, although somewhat arbitrary, is important for several external costs for which the values used are set for urban vs. rural environments.

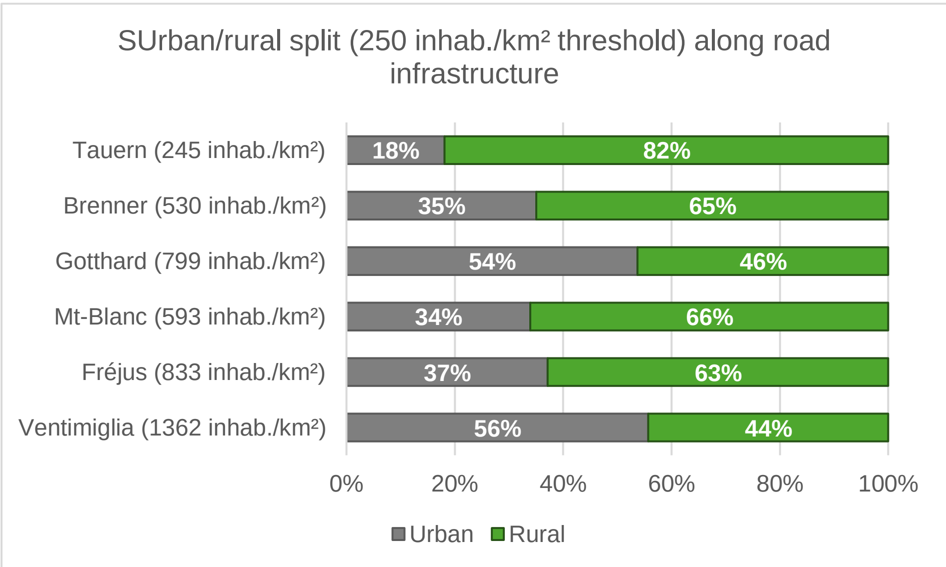


Figure 4 : Urban – rural environment on corridors

1.1.1.b. Infrastructure and topography

Road and rail infrastructures are described in a database indicating altitude, average gradient (recalculated with the altitude at each end of a section), tunnels, maximum speeds, and number of lanes extracted from OpenStreetMap with a route choice calculated with OpenRouteService. There is a close link between infrastructure and gradient, since tunnels allow vehicles to avoid higher routes though mountain passes.

The following chart presents the maximum altitude and total cumulative ascend on each road corridor. Interestingly, the Ventimiglia corridor is both the lowest in terms of altitude and the one with the most ascend. This is explained by the fact that this corridor follows the edge of the Alps along the coast and must therefore go over many ridges, whereas the other corridors tend to stay at the bottom of valleys and have only one major mountain pass or tunnel to cross.

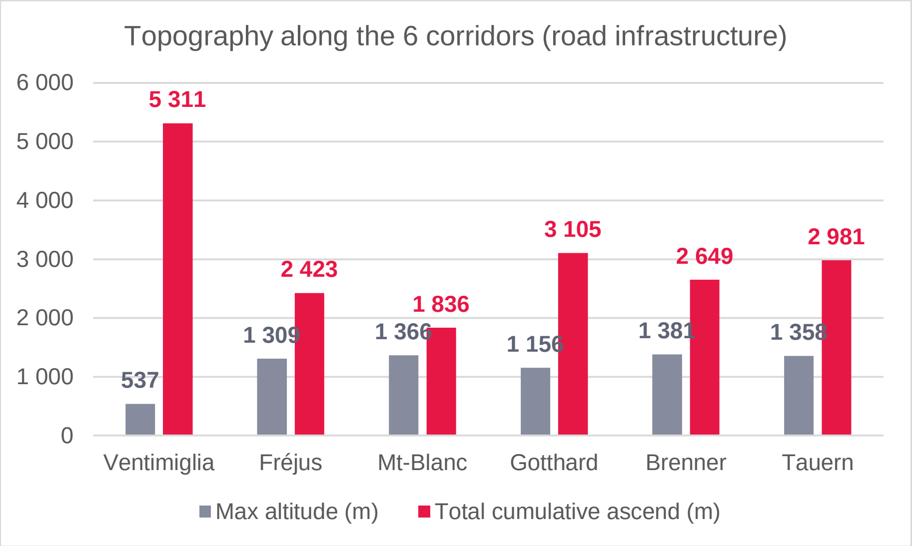


Figure 5 : Topography along the 6 corridors

The following map displays the variations in road gradient along the corridors in the direction towards Italy (for each section the gradient value is of course of the opposite sign in the other direction). Maps displaying each corridor are available in annex.

Road gradient along the 6 corridors (towards Italy)

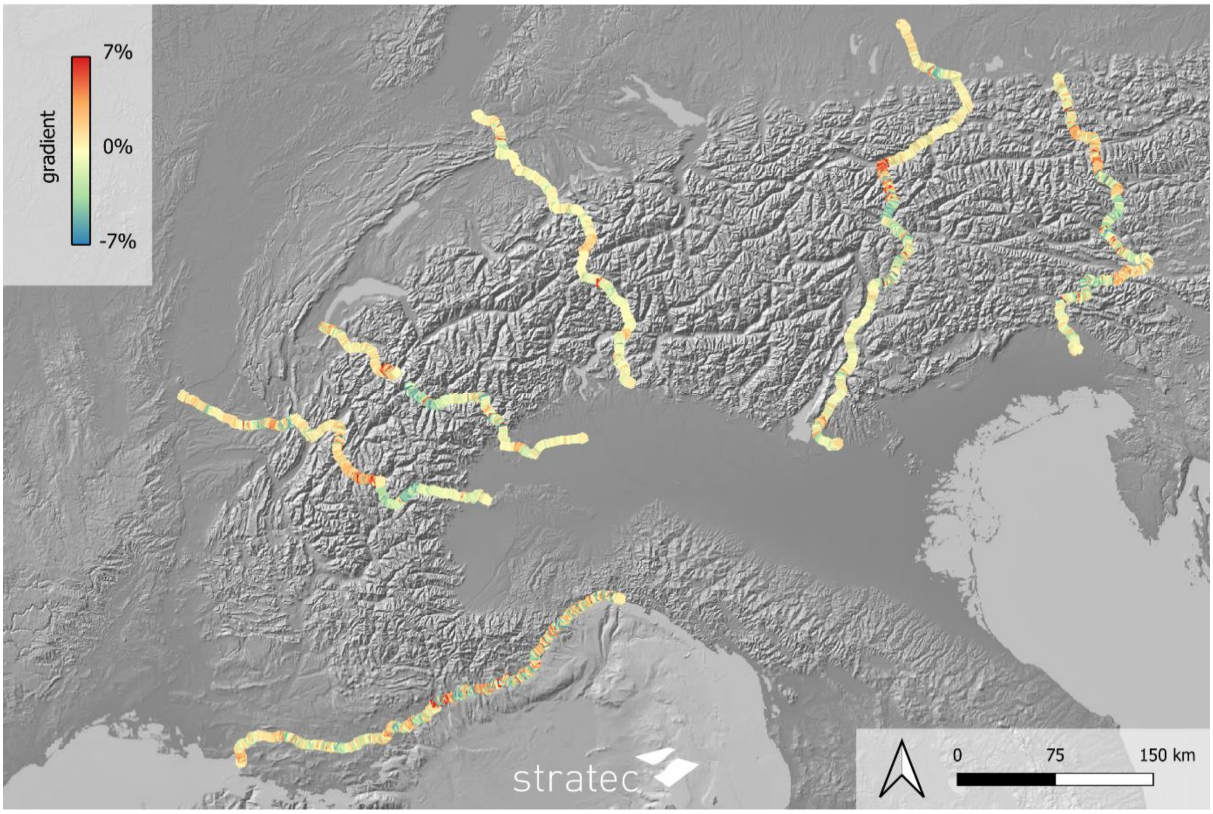


Figure 6: Road gradient

1.1.1.c. Natural environment

The type of mountain environment is an important factor for some external costs, such as air pollution and noise. For the need of this study, corridor sections were divided in four categories: plain, Alpine foothills (intermediary category between plain and properly high mountains), Alpine, coastal Alpine foothills (due to the difference in wind along the coast). This distinction is based on the consultants' own appreciation of natural geography according to maps of the main massifs.

The chart below shows the share of each of those categories for the corridors. Those shares also vary according to the length of each corridor, as longer corridors tend to reach further away from the Alps.

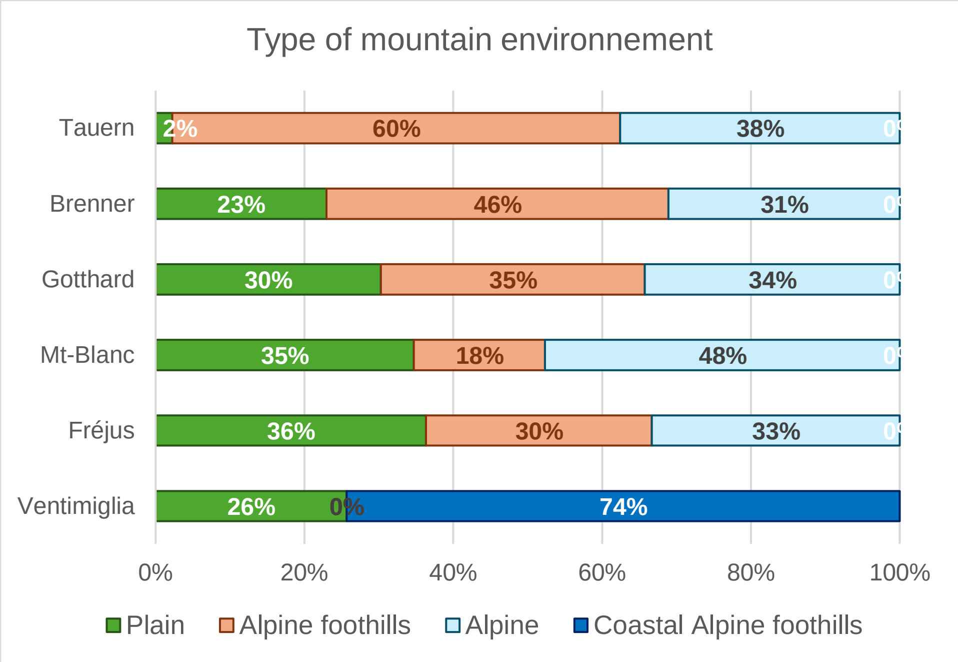


Figure 7: Type of mountain environment (share of total corridor length)

The next chart presents the absolute values in absolute values, i.e. kilometres of corridor length.

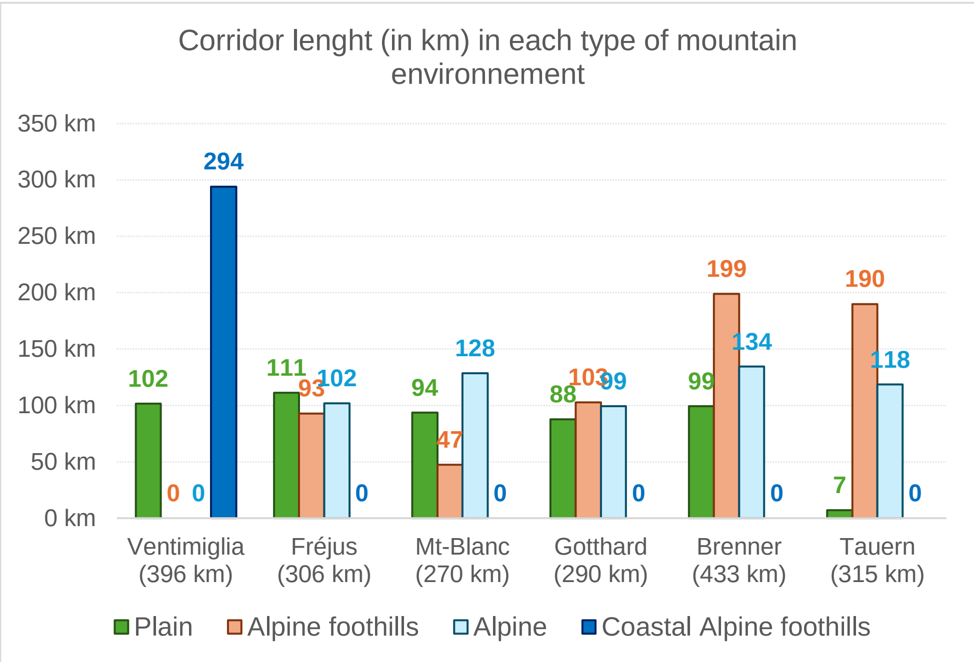


Figure 8: Type of mountain environment (total length in km)

2. LITERATURE REVIEW

A literature review was conducted to develop and document the methodological framework and to define the scope and the corridors which will be studied in detail.

The Alpine space is characterised by unique geographical, climatic and socio-economic conditions that make the assessment of transport externalities particularly challenging. The work presented here aims at setting the foundation for a robust and comparable evaluation of the external costs borne by freight and passenger transport crossing the Alps.

The methodological framework adopted in this study builds upon existing European reference values for external costs, complemented by Alpine-specific adjustments. The process began with a thorough literature review of previous studies dedicated to environmental and socio-economic costs in mountain regions. Building on these insights, a systematic inventory of data sources was conducted to assess the feasibility of quantitative estimations.

The external cost categories have been defined according to European standards, but particular attention was given to adapting them to the Alpine context. For example, gradient, altitude and topographical constraints may influence energy consumption, pollutant dispersion and noise propagation. Furthermore, specific corridors were selected to capture the diversity of Alpine transport flows. The approach therefore combines a pan-European methodological base with targeted local refinements.

2.1. Studies focussing on the Alps

Studies reviewed can be divided in serval main categories according to their geographical areas of focus. We start by presenting studies which are specific to the Alps:

- GRACE, 2006. Generalisation of Research on Accounts and Cost Estimation (GRACE): Deliverable 3 - Environmental costs in sensitive areas.
- CEREMA, 2016. External Environmental Costs.
- EUSALP, 2017. External costs in mountain areas. on behalf of EUSALP (EU Strategy for the Alpine Region), Zurich: INFRAS and Herry Consult.
- CEREMA, 2018. Assessment of external costs induced by noise in mountainous areas.
- Oekoscience, 2013. The "Alpine factor": Higher emissions per emission unit in Alpine valleys - Analysis of 2004–2012, on behalf of the Federal Office for the Environment FOEN.

1.1.1.d. GRACE 2006

The GRACE project (2006) was among the first to systematically analyse environmental costs in sensitive areas. The objective of the study was to compare Alpine and flat regions for road and rail transport, and to identify key reasons for cost differences. Its methodology, based on the impact-pathway approach, identified key mountain factors and differentiated them by passenger and freight transport. The cost studied were air pollution, noise, visual intrusion, recreational value of mountain areas / tourism, non-environmental effects (accidents and infrastructure costs).

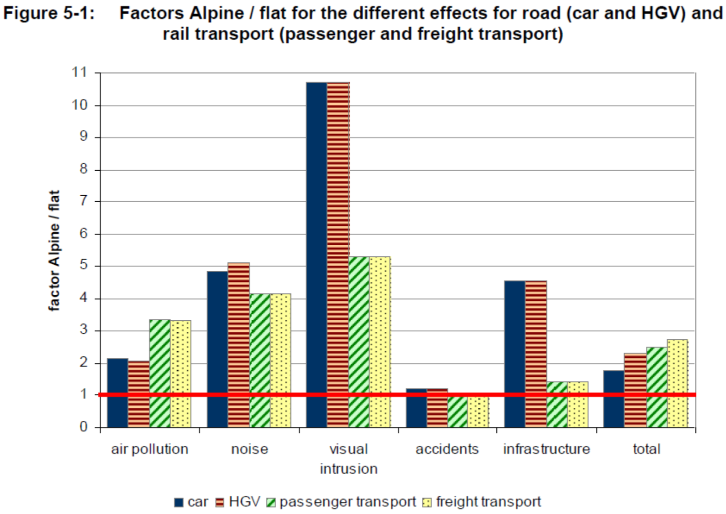


Figure 9: Alpine factors for road and rail according to GRACE 2006 study

As shown in the tables below, the authors specified the following aspects for each external cost:

- Why costs differ between mountain and non-mountain areas,
- Summary of methodology & data sources used to assess a "mountain factor" (external cost multiplier in an alpine context),
- Results of the analysis.

Table 1: Particularities of external costs in the Alps according to GRACE 2006 study (C. Nash et al.)

External cost	Cost drivers	Mountain area specificity	Method	Road	Rail
Air pollution	Gradients	More pronounced for cars than for HGVs	Calculation based on UBA and BUWAL 2004	x	
	Altitude	Higher exhaust emissions from internal combustion engines at 1000m above sea level due to lower oxygen density.	Calculation based on BUWAL 1995 and EMPA 2002	x	
	Topographical and meteorological conditions	Damages higher in Alpine areas because same level of emissions lead to higher concentrations (immissions) mainly due to temperature inversion between the bottom of the valleys and the higher levels.	Case study based on two studies of the iMONITRAF-project: evaluate data from different Swiss measurement stations	x	x
	Population density	Lower population density in Alpine areas	Analysed the population density in the permanent settlement area (defined as the area for settlement, infrastructure and agriculture or in other words the area excluding forests, Alpine agricultural land, lakes and	x	x

			rivers, and areas with little or no vegetation).		
Noise	Gradients	Gradients increase the energy consumption of vehicles. The impact is higher for HGVs carrying heavy loads than for cars which are lighter.	Own calculation based on EMPA 1997	x	
	Topographical and meteorological conditions	Two effects considered: temperature inversion and amphitheatre effect and reflections	Based on Swiss, German and Austrian data found in a literature review	x	x
	Population density	Lower population density in Alpine areas	Own calculation based on data from the Gotthard motorway for road and from the Gotthard rail line for rail	x	x
Visual intrusion	Average cost only	More severe in Alpine areas where the traffic routes can be seen from much farther away. Traffic volume higher in the Alps	Analyse the visual intrusion of the Gotthard motorway (or rail line) by comparing the scenic landscape with and without the traffic route according to the NISTRA method	x	x
Recreational value	Average cost only	Attractiveness of the Alpine region for tourism is strongly correlated with the possibilities of undisturbed outdoor activities	Not possible to monetize so far.	x	x
Accident	Causality rate	Accidents in tunnels and on bridges can have more serious consequences	Evaluate detailed accident data from the Swiss motorways (number of accidents and casualties for 500m stretches of the Swiss motorway between 1994 - 1998)	x	
Infrastructure	Maintenance costs	Road maintenance costs are higher in Alpine areas due to bridges, tunnels, and rutting of slow HGV traffic.	Evaluated detailed data from the Swiss railway company (SBB) of 371 stretches in the years 2003 – 2005	x	

1.1.1.e. CEREMA 2016

The second study in this literature review was conducted by CEREMA in 2016. The focus was on external environmental costs (air pollution and noise) from Heavy Goods Vehicles (HGVs). Cerema has conducted 15 studies between 2003 and 2015 with 4 studies focusing on mountains area. In these studies, methods were developed to calculate external costs and the authors carried out a comparison of the values for air pollution and noise with Eurovignette III European Directive baseline values.

1.1.1.f. EUSALP (INFRAS 2017)

The objective of the third study, EUSALP study carried out by INFRAS in 2017, was to validate and update the mountain factors for external costs, i.e. the factor by which external costs in plain can be multiplied with to estimate the amount of external cost in mountains. The study was mainly focusing on the methodological approach of the GRACE study (2006): methodology based on cost drivers and 'cost differential factors' (mountain factors) along the impact pathway. The external costs studied were air pollution, noise, nature and landscape, accidents and climate change. The focus was on rail and freight transport, and the study was based on a corridor approach (focus on Gotthard and Brenner).

The authors concluded on these potential mountain factors:

- 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.

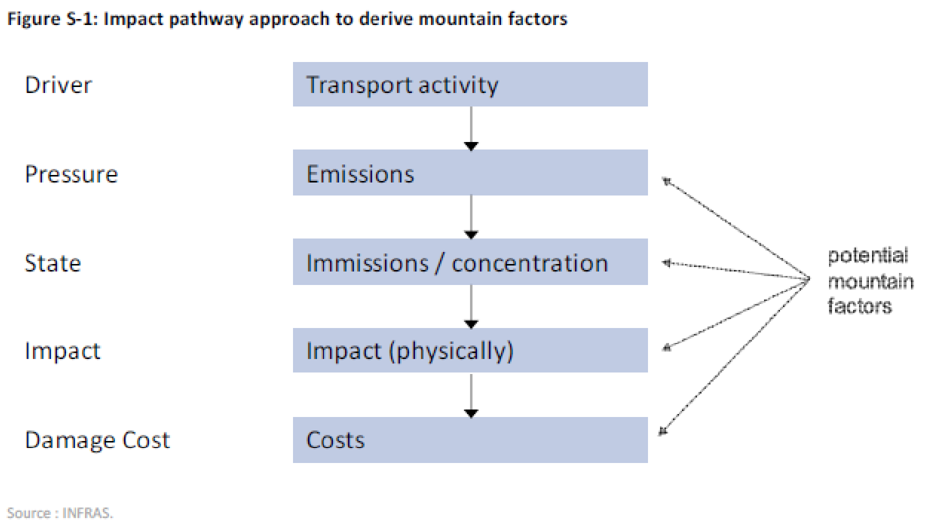


Figure 10: Impact pathway approach to derive mountain factors (INFRAS 2017)

Considering the specific mountain factors for each level of the impact-pathway approach leads to the establishment of an overall factor. This factor expresses the cost per unit of transport performance (vehicle-kilometre) in mountain regions, compared with non-mountainous regions or the national average.

The analysis thus results to the determination of a 'mountain factor' specific to a given category of external costs (e.g. air pollution costs, noise costs, accident costs) and transport mode (road, rail).

As shown in the table below, for each external cost, the study explains:

- Reasons for differences: key cost drivers (e.g., gradient & altitude for air pollution),
- Evaluation method: how the "mountain factor" was calculated for each driver,
- Results: mountain factor and comparison with previous studies.

Table 2: Particularities of external costs in the Alps according to EUSALP study by INFRAS in 2017

External cost	Cost drivers	Mountain area specificity	Method
Air pollution	Gradient	Higher PM10 exhaust emissions in Alpine regions due to gradients	A polynomial function describing emission factors of HGVs depending on road gradients according to specific HGV emission factors for the mean gradients of 0%, ±2%, ±4% and ±6%. Longitudinal inclination calculated according to a GIS elevation model of the region -> Mean gradient calculated (weighted with the section length)
Air pollution	Altitude	Emissions from HGVs increase with altitude due to lower air pressure and lower oxygen contents in higher altitudes	Based on literature research
Air pollution	Topographical and meteorological conditions	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 (for road and rail).	Based on a study specifically looking at measured emission levels in different Alpine and non-Alpine regions (Oekoscience 2013)
Air pollution and noise	Population density	Number of residents affected is lower in Alpine regions due to lower population density	Population analysed in both types of regions within 500m from road or railway (excluding tunnels): GIS analysis. Depends largely on the choice of distance from the motorway or railway that is included
Noise	Gradient	Noise emissions increase with ascending slopes and decrease with descending slopes	New models (sonRoad project and CNOSSOS-EU) Or model developed by EMPA (Grace 2006) + update gradient value and vehicle speed values + multiplied by 0.5 to consider both ascending and descending slopes
Noise	Topographical and meteorological conditions	Higher noise emission levels in Alpine regions due to inversions and the amphitheatre effect	No new studies since GRACE (2006)

Nature and landscape	Habitat loss, habitat fragmentation and visual intrusion	Negative effects differently relevant in mountain areas: Habitat loss and habitat fragmentation depend on the type and quality of the ecosystem that is lost. Visual intrusion depends on the quality of the landscape.	Swiss studies on external costs of transport habitat loss is monetized based on a restoration cost approach: - Restoration cost approach - Today's photos were compared with photos from the 1950's and the types (and areas) of ecosystems lost or fragmented were analysed
Accidents	Construction and maintenance costs	Based on abatement costs: higher cost partially due to safety measures	Estimation of mountain factor (Austrian motorway network, 2014): - estimation of the share of tunnel length with the necessity of a 2nd tube due to safety and not due to traffic volume - unit costs for the safety relevant infrastructure elements and winter operation
Climate change	Vulnerability (resilience)	Vulnerability of mountain regions to climate change is clearly higher (higher risk for extreme weather events and higher costs for adaptations, …)	Climate change is a global issue with global effects due to local emissions -> recommend not to consider a mountain factor for climate change costs, since this would be methodologically not appropriate

1.1.1.g. CEREMA 2018

The fourth study was also conducted by the French institute CEREMA in 2018. The aim of this study was to further the analysis of the 2016 literature review by assessing external costs induced by noise on two French transalpine routes in comparison with a route in the plain:

- Pont d'Ain to Chamonix via Scientrier (Mont-Blanc corridor),
- French portion of the Lyon-Turin axis (Fréjus corridor),
- A7 between Chasse-sur-Rhône and Valence South (plain corridor for comparison).

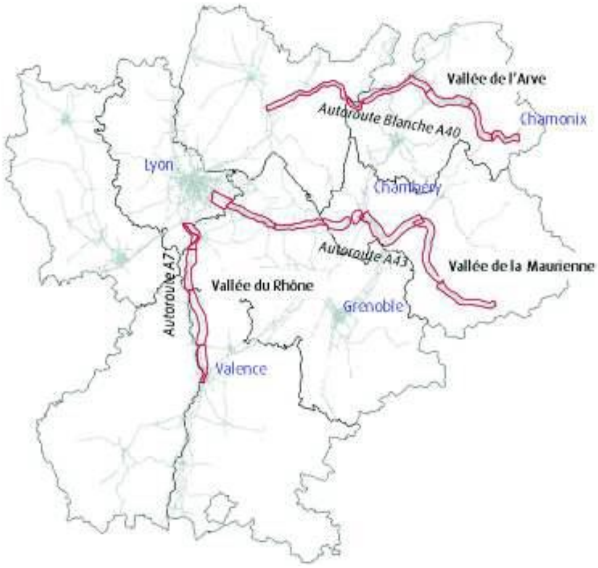


Figure 11. Three French routes analysed by Cerema (2018)

The results were obtained by modelling the topography and road traffic to assess the exposure of populations.

The first step of this study was to calculate the cost of noise pollution due to traffic. For this, two methods were used. The first one is a detailed calculation and is used to estimate tolls because of external costs higher than reference values. The second one is the application of additional unitary values (differentiated between night/day and suburban/interurban road) and multiplied by maximum 2 in mountain areas which is justify by dispersion, road gradient, altitude or temperature inversions.

The second step of this study was the assessment of the cost of noise exposure of populations. This method is explained in 4 steps:

1. Reference value applied in France expresses in €/exposed person/year according to noise exposure level
2. Noise exposure indicator: Strategic Noise Maps
3. Noise levels calculation method:
    - Modelling of acoustic sources,
    - 3D modelling of the environment,
    - Calculation of noise levels at 4 meters above ground level and on the facades of residential buildings,
    - Counting the exposed populations,
4. Equivalence factor for HGVs/LVs: based on the French calculation method (NMPB08).

The results are summarised in the following chart and table. The comparison between flat (plain) and mountain environment shows that the noise impact on local population per inhabitant is lower in the plain, but the lower population density more than compensate for this effect in the total external cost per vehicle.

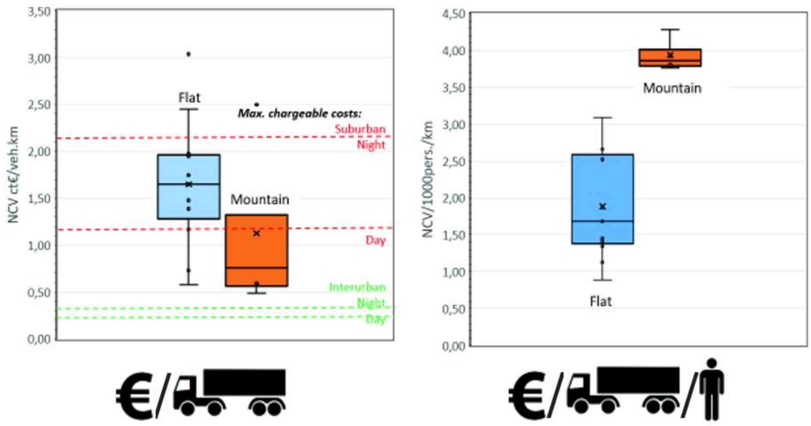


Figure 12: Noise cost of HGV on French corridors in mountains vs. plain according to CEREMA 2018

The values presented in the table below provide the detail for each road section analysed. Road sections are divided into three categories: flat (plain), mix flat/mountain (intermediary category equivalent to Alpine foothills), and mountain.

Table 3: Noise cost of road transport on French corridors according to CEREMA 2018

Motorway	Subsections	Mountain/Flat	Length (km)	AADT Annual average daily traffic (veh/day)	%HDV (Heavy Duty Vehicles)	Exposed population density (inh./km²)	Noise cost NCVj (ct€/veh.km)	NCVj/1000 Pers/km (ct€/veh./pers)
E21-E25	Pont d'Ain / Tunnel Vuache	Mix Flat/Mountain	11.8	20 307	14.1%	654	1.65	2.52
	Tunnel Vuache / Scientrier	Mix Flat/Mountain	38.7	29 061	8.6%	418	1.39	2.67
	Scientrier / Cluses	Mix Flat/Mountain	23.6	26 396	8.8%	983	3.04	3.09
	Cluses / Le Fayet	**Mountain**	21.1	17 216	11.2%	665	**2.5**	**3.76**
	Le Fayet / **Chamonix**	**Mountain**	35.6	13 876	15.3%	**149**	**0.59**	**3.92**
E70	St Priest N346/ A43-A48 Coiranne	Flat	26.2	73 170	10.5%	1 204	1.75	1.45
	A43-A48 Coiranne/L'Epine	Flat	12.6	71 874	13.1%	820	0.73	0.89
	L'Epine / A41-A43	Flat	5.5	47 387	12.7%	1 156	1.95	1.68
	A41-A43 / Aiton	Mix Flat/Mountain	32	32 040	12.0%	920	2.45	2.66
	Aiton / St-Jean-M	**Mountain**	37.4	10 229	22.0%	129	**0.49**	**3.8**
	St-Jean-M / Fréjus	**Mountain**	25	7 220	36.0%	217	**0.93**	**4.28**
E15	Chasse/Reventin	Flat	15.6	109 005	15.4%	1 311	1.48	1.13
	Reventin/St Rambert d'Albon	Flat	20.6	70 141	18.3%	870	1.17	1.34
	St Rambert d'Albon / Tain l'Hermitage	Flat	29.2	65 315	18.0%	311	0.58	1.87
	Tain l'Hermitage/Valence Sud	Flat	18.4	62 233	18.1%	1 350	1.98	1.41
					Average (std. dev.)		**1.51 (0.78)**	**2.43 (1.13)**
					Average « Flat »		**1.26**	**1.39**
					Average « Mix Flat/Mountain »		**2.13**	**2.74**
					Average « Mountain »		**1.13**	**3.92**
					Ratio « Mountain/Flat »		**0.897**	**2.82**
					Ratio « Mix/Flat »		**1.69**	**1.97**

1.1.1.h. Oekoscience 2013

Finaly the last Alps study reviewed was done by Oekoscience in 2013. The author contributed with a detailed analyses of road traffic and air pollutant emissions and immissions (PM10, black carbon and organic components) in Swiss plains and Alpine valleys at 6 locations in Switzerland (see map below).

A comparison of estimated road traffic emissions and locally measured immissions (concentration measured) on transalpine routes (Gotthard in particular) was carried out. The aim of this analysis was to estimate a factor to consider local dispersion effect.

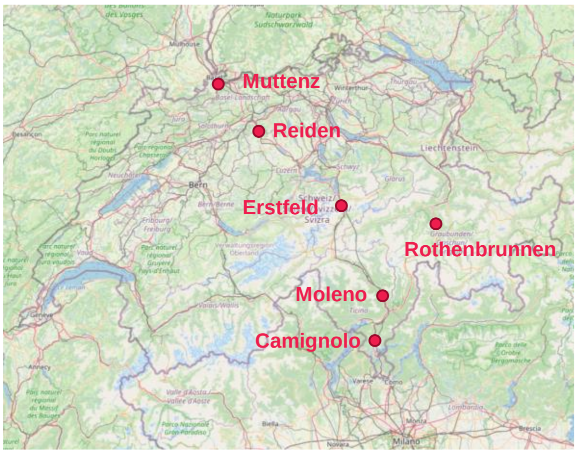


Figure 13: Location of air pollutant analysis by Oekoscience 2013 (map by Stratec)

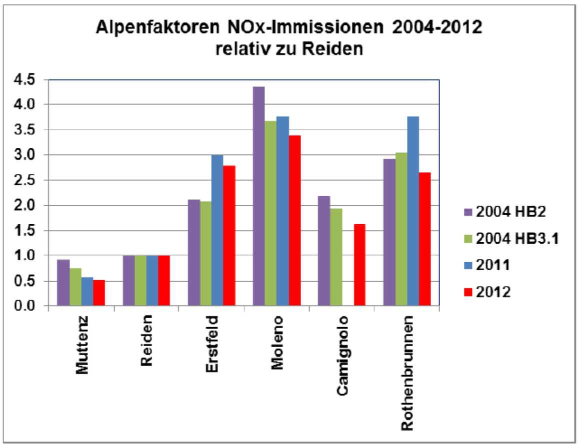


Figure 14: Results of Alpine factors for NOx immissions (Oekoscience 2013)

The full results are presented in the table below for which we identified the type of natural environment according to the category which we use for our own analysis.

Table 4: Alpine factors for air pollution according to Oekoscience 2013

Location in Switzerland	Alpine Environment (Stratec)	NOx	PM10	EC	OC	Average
Muttenz	Plain	0.50	0.45	0.55	0.43	0.48
Reiden	Plain	1.00	1.00	1.00	1.00	1.00
Erstfeld	Alpine	2.80	1.70	2.20	1.60	2.08
Moleno	Alpine	3.38	1.90	3.20	2.40	2.72
Camignolo	Alpine foothills	1.60	1.25	1.60	1.25	1.43
Rothenbrunnen	Alpine	2.65	3.10	2.90	3.15	2.95
	Plain	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
	Alpine foothills	**2.1**	**1.7**	**2.1**	**1.7**	**1.9**
	Alpine	**3.9**	**3.1**	**3.6**	**3.3**	**3.5**

1.1.1.i. Summary of content of the Alpine studies

Table 1: Content of the main Alpine studies on external costs

Sources	Type of external costs							Monetarisation?	Market	
	Accidents	Climate (GHG/CO2)	Air pollutants	Noise	Congestion	Upstream/ downstream	Ecosystems		Freight	Passengers
GRACE, 2006. Generalisation of Research on Accounts and Cost Estimation (GRACE): Deliverable 3 - Environmental costs in sensitive areas	X		X	X				X	X	X
CEREMA, 2016. External environmental costs of Transport			X	X				X	HGV	
EUSALP, 2017. External costs in mountain areas. on behalf of EUSALP (EU Strategy for the Alpine Region), Zurich: INFRAS and Herry Consult	X	X	X	X			X		X	
CEREMA, 2018. Assessment of external costs induced by noise in mountainous areas				X				X	HGV	
Oekoscience, 2013. The "Alpine factor": Higher emissions per emission unit in Alpine valleys			X						X	X

2.2. European and national studies

The second type of studies included in this review are general European or national studies on external costs. This includes the following:

- **European Union**: CE Delft, 2019. European handbook on the external costs of transport.

  The European handbook from 2019 remains the reference for external cost valuation, covering all major transport modes and all member states plus Switzerland and Norway. At the time of the present study, the European handbook is being updated.

- **Switzerland**: Ecoplan & Infras 2024, Externe Effekte des Verkehrs 2021 - Umwelt-, Unfall- und Gesundheitseffekte des Strassen-, Schienen-, Luft- und Schiffsverkehrs.

  This study for the Swiss federation provides estimates of the external costs of transport of all modes in terms of environment, accidents and health. Though interesting, it does not focus on the Alpine context.

- **Germany**: Umweltbundesamt (UBA, ministry of environment)
  - Methodological convention 3.1 for determining environmental costs (work in progress on a new 4.0 version), 2020
  - TREMOD 2024 - Determination of transport emission values in 2023

- **France**:
  - DGITM 2019, Fiches outils pour l'évaluation socio-économique de projets d'infrastructures de transport. This is the national framework for cost-benefit analysis of transport infrastructure projects.
  - France Stratégie 2025, La valeur de l'action pour le climat, Rapport de la commission présidée par A. Quinet. This study reevaluates the cost of carbon according to the avoidance method.

- **Other**: The Handbook of Emission Factors for Road Transport (HBEFA) estimated by INFRAS provides a large database of emissions and energy consumption of road vehicles in Switzerland, Germany, Austria and France. It takes into account the main factors, and in particular: type of road, fleet (norms, type of engine), road gradient and congestion.

The table was created to summarise the information provided by these studies:

Table 2: Content of the main European and national studies on external costs

Sources	Type of external costs							Monetarisation?	Market		26SSSSS Soo the Alps?
	Accidents	Climate (GHG/CO2)	Air pollutants	Noise	Congestion	Upstream/ downstream	Ecosystems		Freight	Passengers	
CE Delft, 2019. European handbook on the external costs of transport	X	X	X	X	X	X	X	X	X	X	**Focus**
Umweltbundesamt (UBA), 2024 (Germany). TREMOD emission values		X	X						X	X	
Umweltbundesamt (UBA), 2020. Methodological convention 3.1 for determining environmental costs		X	X	X				X	X	X	
DGITM 2019, Fiches outils pour l'évaluation socio-économique de projets d'infrastructures de transport	X	X	X	X		X		X	X	X	
Ecoplan & Infras 2024, External effects of transport in 2021 – environmental, accident and health effects of road, rail, air and inland waterway transport	X	X	X	X		X	X	X	X	X	

3. DATA AVAILABILITY

Data availability is a major issue due to the multinational context and high number of parameters to be considered (freight and passenger data, data specific to modes…).

3.1. Traffic data

Traffic data differentiates between number of vehicles (cars, HGV, trains, etc.) and demand (passengers or tonnes), as well as between transalpine traffic (the object of the study) and local traffic (out of scope, but sometimes important to take into account).

For freight transport, both road and rail, there is a high availability of data on transalpine traffic, as the 2023 report 'Observation and analysis of transalpine freight transport flows' published by the EU and Switzerland can be used.[3] This report provides data in tonnage for both road and rail for all corridors for 2023. For road, traffic counts are available for heavy vehicles (HGV) and for the rail, there is distinction in the different markets (conventional, combined and accompanied).

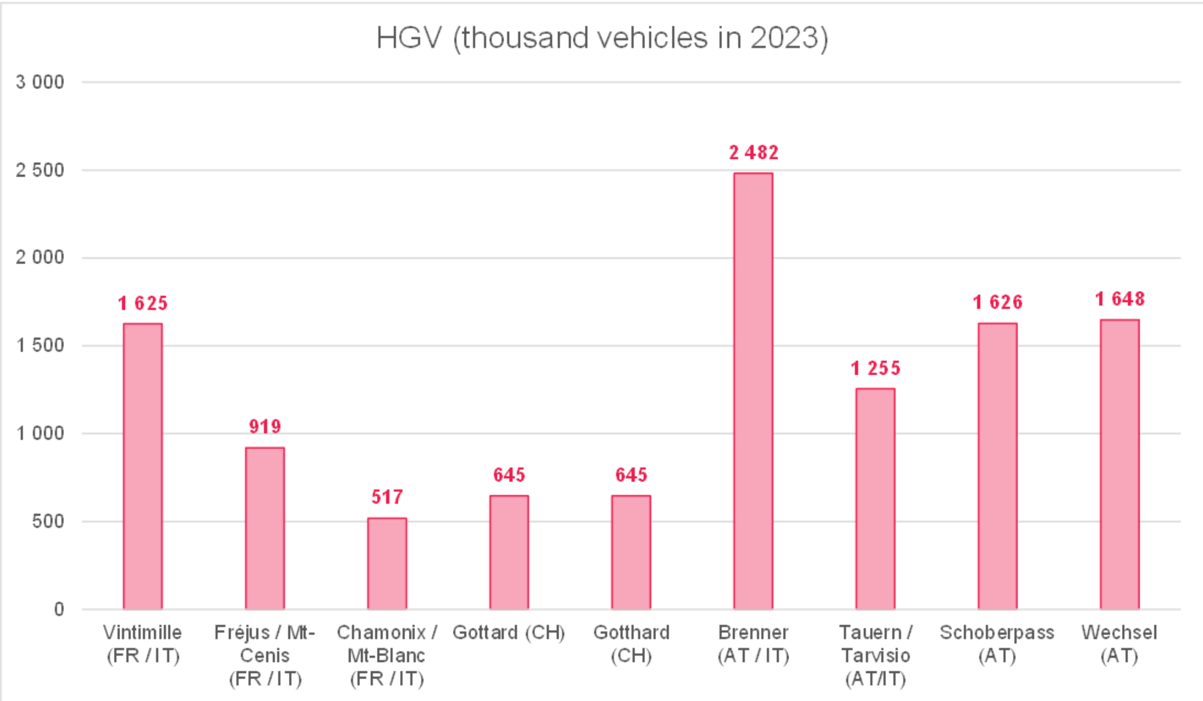


Figure 15: Source: Observation and analysis of transalpine freight transport flows, report for 2023

[3] Dörnenburg et al., 2025, Observation et analyse des flux de transports de marchandises transalpins - Rapport annuel 2023 bav.admin.ch/dam/fr/sd-web/uMdIdteImaeB/alpenobservatorium-2023.pdf

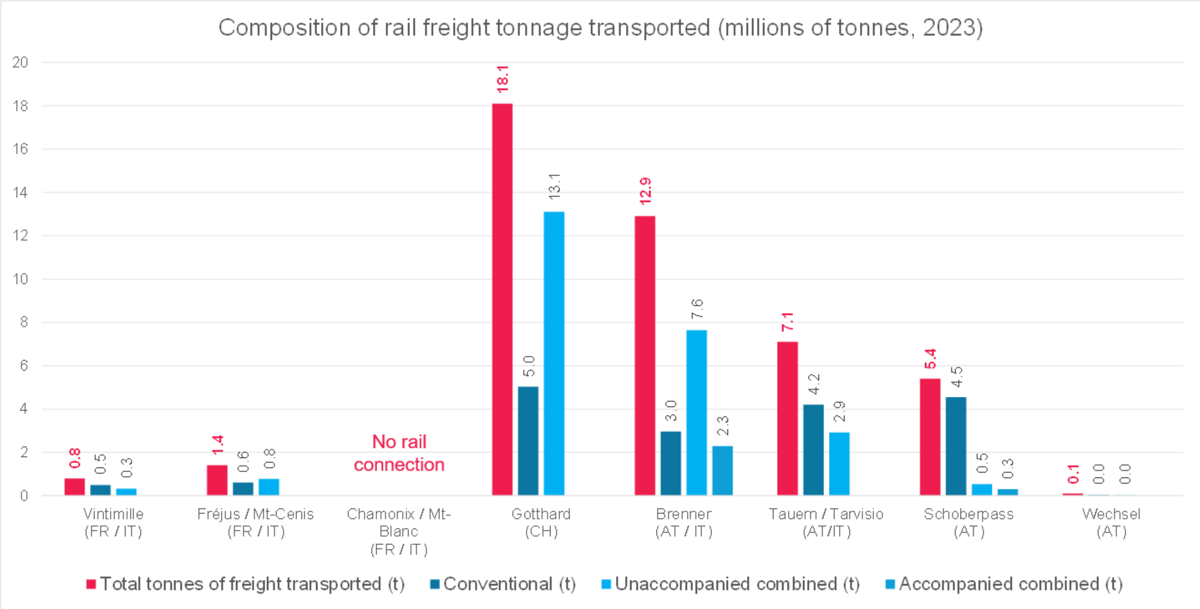


Figure 16. Source: Observation and analysis of transalpine freight transport flows, report 2023

For passenger transport, there is a lower availability of data. Road traffic counts are available for light vehicles (LV) for most corridors for the year 2023 in the iMONITRAF report.[4] Some traffic counts can also be available in local sources (case by case). Road traffic counts do not distinguish between HGV (freight) and coaches (passengers) in traffic counts.

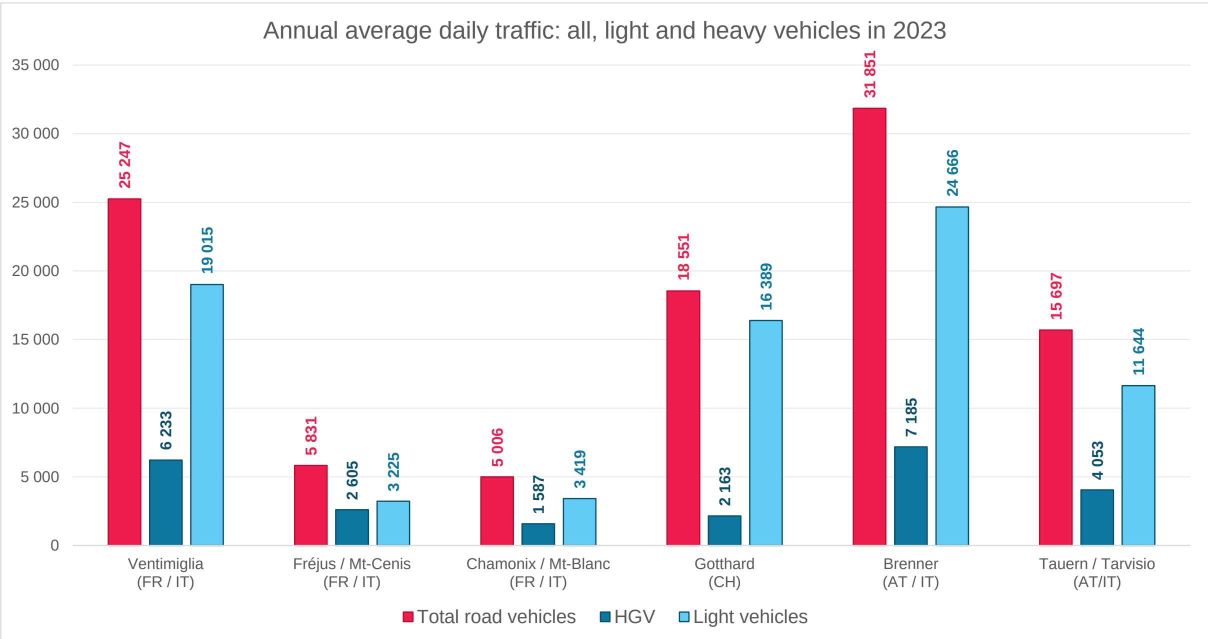


Figure 17. Source: iMONITRAF 2024 report

[4] Lückge et al., iMONITRAF! annual Report 2024, 16th February 2025 imonitraf.org/fileadmin/downloads/3-Publications/AnnualReports___Studies/Annual_Reports/iMONITRAF__Annual_Report_2024.pdf

For rail, no publicly available data could be found. Data owners depend on the type of train service:

- Regional trains are operated under PSO (Public Service Obligation) and the data are owned by regional authorities,
- Commercial long-distance services are operated as open access services (TGV, Frecciarossa, ICE) and data owned by operators are therefore a commercial secret.

There is however publicly available data on train services (timetables), and assumptions can be made on train capacity and occupancy rates to estimate passenger numbers.

3.2. Energy and types of vehicles

No data addressing the types of vehicles on the different transalpine corridors have been identified. For road transport, data on vehicle fleets are available by country (type of engine and euro classes). It is therefore necessary to make an assumption on an average split by country for each corridor according to our own understanding of the likely origin-destination of transalpine flows. The table below presents our assumptions.

Table 3: Stratec assumptions on the nationality of road vehicles on each corridor

		Ventimiglia (FR / IT) Marseille (FR) Genova (IT)	**Fréjus / Mt-Cenis (FR / IT)** Lyon (FR) Torino (IT)	**Chamonix / Mt-Blanc (FR / IT)** Geneva (CH/FR) Novara (IT)	**Gotthard (CH)** Basel (CH) Chiasso (IT)	**Brenner (AT/IT)** Munich (DE) Verona (IT)	**Tauern / Tarvisio (AT/IT)** Slazburg (AT) Udine (IT)
Light vehicles (LV)	AT					34%	40%
	CH			10%	50%		
	DE				25%	33%	20%
	FR	50%	50%	45%			
	IT	50%	50%	45%	25%	33%	40%
Total LV		100%	100%	100%	100%	100%	100%
Heavy good vehicles (HGV)	AT					20%	30%
	CH			0%	20%		
	DE				40%	40%	30%
	FR	50%	50%	50%			
	IT	50%	50%	50%	40%	40%	40%
Total HGV		100%	100%	100%	100%	100%	100%

Road energy consumption and emissions can be best assessed with the Handbook of Emission Factors for Road Transport (HBEFA) data base provided by INFRAS for all 5 countries, except Italy.

For rail transport, data about the rolling stock depends in each case on the rail undertaking. There is in any case a general lack of data on energy consumption and emissions of rail. Only some general order of magnitude of train consumption per kilometre (kWh/train.km) of different national operators is available for passenger trains, with no distinction according to the type of train, speed, or gradient. We use the value of **9.79 kWh/train.km** recalculated by Stratec with the Swiss data published by the CFF/SBB on the energy consumption per passenger.km (7.77 kWh/100pax.km) and average number of passengers per train (126 pax/train) in 2023.

For freight we rely on data from two sources. Firstly, the 2025 study on energy efficiency carried out by the consultancy HERRY for EUSALP which indicates:

- "Tractive force required to move (not accelerate) a gross ton in the plain: 35 Newtons (N) per total gross ton (GT) [i.e. 0,972 kWh per gross tonne for a speed of 100 km/h],
- Tractive force required in addition to the force in the plane per one per mill gradient to move a gross ton on this gradient (not to accelerate): 10 N/Gbt [i.e. 0,278 kWh per gross tonne for each additional ‰ of gradient]"

Additional research shows however that "compared to passenger stock the potential for regenerative braking in freight trains is very limited. The main reason is the lower ratio of powered to unpowered axles. […] Even comparing to loco-hauled passenger trains, freight trains have a disadvantage since they are much longer and heavier and have a larger mass to be braked by unpowered axles."[5]

Secondly, the values published by the French ADEME (Agence de l'environnement et de la maîtrise de l'énergie) on the energy consumption of freight trains (see table below) provide average values per tonne.km by load.[6]

Table 4: ADEME assumptions on the energy consumption of freight trains

Load	Tonnage associated	Consommation - Diesel traction (l/t.km)	Consumption – Electric traction (kWh/t.km)
Dense goods	**600 t**	0.0076	**0.0278**
Medium goods	520 t	0.0088	0.0322
Light goods	400 t	0.0113	0.0415

We choose to combine those two sources by using the average consumption of 600 t trains from ADEME as a value for plain, to which we add the extra energy consumption per positive ‰ of gradient. We use thus a conservative estimate of the energy consumption of freight trains.

Finally, data for well-to-tank emissions (energy production) of electricity are available for all European countries for the year 2023 on the site electricitymaps.com.

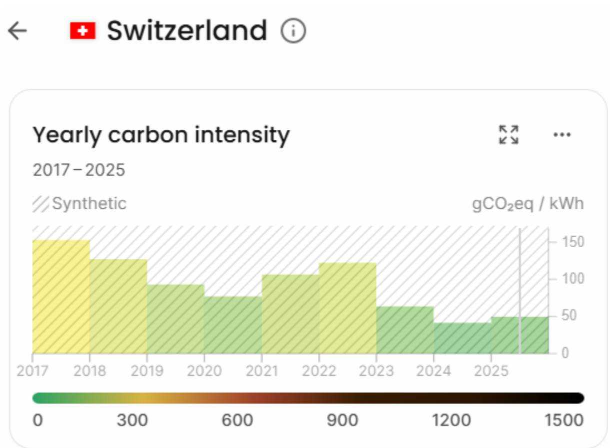


Table 5: Average carbon intensity of energy consumed in each country

Country	Carbon intensity (CO_2eq/kWh)
AT	113
CH	62
DE	370
FR	53
IT(Northern)	296

For rail transport, energy consumption corresponds for each kilometre to the country in which the train is running and being supplied in electricity by catenary. For road, the link is less direct as electric road vehicles can charge at various steps of their journey. We assume that the charging occurs in each country according to the same assumptions as the country of origin of the vehicles.

[5] UIC, Regenerative braking in freight trains railway-energy.org/static/Regenerative_braking_in_freight_trains_43.php

[6] ADEME online data on energy consumption of transport prod-basecarbonesolo.ademe-dri.fr/documentation/UPLOAD_DOC_FR/index.htm?ferroviaire.htm

3.3. Road congestion

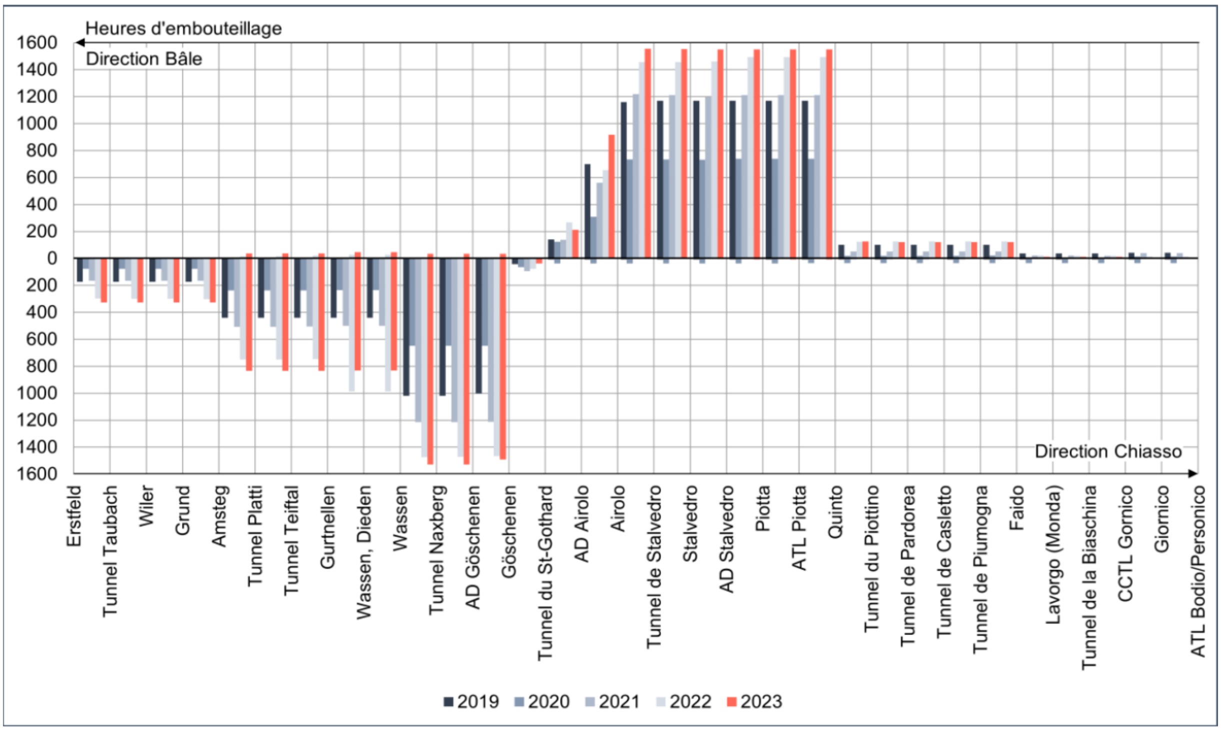
There were no general study or data found on alpine road congestion. Some information is available at specific bottlenecks, with forecasts addressed to road users of green, yellow or red days during the pick season at Gotthard, Brenner, Fréjus and Mont-Blanc. Also, real time congestion can be measured by online aps and cameras.

The difficulty with congestion is that it is not linear and one given day is not necessarily representative of any other day or the year. To estimate annual averages, annual travel time data and/ or a fine traffic model with different time periods would be required, which is out of scope of this study.

The ALPIFRET 2011, Observatory of transalpine freight traffic - 2010 annual report, provides some data on road congestion at the French-Italian border, expressed in hour.km (see below), but this is too old and too geographically limited to be used.

Switzerland publishes valuable data on the fluidity of road traffic for 2023, with a focus on the Gotthard tunnel (see chart below).[7]

Table 6: Evolution of congestion on A2 between Erstfeld and Biasca in Switzerland (OFROU with VMON and Viassuisse data)



3.4. Accidents

For the road transport, Eurostat publishes the number of road accidents by NUTS 3 region between 1999 and 2023, but there is no other information on the types of vehicles or the precise location of accidents. National datasets are available, but in different format and variations in the type of information provided. Stratec managed to access and treat GIS data on road accidents for Switzerland, Italy, and France. Data for Austria where also found, but in a different GIS format which could not be exploited.

[7] Office fédéral des routes (OFROU), Évolution et fluidité du trafic en 2023, February 2025

astra.admin.ch/dam/astra/fr/dokumente/abteilung_strassennetzeallgemein/verkehrsentwicklung_verfuegbarkeit_nationalstrassen_jahresbericht_2023.pdf.download.pdf/Trafic_et_disponibilite_des_routes_nationales-Rapport_annuel_2023.pdf

The national databases used are the following:

- Swiss: Swiss road traffic accidents map
- Italy: lis.aci.it/#/datiLocalizzati/2023/01/001
- Austria: statistik.at/atlas/verkehrsunfall/
- France: onisr.securite-routiere.gouv.fr/en/crash-map

Rail accidents are rare occurrences and can only be analysed over a large geographical perimeter and a long timeframe. Although a freight train accident did occur in the Gotthard base tunnel in 2023 (with no casualties), we assume that rail accidents are too rare to be evaluated.

3.5. Population

Data on population is available from European and national sources according to administrative boundaries. Population data is taken from Global Human Settlement Layer (GHSL) Data Package for 2023 published by the Joint Research Centre of the European Commission.[8]

4. METHODOLOGICAL APPROACH

The estimation of external costs will be conducted according to a structured approach. The approach is divided in three phases. The first phase consists of obtaining the European standard values for external effects. The second phase is to adjust these standard values to the Alpine context and also to add the observed flows and routes specificities per corridor and mode. Finally, the third phase is to estimate the external effects per corridor and to compare these results to the locally observed external effects.

4.1. Conclusion

Phase 1 has defined the methodological basis for the analysis of external costs in Alpine corridors. It has reviewed the most relevant studies, assessed the availability of data and selected representative corridors. The next phases will operationalise this framework to quantify external costs per corridor and transport mode. Special emphasis will be placed on adapting European average values to Alpine conditions, and on filling data gaps through innovative estimation methods.

5. DATA TREATMENT AND ANALYSIS

5.1. Cost Values

5.1.1. Monetary values for external costs

The stating points for most values used is the European handbook (CE Delft 2019) which are presented in 2016 euros for 2016. The only exception is for the climate change which is based on the most recent French value (see below).

The values have been selected and updated with Eurostat data to fit our purpose:

[8] Carioli, Alessandra; Schiavina, Marcello; MacManus, Kytt J; Freire, Sergio (2023): GHS-POP R2023A - GHS population grid multitemporal (1975-2030). European Commission, Joint Research Centre (JRC) [Dataset] doi: 10.2905/2FF68A52-5B5B-4A22-8F40-C41DA8332CFE

PID: http://data.europa.eu/89h/2ff68a52-5b5b-4a22-8f40-c41da8332cfe

- Values for each of the country in which external costs occur (IT, FR, CH, DE or AT, depending on the corridor), no local adjustment to regional GDP per inhabitant were carried out,
- 2023 monetary values (price index at January 2023 prices) for base year 2023 (reference year), according to the evolution of GDP per inhabitant in each country,

The European handbook provides values for urban and rural (or interurban) environments but does not indicate the criteria used to distinguish the two categories. We use a threshold of 250 inhabitant per square kilometre, which corresponds to low density suburban areas.

The Alpine factor per external cost have been taken from best literature available (see below), they have been re-estimated when possible and generalised to other corridors.

5.1.2. Value of tCO2eq

The value attributed to greenhouse gas emissions (GHG) causing climate change is a delicate topic, and values tend to be reevaluated upward over time. Although we base most of our cost estimates on the values from European handbook on external costs, it seems necessary to consider a more recent higher value. Four sources have been consulted:

1. European handbook (CE Delft 2019), currently being updated,
2. German value from UBA 2020, currently being updated,
3. French value from France Stratégie in 2019 and 2025, recently updated according to avoidance cost.

The result of the comparison is presented in the following chart. It shows that the most recent value from France Stratégie is above the other older values. A higher value for CO_2eq. (still unknown at this stage) is also expected for the coming update of the European handbook. **We therefore use the 2025 French value for the present estimation of external costs of transport on transalpine corridors.**

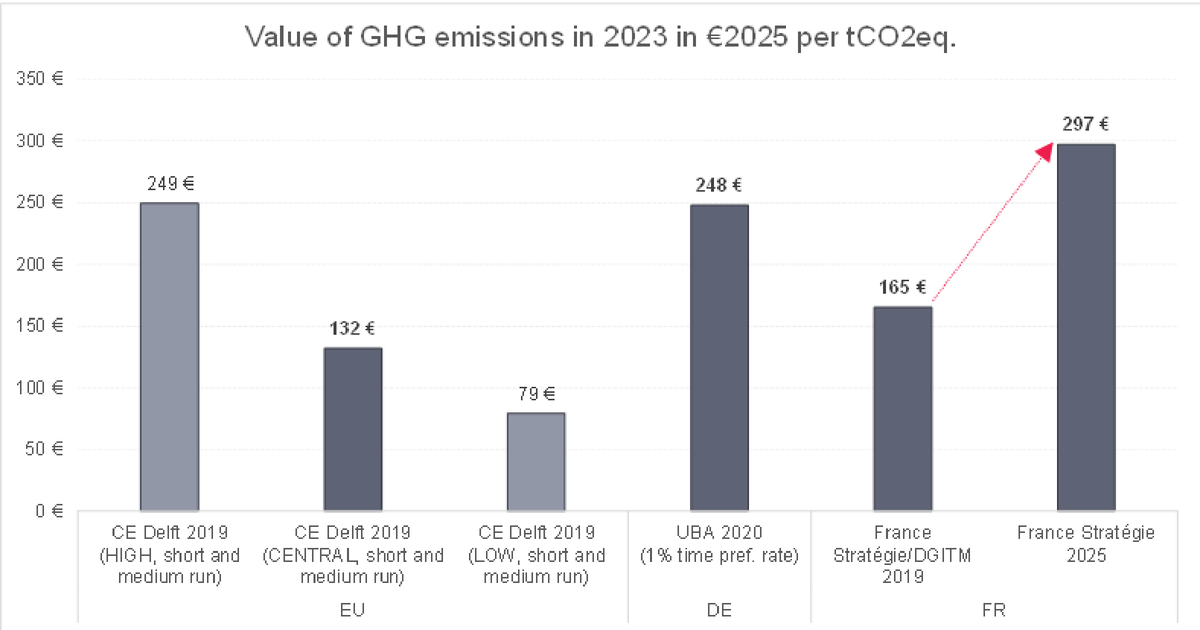


Figure 18: Comparison of the values attributed to GHG emissions by three European sources

5.1.3. Overview of sources used for cost values

The table below presents the sources that have been used for cost values:

Sources	Type of external costs						Monetarisation?	Market	
	Accidents	Climate (GHG/CO2)	Air pollutants	Noise	Congestion	Ecosystems		Freight	Passengers
CE Delft, 2019. European handbook on the external costs of transport	X	X	X	X	X	X	X	X	X
France Stratégie 2025, La valeur de l'action pour le climat, Rapport commission A. Quinet		X							
EUSALP, 2017. External costs in mountain areas. on behalf of EUSALP (EU Strategy for the Alpine Region), Zurich: INFRAS and Herry Consult	X	X	X	X		X		X	
CEREMA, 2018. Assessment of external costs induced by noise in mountainous areas				X			X	HGV	
Oekoscience, 2013. The "Alpine factor": Higher emissions per emission unit in Alpine valleys			X					X	X

5.1.4. CALCULATION OF EXTERNAL COSTS

For the external cost, the European cost values (CE Delft 2019), adjusted by country and for 2023 (adjusted with inflation index and GDP/inhabitant), have been taken. Types of engines, age of the fleet and gradient have been taken from HBEFA 4.2 for the emissions per road vehicle. Data for the energy consumption from trains were taken from energy efficiency study for freight and Stratec assumption.

The Alpine factors taken from literature or measured are:

- Air pollution: lower dispersion of air pollutants (inversion)
- Suboptimal combustion due to altitude
- Noise: higher impact due to geography
- Population density from GIS analysis
- Underestimation of local population in the Alps due to seasonal residents

Also, corridor data were collected to calculate effects according to:

- Characteristics of infrastructure (distances, speeds, slopes, tunnels, altitude)
- Population density (1 km corridor, i.e. 500m on each side)
- Natural environment (plain / Alpine foothills / coastal Alpine foothills / Alpine)

Finally, the annual traffic for 2023 based on collected data (road and rail freight) or estimations by Stratec (pax rail).

5.2. Alpine factor for air pollution

5.2.1. Alpine factor for air pollution

In the EUSALP 2017, external costs in mountain areas were selected and sometime adjusted:

Impact pathway	Cost driver	Mountain factor	Short description (Source)	Stratec methodological choice
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)	Values recalculated for each road section according to gradient and HBEFA (4.2.2) values
	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))	Value linearised from 1 at sea level to 1.34 at altitude 1'000 m
	Fleet	- *(1.0)*	*Different fleet composition could lead to different emissions. However, this should be directly covered by the HGV toll (differentiated cost factors)*	Values recalculated for each corridor according to HBEFA (4.2.2) values For Italy, the French values were used while taking into account the differences in fleet composition (engine types)
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))	Values from the same source, but with a finer distinction according to the type of natural environment (plain, Alpine foothills, Alpine)
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)	Own population density analysis per corridor. Additional correction for non-residents
	Health risk	- *(1.0)*	*No evidence on higher health risk in mountain regions.*	Identical
Costs	*Specific damage costs*	- *(1.0)*	*Regional differences of cost factors due to different income levels not appropriate.*	Identical

5.2.2. Road emissions values

For road, emission values were extracted from HBEFA:

- Motorways, 80 to 130 km/h, freeflow or heavy traffic
- Gradients +/- 6%, +/- 4%, +/- 2%, 0%
- Main emission components (CO2eq, PM, NOx, SO2, NMHC) and energy consumption (MJ)
- 11 types of motorisation are recorded, but only the 5 main motor categories are taken into account: petrol, diesel, electricity (battery), LPG and CNG (the last 2 are more common in Italy, see below),
- For Austria, Switzerland, Germany and France (Italy not available, associated with France)

Table 5: Eurostat data on engine type by member state

Eurostat code	PET	DIE	ELC	LPG	GAS	Total
HBEFA name	**petrol (4S)**	**diesel**	**electricity**	**bifuel LPG/petrol**	**CNG**	**2023**
AT	46%	51%	3%	0%	0%	99.9%
CH	67%	29%	3%	0%	0%	99.8%
DE	66%	30%	3%	1%	0%	100.0%
FR	45%	51%	2%	0%	0%	98.7%
IT	48%	42%	1%	7%	2%	100.0%
AT	46%	51%	3%	0%	0%	100.00%
CH	68%	29%	3%	0%	0%	100.00%
DE	66%	30%	3%	1%	0%	100.00%
FR	46%	52%	2%	0%	0%	100.00%
IT	48%	42%	1%	7%	2%	100.00%

The first 5 values were corrected to obtain 100% total for each country.

For the assumed countries of origin per corridor the HBEFA data were studied for Austria, Switzerland, Germany and France (Italy not available, associated with France). A proposal for country was made to split per corridor because no data were available on actual traffic origin-destinations.

Coaches are counted as heavy vehicles in traffic data, their precis number is not available and assumed small and in decline so as in other studies, coaches were associated with HGV.

Table 6: Own assumptions on HBEFA cases to be applied for each corridor

HBEFA cases used (IT assimilated to FR)		**Ventimiglia (FR / IT)** Marseille (FR) Genova (IT)	**Fréjus / Mt-Cenis (FR / IT)** Lyon (FR) Torino (IT)	**Chamonix / Mt-Blanc (FR / IT)** Geneva (CH/FR) Novara (IT)	**Gotthard (CH)** Basel (CH) Chiasso (IT)	**Brenner (AT/IT)** Munich (DE) Verona (IT)	**Tauern / Tarvisio (AT/IT)** Slazburg (AT) Udine (IT)
Light vehicles (LV)	AT					34%	40%
	CH			10%	50%		
	DE				25%	33%	20%
	FR / IT	100%	100%	90%	25%	33%	40%
Total LV		100%	100%	100%	100%	100%	100%
Heavy good vehicles (HGV)	AT					20%	30%
	CH			0%	20%		
	DE				40%	40%	30%
	FR / IT	100%	100%	100%	40%	40%	40%
Total HGV		100%	100%	100%	100%	100%	100%

For the road network, data used are the OpenStreetMap (OSM) for the maximum speed and OpenRouteService from Heidelberg Institute for Geoinformation Technology (HeiGIT) for the average gradient.

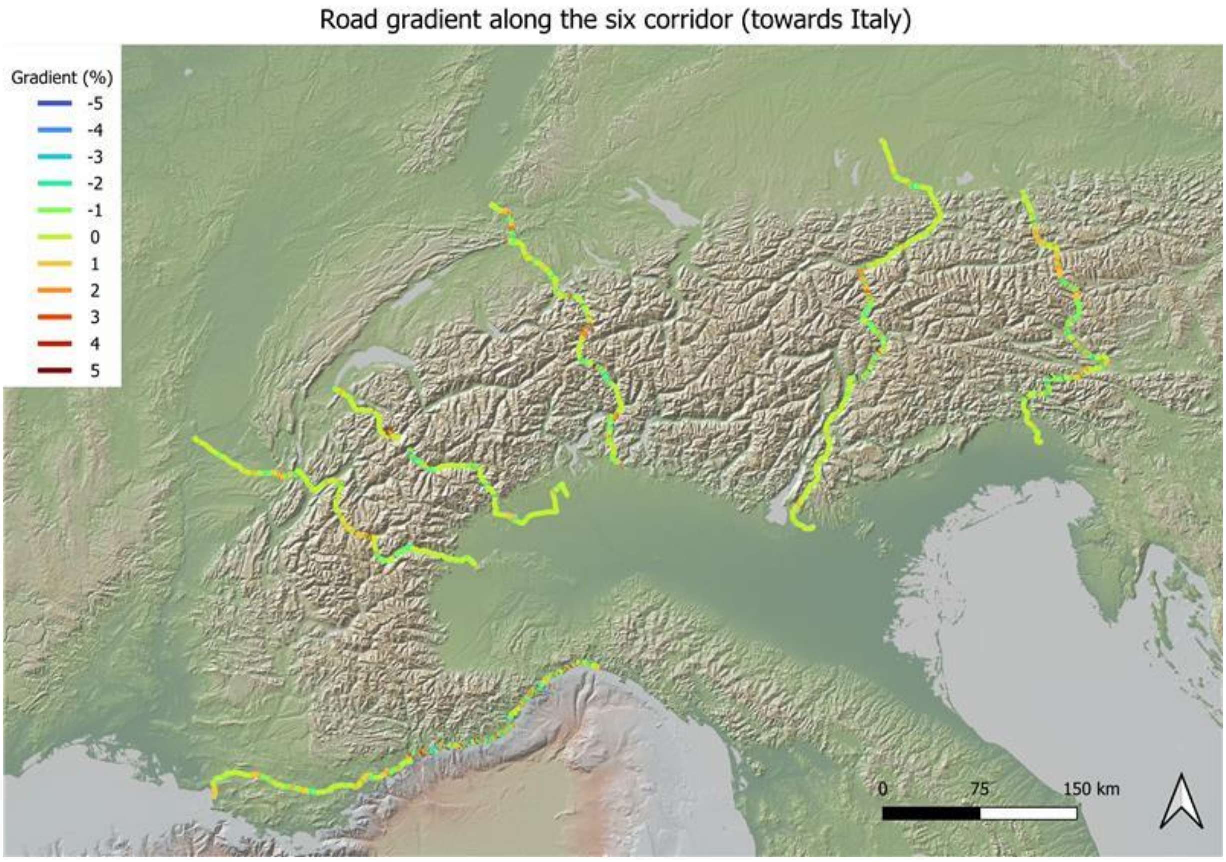


Figure 19: Road gradient along the six corridors

5.2.3. ALPINE FACTOR FOR AIR POLLUTION

For air pollution, we use the geographical environment in 5 types described earlier:

- Plain
- Alpine foothills (pre-alps)
- Alpine
- Coastal Alpine foothills (Ventimiglia corridor only).

The local dispersion effect based on Swiss study (Oekoscience, 2013) and these Stratec categories are:

- An average for all air pollutant
- Coastal environment assimilated to plain

Table 7: Alpine factor by air pollutant according to Oekoscience 2013

Location in Switzerland	Alpine environment (Stratec)	NOx	PM10	EC	OC	Average
Muttenz	Plain	0.50	0.45	0.55	0.43	0.48
Reiden	Plain	1.00	1.00	1.00	1.00	1.00
Erstfeld	Alpine	2.80	1.70	2.20	1.60	2.08
Moleno	Alpine	3.38	1.90	3.20	2.40	2.72
Camignolo	Alpine foothills	1.60	1.25	1.60	1.25	1.43
Rothenbrunnen	Alpine	2.65	3.10	2.90	3.15	2.95
	Plain	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
	Alpine foothills	**2.6**	**2.5**	**2.4**	**2.6**	**2.5**
	Alpine	**5.9**	**5.0**	**5.0**	**5.5**	**5.4**

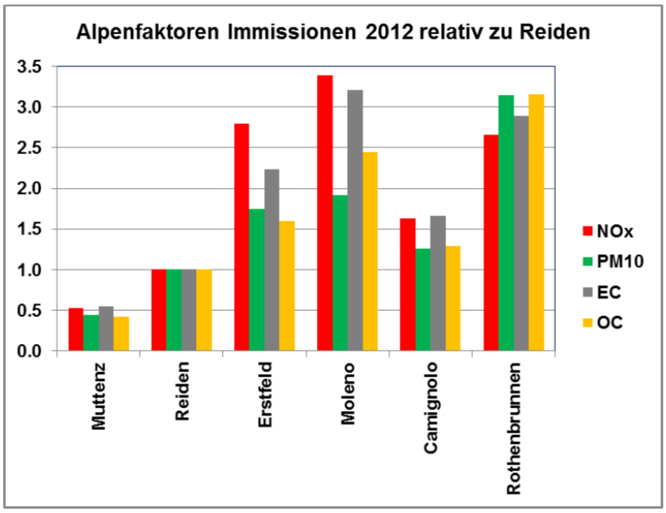


Figure 20: Alpine factors by air pollutant according to Oekoscience 2013

5.3. Rail emissions

5.3.1. Rail energy consumption and emissions

In the European handbook on external costs (CE Delft, 2019) assumptions from TREMOD are used. They are German, average estimates. But it also provides values for air pollution from electric rail, which is not mentioned in TREMOD and source is not provided.

Braking (and track gradient) is among the main factors of rail air pollution (UIC 2025)[9] and there is more air pollution from rail on Alpine routes due to high gradient. But electric trains are also able to limit recover some energy from regenerative braking and limit its use of mechanical braking, but with limits, especially for freight as explained in the International Union of Railways:

"Due to high average weights of freight trains and the fact that only locomotive axles are powered, high shares of braking power come from the mechanical brakes in the freight cars, and only a small share is

[9] International Union of Railways (UIC) - Workshop on air quality management in rail, 13 March 2025 uic.org/events/IMG/pdf/20250313_uic_air_quality_workshop.pdf

added by the locomotive itself. Based on conventional freight trains, there exists limited potential to raise the share of recovered braking energy." (UIC 2002)[10].

To simplify, the following assumption is made: 0 energy recovered for freight trains. Also, average European values (handbook) for want of anything better.

For the energy consumption of electric trains (kWh/trains.km) for freight, assumption from Energy efficiency study (incl. gradients, but with a floor value of 0 kWh/train). For pax, average energy consumption per type of train estimated by French trains (SNCF 2024)[11], gradient not taken into account.

For the estimation of gradient, no exploitable data were found for rail (e.g. SNCF Réseau provides gradients at precise measurement points but not averages on entire sections).

As for road, were therefore rely on our own GIS analysis based on altitude to calculate average gradients.

5.4. Estimation of noise

5.4.1. Road noise impact

For this topic, two studies have been compared: Eusalp 2017 and Cerema 2018. In the first one, the authors have done a literature review and modelling, in the second one, the authors have done noise modelling along 3 French corridors.

This is the mountain factors of the first study:

In the second study, 3 French corridors have been examined:

Table 8: Alpine factor for road noise according to EUSAL 2017 study

<table>
<tr><th>Impact pathway</th><th>Cost driver</th><th>Mountain factor</th><th>Short description / Source</th><th>Comment</th></tr>
<tr><td>Pressure (emissions)</td><td>Gradient</td><td>1.16
(1.05 – 1.31)</td><td>Higher noise emissions (rolling and motor noise) in Alpine regions (based on EMPA 1997)</td><td rowspan="2">1.16 x 5.0 = 5.8</td></tr>
<tr><td>State (immissions, concentrations)</td><td>topographical and meteorological conditions</td><td>5
(2.5 - 12.5)</td><td>Higher noise immission levels in Alpine regions due to inversions and the amphitheatre effect (based on GRACE 2006, Lieb et al. 2006) [from 1997 model]</td></tr>
<tr><td rowspan="2">Impact</td><td>Population density</td><td>0.7
(0.5 - 0.9)</td><td>Lower number of affected residents due to lower population density in Alpine regions (based on GIS analysis)</td><td>0.7</td></tr>
<tr><td>Health risk</td><td>-
(1.0)</td><td>No evidence on higher health risk in mountain regions.</td><td>"0.61 for the Gotthard</td></tr>
</table>

[10] International Union of Railways (UIC) - Regenerative braking in freight trains

railway-energy.org/static/Regenerative_braking_in_freight_trains_43.php

[11] Information sur la quantité de gaz a effet de serre émise a l'occasion d'une prestation de transport, version 2024

sncf-voyageurs.com/medias-publics/2025-01/sncf_voyageurs_methodologiegenerale-infoges_2024.pdf

Costs	*Specific damage costs*	*-* *(1.0)*	*Regional differences of cost factors due to different income levels not appro priate.*	corridor with road transport”
Total mountain factor for noise costs		**4.1** **(1.3 – 14.7)**		

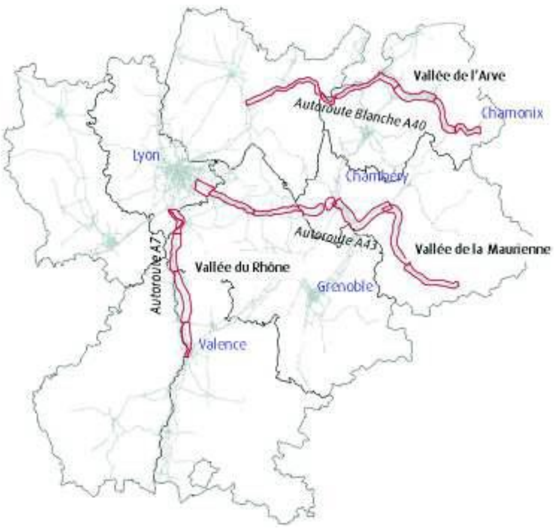


Figure 21: Road corridors analysed in the Cerema 2018 study

Cerema identified three factors:

- Gradient + topographical and meteorological conditions: 2.8
- Population density: 0.32
- Total mountain factor for noise costs: 0.9

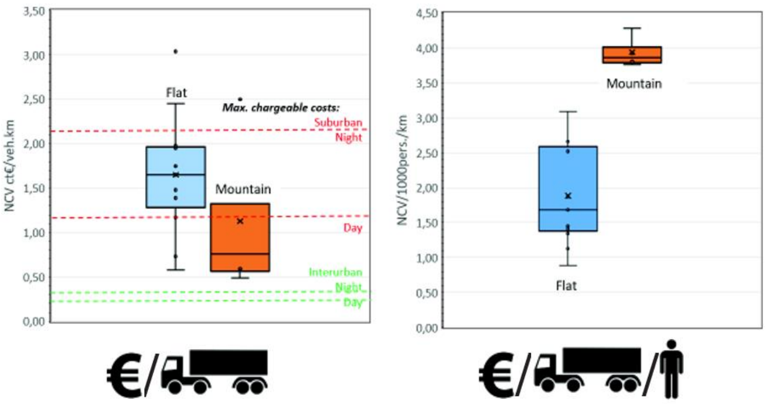


Figure 22: Alpine factors for noise as estimated by Cerema 2018 study

For the road noise impact, we suggest using the estimation from Cerema 2018, adjusted to:

- Fit European cost values from the handbook, rather than older French values
- Adjust to take the impact on seasonal residents into account (in addition to population)
- Include light vehicles, with discount (÷4) from French methodology (DGITM 2019)
- Reevaluate to €2023 values

- Adjust to population density per corridor (comparison with French corridors based on Stratec GIS analysis)).

5.4.2. Rail noise impact

In the Eusalp 2017 study, these factors for rail noise impact were available:

Table 9: Alpine factor for rail noise according to EUSAL 2017 study

Impact pathway	Cost driver	Mountain factor	Short description / Source	Comment
Pressure (emissions)	Gradient	- *(1.0)*	No data available	
State (immissions, concentrations)	topographical and meteorological conditions	**5** (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)	
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)	Population: “0.41 or 0.43 for the Gotthard rail transit corridor with the old Scheiteltunnel or the new Gotthard Base Tunnel”
	Health risk	- *(1.0)*	*No evidence on higher health risk in mountain regions.*	
Costs	*Specific damage costs*	- *(1.0)*	*Regional differences of cost factors due to different income level not appropriate.*	

No other comparable study for rail was found.

In regard to this study, the decision taken was to use:

- European cost values from the handbook, reevaluated to 2023 values
- With mountain and mix (Alpine foothills) factors readjusted
- Adjusted to take the impact on seasonal residents into account (in addition to population)
- Adjusted to population density per corridor (Stratec GIS analysis)

5.5. Population impacted

5.5.1. Estimation of population impacted

Although data on population is easily available as it is collected and made available by national statistical offices, we consider that there is an underestimation of the number of persons impacted by transport in the Alpine environment due to high number of non-residents staying in Alpine areas.

This phenomenon can be observed on the following maps presenting, for Switzerland and France (Haute-Savoie département), the share of secondary residencies in the local housing stock.

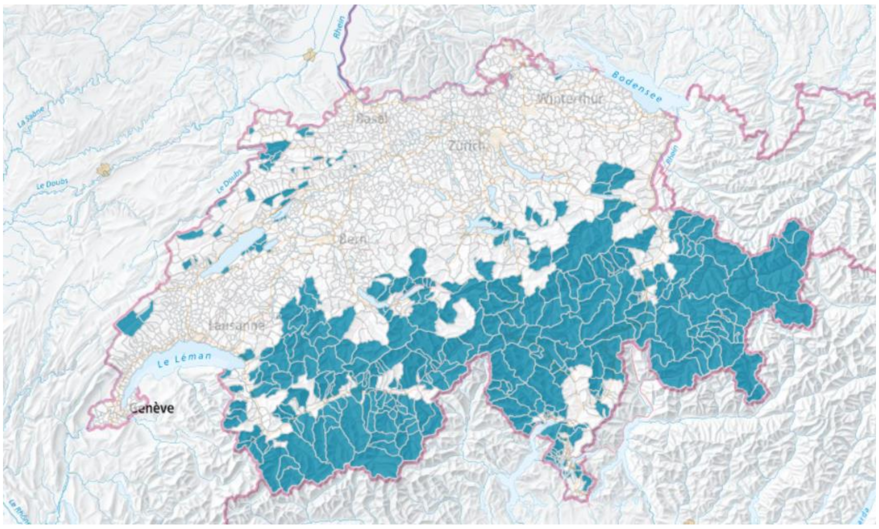


Figure 23. Swiss communes with over 20% of secondary residencies

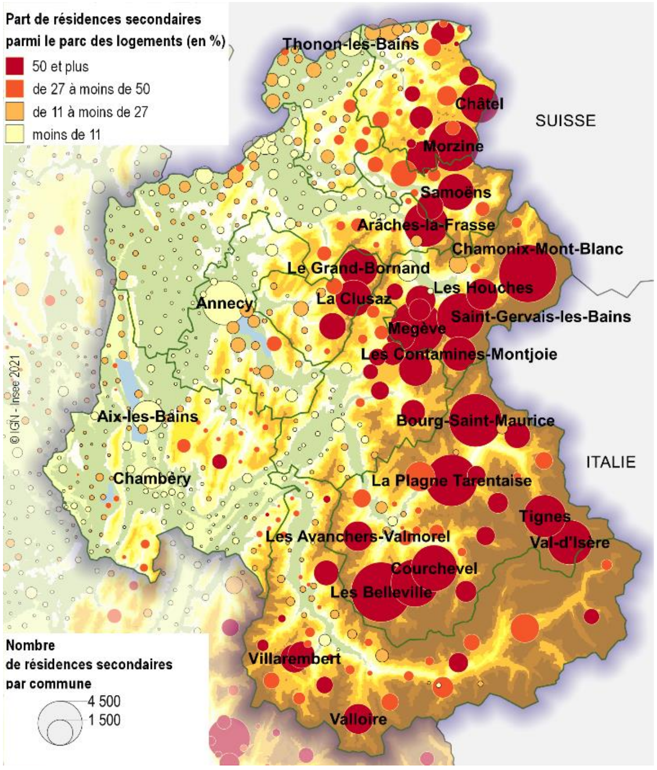


Figure 24. Share of secondary residencies in Haute-Savoie, France

To confirm this hunch and to estimate the potential resulting Alpine factor, a small analysis was conducted with French data for 31 municipalities on the 3 French corridors. Due to the variation in the nature and availability of data in different countries, this analysis had to be limited to France but is assumed to be relevant for the other Alpine corridors.

This analysis compares official municipal population with an estimate of the number of secondary residents (or seasonal visitors) based on:

- The share of secondary residencies, with assumptions of 2.5 persons per residency present 5 weeks per year,

- The touristic offer in hotels, camping and such (63% occupancy rate, as measured by Auvergne Rhône-Alpes Tourisme for Savoie and Haute-Savoie for 2024).[12]

For this topic, 5 categories of municipalities were compared depending on their natural and human environment: metropolitan (Lyon, Marseille), plain, Alpine foothills, Alpine and coastal. This leads to a **factor of 1.20 for Alpine municipalities**, compared to plain and metropolitan area, but also to **a factor of 1.08 for coastal municipalities**. Municipalities in Alpine foothills display values similar to plain and metropolitan areas (factor of 1.0).

Table 7: Analysis of official population compared to estimated seasonal population on French corridors

		Total			correction ((visitors + secondary pop) / official population)				
ıment	Municipalities analysed	Official population (2021)	Visitors (tourists)[1]	Secondary population[2]	Average	Min	Max	Max municipality	Correction factor to population
Metropolitan	4	1 504 635	23 995	8 062	2.1%	0.9%	3.1%	Lyon	1.00
Plain	5	96 486	1 062	310	1.4%	0.4%	3.9%	Les Abrets en Dauphiné	1.00
Alpine foothills	5	98 163	1 297	371	1.7%	0.3%	1.9%	Chambéry	1.00
Alpine	9	54 413	8 146	4 032	**22.4%**	2.1%	82.5%	Chamonix-Mont-Blanc	**1.20**
Coastal Alpine foothills	8	607 988	35 153	24 526	**9.8%**	2.1%	28.0%	Fréjus	**1.08**
Total	31	2 361 685	69 654	37 301	**4.5%**	0.3%	82.5%	Chamonix-Mont-Blanc	
Mont-Blanc	7	110 660	8 057	3 882	**10.8%**	1.4%	82.5%	Chamonix-Mont-Blanc	
Fréjus/Mont-Cenis	14	716 052	15 629	5 166	**2.9%**	0.3%	36.5%	Modane	
Ventimiglia	10	1 534 973	45 967	28 252	**4.8%**	0.9%	28.0%	Fréjus	

1 Estimated by Stratec with the share of secondary residencies (assumptions of 2,5 persons per residency present 5 weeks per year)
2 Based on touristic offer in hotels, hostels, campings and such (63% occupancy rate)

5.5.2. Urban vs. rural environment

In the European handbook, cost values for urban vs. rural environment can be found but it does not provide the corresponding population density values.

Based on an analysis of Eurostat region nomenclature and the French values:

- Urban: ≥250 inhabitants per km²
- Rural: <250 inhabitants per km²

12 pro.auvergnerhonealpes-tourisme.com

2023	Pop (1'000)				Area (1'000 km2)				Population density (inh./km²)			
geo	RUR	INT	URB	Total	RUR	INT	URB	Total	RUR	INT	URB	Total
	Predominantly rural regions	Intermediate regions	Predominantly urban regions	Total	Predominantly rural regions	Intermediate regions	Predominantly urban regions	Total	Predominantly rural regions	Intermediate regions	Predominantly urban regions	Total
AT	3 270	2 764	3 071	9 105	62	15	6	83	53	190	529	110
CH	276	3 949	4 590	8 815	8	24	8	40	35	162	607	221
FR	18 296	25 461	24 521	68 277	328	257	50	634	56	99	494	108
IT	4 924	23 507	30 566	58 997	82	153	62	298	60	153	493	198
Total	**26 767**	**55 680**	**62 748**	**145 195**	**480**	**449**	**125**	**1 054**	**56**	**124**	**502**	**138**

	Interurban	Urban scattered	Urban	Urban dense	Urban very dense
Range (inhab./km^2)	< 37	37-450	450-1'500	1'500-4'500	> 4'500
Average density (hab./km^2)	25	**250**	750	2 250	6 750

Figure 25. French "Fiche outils" (DGITM 2019)

5.6. Road congestion

In the absence of better alternatives, values from the 2019 European handbook are used to estimate the delay cost caused by road congestion. It should be noted that road congestion is not a typical external cost, as road users are themselves causing the cost to one-another and other actors are not impacted.

For future analysis, two solutions could be deployed for a finer estimation of road congestion:

- Purchase of Floating Car Data (FCD) on each corridor to measure precisely the time lost,
- A comprehensive road transport modelling exercise, which would also require additional budget and data.

A quick attempt at road traffic modelling was however conducted by Stratec on the 4 Western corridors, using the road traffic data (AADT) already collected and treated for the analysis of road accident.

The following charts present the resulting values obtained with a limited exercise in road modelling in Excel using standard speed-slow curves. The resulting values are similar to the ones calculated with delay cost from the European handbook, except for the Gotthard corridor where the modelling lead to much higher costs.

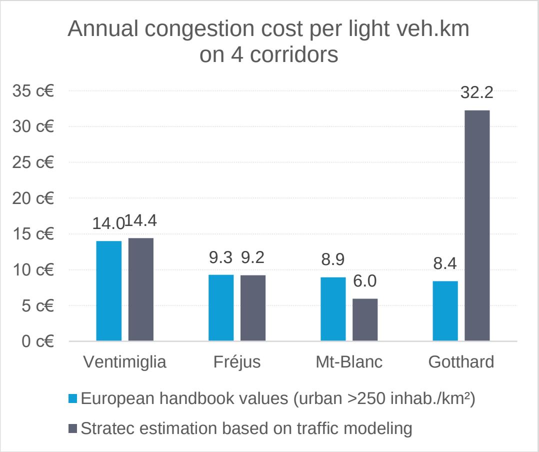


Figure 26: Road congestion estimation for light vehicles

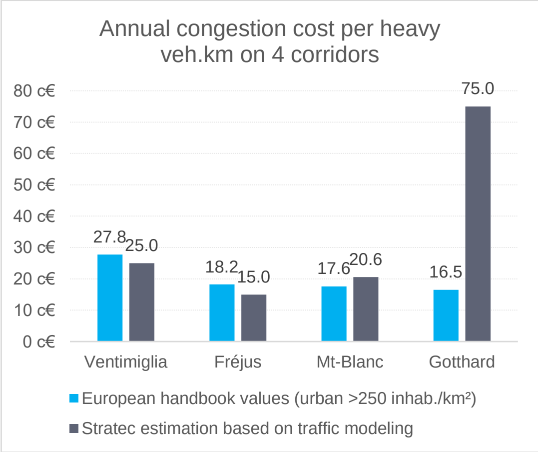


Figure 27 : Road congestion estimation for heavy vehicles

Further comparison with the Swiss congestion data point to even higher values for road congestion on the Gotthard corridor (see charts below).

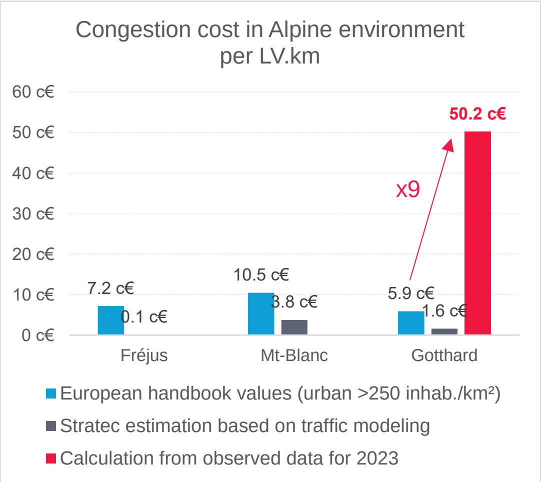


Figure 28: Road congestion estimation for light vehicles

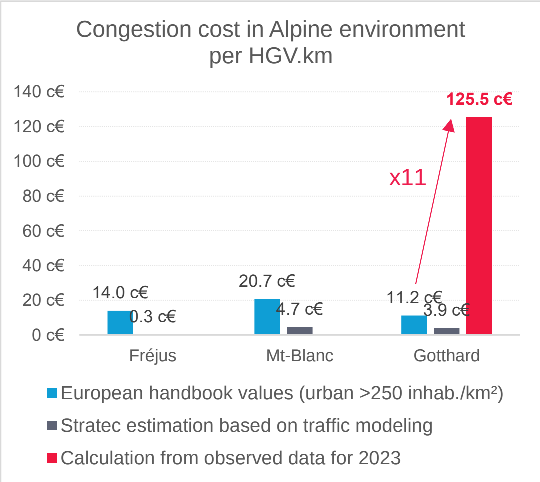


Figure 29 : Road congestion estimation for heavy vehicles

5.7. Accidents

Swiss, Italian, and French road data were integrated into a common GIS database. The Austrian data could not be exploited due to its difference in GIS format (raster).

An analysis was conducted to evaluate the rate of accidents in different geographical environments. The methodology used was to select accidents on the corridors for several years (2019, 2022 and 2023) and to compare the number of accidents to the average annual daily traffic (AADT), including local traffic. The charts below present the results obtained, which do not seem to reveal any pattern.

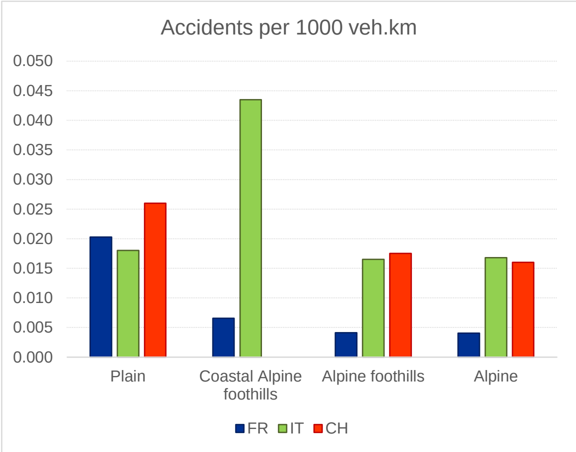


Figure 30: *Accidents per 1'000 vehicle.km on different corridor environments*

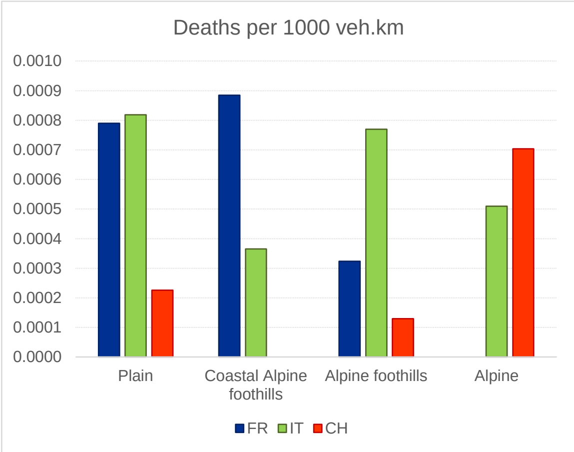


Figure 31: *Deaths from accidents per 1'000 vehicle.km on different corridor environments*

This result could be explained by the fact that Alpine infrastructure benefit from extra measures to reduce accident risks (see EUSALP 2017). Hence, the extra accident costs in Alpine environment tend to be borne by infrastructure managers which must invest in additional safety equipment. According to the 2017 Eusalp study, this extra Alpine cost is estimated at 3.9 of the external cost of transport in plain.

However, **considering that most road infrastructure on the Alpine corridors have tolls for light and heavy vehicles in one form or another (vignette, kilometric, gates), we consider those extra infrastructure costs to be already internalised** (i.e., borne by road users).

5.8. Rail passenger traffic

In the absence of publicly available data on rail passenger (except for Switzerland for the Gotthard corridor), rail traffic was estimated for all corridors except Gotthard with the flowing steps:

- Survey of passenger train offer on transalpine corridors (source: bahn.de),
- Desk research on rolling stock types used by operators and their capacity,
- Assumption on average occupancy rates taken from French data published by ART:[13]
    - 33% for regional trains (average for PACA Region trains in 2023 according to ART),
    - 63% for intercity trains,
    - 76% for high-speed trains (TGV, ICE, Frecciarossa).

For the Gotthard corridor, the methodology is to use SBB/CFF data publicly available on number of trains (2018-2024) and passengers (2024).

[13] Autorité de régulation des transports (ART), *Le marché du transport ferroviaire en France en 2023*, December 2024
autorite-transports.fr/actualites/le-transport-ferroviaire-bat-des-records-de-frequentation-en-2023/

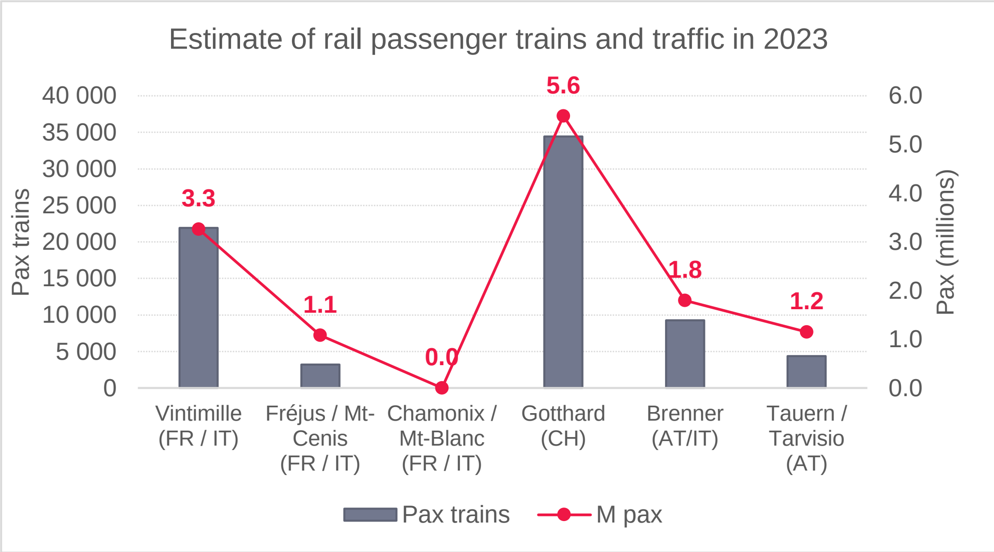


Figure 32: Estimated rail passenger trains and traffic in 2023 on corridors

Regarding the trains that must be considered for traffic estimation, there is rarely one train service going from one end of a corridor to the other (the only exception is the Frecciarossa Lyon – Turin/Milan). Passenger traffic estimates should correspond to the trains actually crossing the Alps (mountain pass / tunnel / border), as for road or rail freight. Hence, other trains along the corridor (such as regional trains Marseille – Nice, see below) are used to service local functions, and not to cross the Alps and should not be accounted in transalpine external costs. Only trains crossing the Alps at the border point, mountain pass or main tunnel, are considered in the calculation of external costs, even when they do not cover the entire length of the corridor.

Figure 33: Train connections between Marseille and Genoa on the Ventimiglia corridor

5.9. Rail-road transport

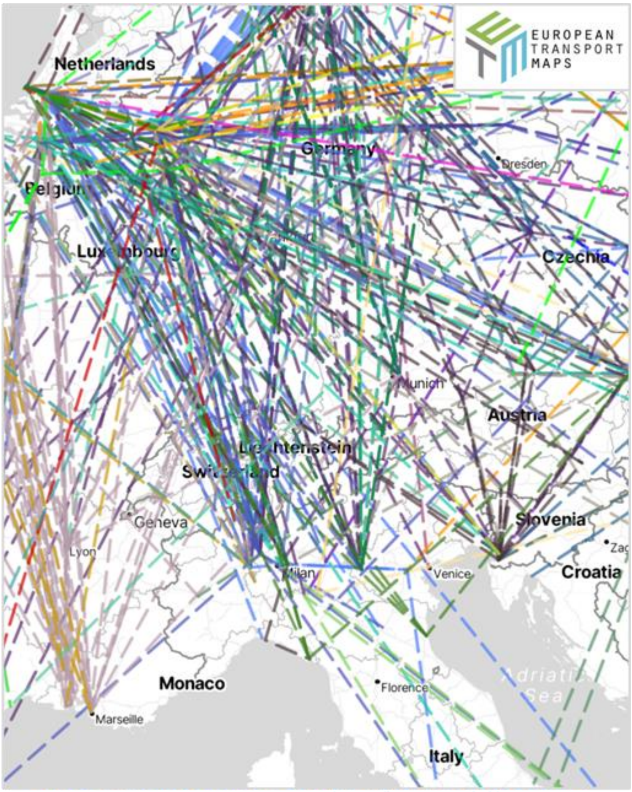
5.9.1. Pre/post-carriage

Rail combined transport includes necessary road haulage before and after the main rail transport. To present a fair comparison of external costs of the different modes of transport, this road transport should be taken into account. We therefore used a set of assumptions on the distances covered by mode (road / rail) and type of service (see table below).

Table 10: Assumption on pre and post road carriage for combined transport and rolling motorway

Type of rail transport	Rate of empty return	Average road access	
		Italy	North/West of the Alps
Combined and unaccompanied rolling motorway	30%	30 km	50 km
Accompanied rolling motorway	0%	50 km	70 km

However, most intermodal services run well beyond the corridor limits. For example, services between the ports of Antwerp or Rotterdam to Northern Italy constitute an important share of transalpine combined transport activities (see map below).



europeantransportmaps.com/map/intermodal/operator

Figure 34: Intermodal connections through the Alps - European Transport Maps

Therefore, the estimation of the costs of pre/post-carriage cannot be attributed entirely to transalpine corridors. Since we do not have data on the origin-destination of flows, the costs of road haulage were weighted according to distances for an average intermodal connection of reference (see table below).

Table 11: Assumptions on the share of pre/post road carriage to be considered for each corridor

Reference service for combined transport	Length (km)	Share of road carriage cost to be considered on the corridor	Countries of pre/post carriage costs	
Lyon - Marseille - Genoa	710 km	54%	FR	IT
Paris - Turin	748 km	40%	FR	IT
Köln - Milan	826 km	35%	DE	IT
Köln - Verona	926 km	44%	DE	IT
Linz - Trieste	490 km	64%	AT	IT

5.9.2. Impact of rail-road terminals

No specific study was found that quantifies the external costs of intermodal terminals as such. Existing assessments of transport-related impacts generally rely on conventional methodologies that focus on transport flows themselves rather than on terminal operations. In this context, the impacts of road transport are already accounted for through pre- and post-carriage activities (see above), while the main long-distance transport leg is performed by rail.

However, certain aspects are only partially considered or excluded. For example, although the main haul is by rail, shunting operations on the last mile are often carried out using diesel shunting locomotives or rail tractors. These operations are typically not included in current assessments, despite their (limited) contribution to local emissions and energy consumption.

Beyond these elements, additional external costs may be questioned. Noise impacts on neighbouring areas are generally limited, as intermodal activities are not particularly noisy, and terminals are usually located in industrial zones with little or no residential population (see table below). Nevertheless, many terminals operate during evening or night hours, with trains sometimes departing as late as midnight, which could create localized disturbances.

Table 12: Population located around combined transport terminals involved in transalpine combined transport

Terminal		Population within 500m of terminal	Area (km²)	Pop density (inhab/km²)
Aiton	FR	362	1.42	254
Freiburg	DE	**7 004**	1.42	4 938
Novara	IT	589	1.15	514
Orbassano	IT	7	1.37	5

Energy consumption and emissions linked to terminal operations—such as those from reach stackers, cranes, and horizontal handling equipment—also merit consideration. These activities are often electrified, meaning their environmental impact is likely to be low. While such impacts could be estimated using reasonable assumptions, they would probably remain marginal compared to those of the transport legs themselves. Finally, land artificialisation associated with intermodal terminals is another potential external cost, although this aspect is not usually taken into account for other modes or forms of transport either.

6. RESULTS

6.1. Absolute values

The chart below presents the results in terms of absolute value of external costs estimated for each of the 6 corridors. Variations in total external cost between corridors mainly reflect:

- Total vehicle flows, especially road traffic — with Brenner and Ventimiglia at the top,
- Corridor length (longer corridors have longer estimated external cost per vehicle crossing the Alps),
- The geographical characteristics of each corridor (population density, slopes/gradients, Alpine environment, etc.).

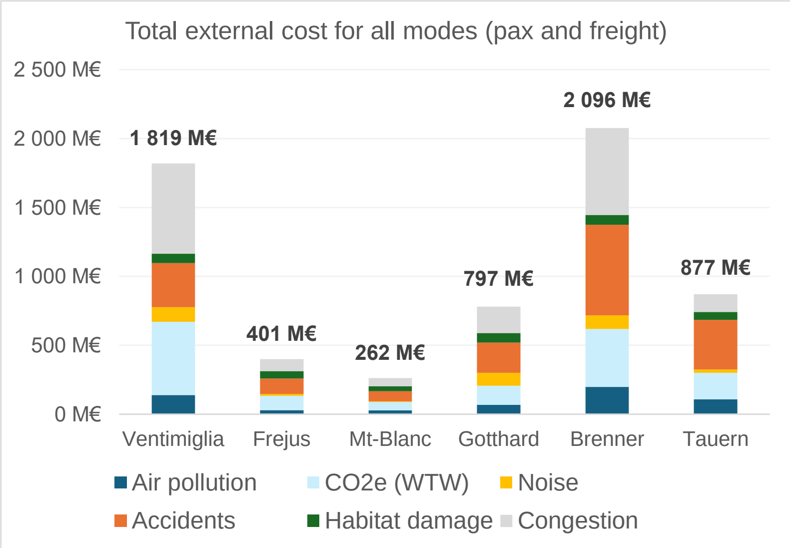


Figure 35: Total external costs for all modes (passengers and freight) in euros 2023 for 2023

To present a fairer comparison between corridors, the following chart presents the average external costs per kilometre of corridor. This is the same values as presented above but divided by the corridor length in kilometre. The differences in traffic volumes explain most of the remaining differences.

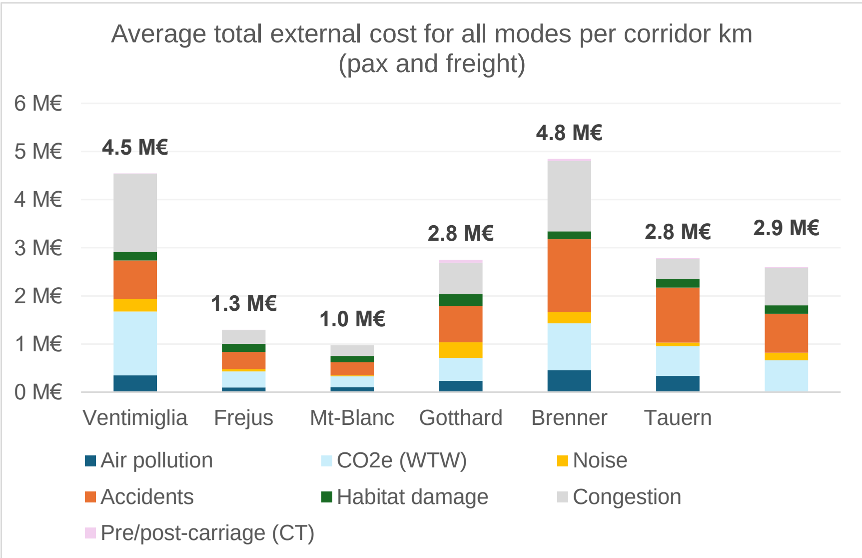


Figure 36: Average total external cost for all modes of transport per corridor kilometre for passengers and freight

There are some noticeable differences in the split between the different types of external costs. The following differences are noticeable:

- Higher accident-related values in Austria, originating from the values of the 2019 European handbook,
- Congestion on the Ventimiglia corridor (densely populated urban areas), with no Alpine factor taken into account for congestion,
- Noise on the Gotthard corridor due to the higher share of rail transport.

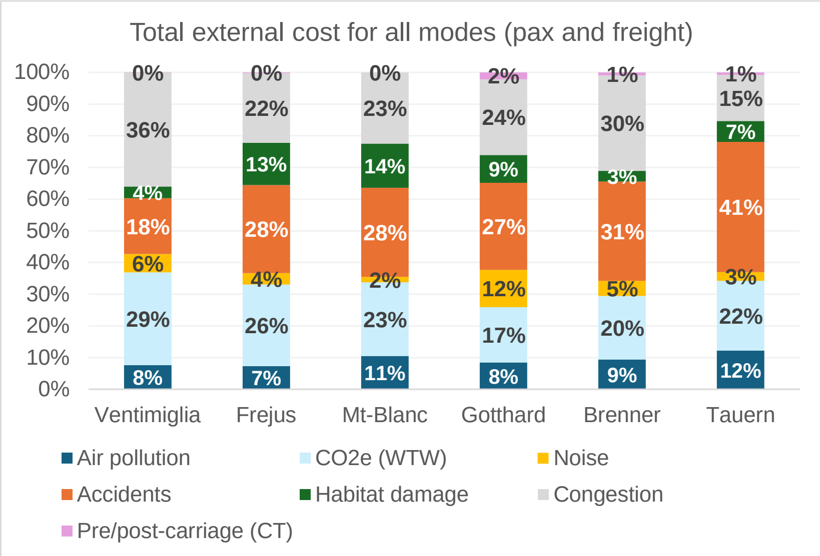


Figure 37: Split of external costs per type for each corridor (passengers and freight)

The following charts reveal the split of external costs per type of market (passengers vs. freight) and per mode of transport (road vs. rail). Road is by far the largest component of external costs, whereas freight generates slightly more external costs than passengers (except on the Gotthard corridor). However, this presentation tends to underestimate external costs generated by passenger, as many long-distance passengers cross the Alps by flying over the Alps, with important greenhouse gas emissions which are not calculated here.[14]

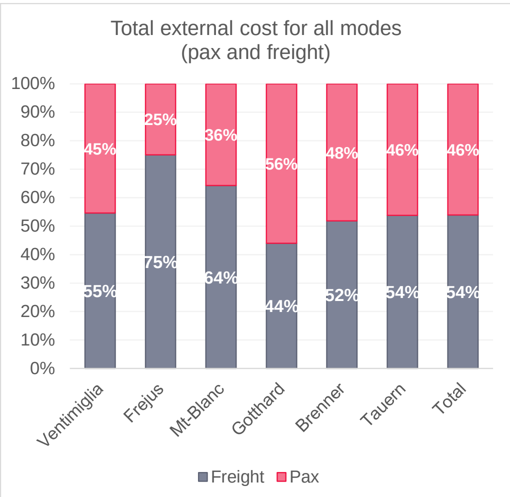


Figure 38: External costs split by market (passengers vs. freight)

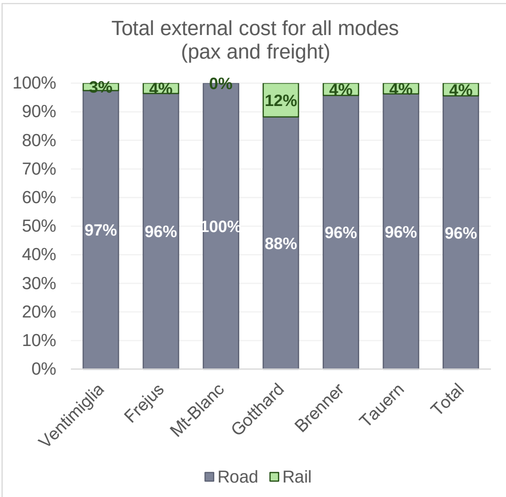


Figure 39: External costs split by mode (road vs. rail)

[14] Air freight is also an issue, but it is a niche market and the volumes are much smaller than air passenger activities.

6.2. External freight costs per tonne.km

An analysis by tonne.kilometre provides us with a finer understanding of the differences in external costs by corridor and mode of transport for freight. This is the costs generated by moving one tonne over one kilometre. Hence, **road generate around 5 times more external costs than rail**.

The higher external costs for road are found on the Ventimiglia corridor due to the high population density along the coast, whereas the Gotthard corridor comes second for the same reason (especially on the Swiss plateau), but also due to its higher GDP per capita (on which local cost values are based).

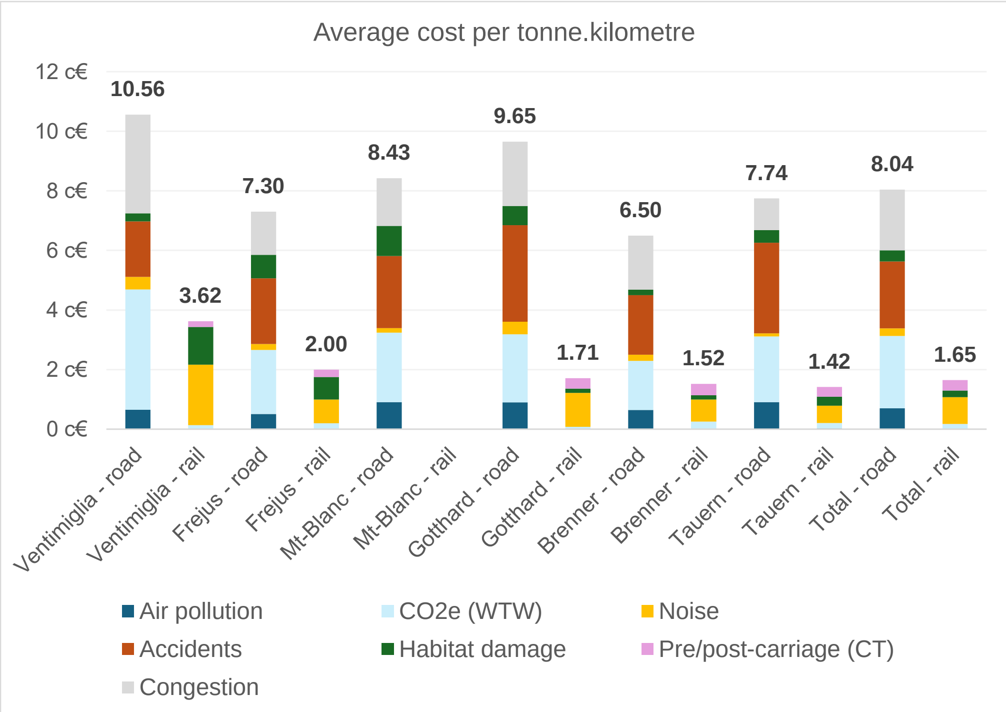


Figure 40: Average external costs per tonne.kilometre by mode and corridor for freight

The cost category "Pre/post-carriage (CT)" refers to the external costs generated by the necessary road leg of combined transport before and after loading on trains at rail-road terminals. This category is an aggregate of different external costs, which are presented in the following chart. Although taking this road haulage into account seems necessary for a fair comparison between rail and fully road transport, it is delicate as we lack data on the distances and locations of rail services.

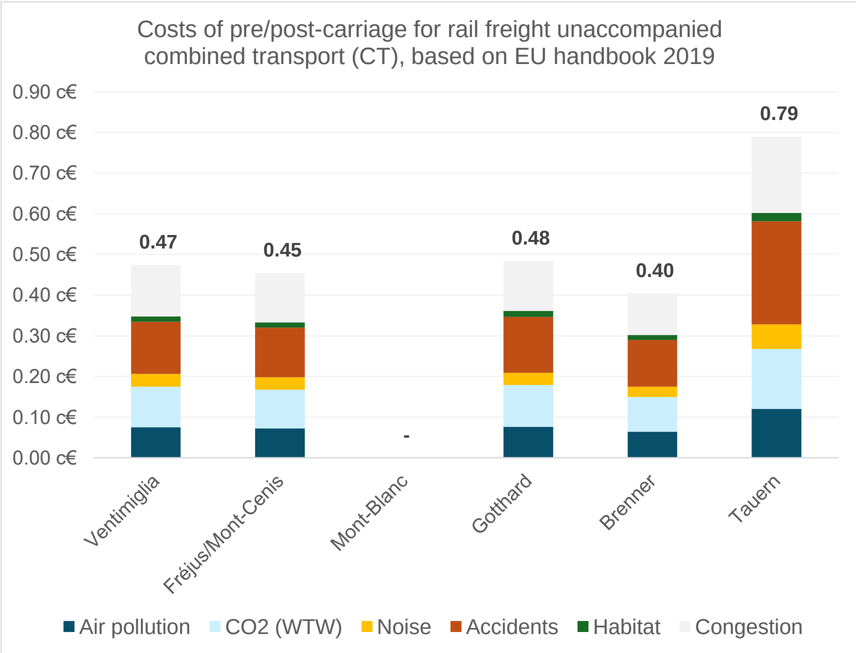


Figure 41: External costs of road haulage for rail unaccompanied combined transport

Since the level of confidence in the estimations is lower for road congestion (25% of road external costs, probably underestimated and an atypical external cost as it impacts only road users) and rail pre/post-carriage (21% of rail), the following chart presents the values without those two categories.

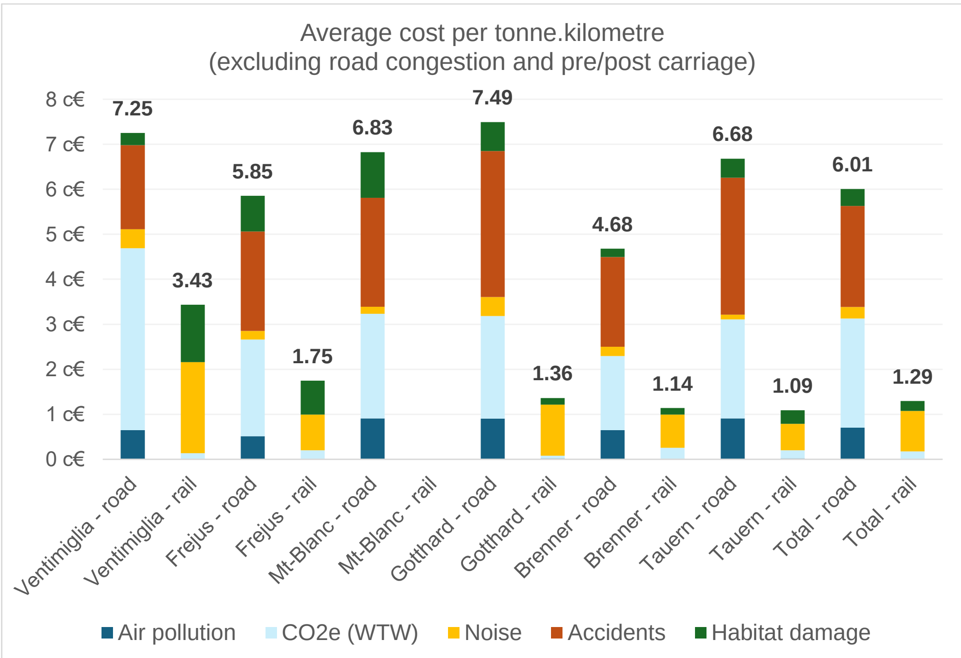


Figure 42: Average external costs per tonne.kilomtre by mode and corridor for freight, without road congestion and rail pre/post-carriage

6.3. External costs per passenger.km

As for freight, a presentation of external costs per passenger.kilometre cancels the differences in volume between the corridors and modes of transport. The differences between corridors are less pronounced than for freight, but the costs between modes of transport are higher with **road generating**

8 times more external costs than rail per passenger.kilometre. However, one should keep in mind that the comparison is not always entirely relevant, as there are not always long distance passenger rail services operating from one end of a corridor to the other. On the Ventimiglia corridor, regional train services only run from Nice to Ventimiglia, although there are connections with other regional services to Marseille and Genoa.

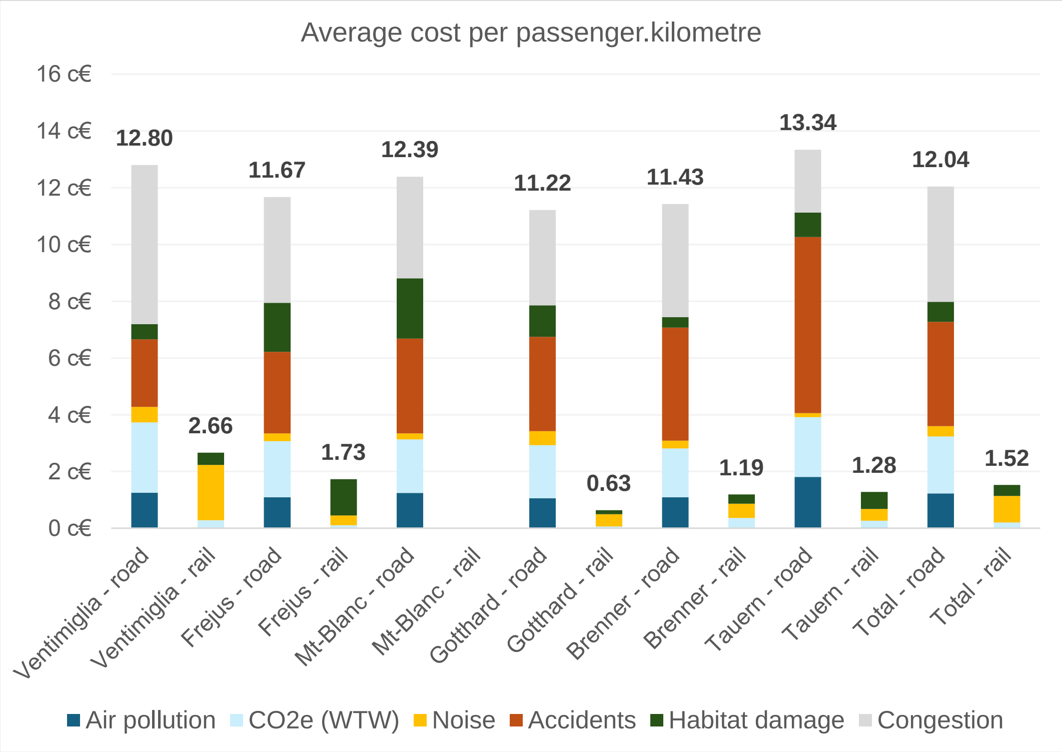


Figure 43: Average external costs per passenger.kilometre by mode and corridor

As for freight, the external costs are also presented without congestion which is not a clear external cost, as it only impacts road users (see chart below). Excluding congestion, external costs of road transport are still on average 5 times the cost of rail per passenger.kilometre.

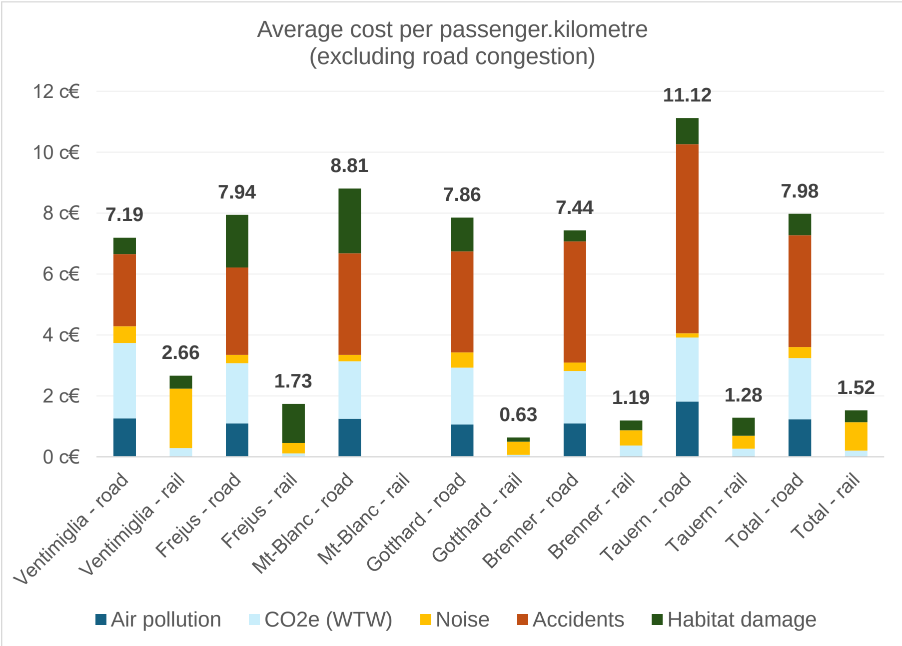


Figure 44: Average external costs per passenger.kilometre by mode and corridor, excluding congestion

6.4. Road external costs per type of vehicle

The following charts present a focus on road transport costs by type of vehicle. In terms of cost per vehicle.kilometre, heavy good vehicles (HGV, trucks) present the highest values due to their size and heavy load. But the cost values of HGV are much lower than for light commercial vehicles (LCV) when the load is taken into account in terms of costs per tonne.kilometre.

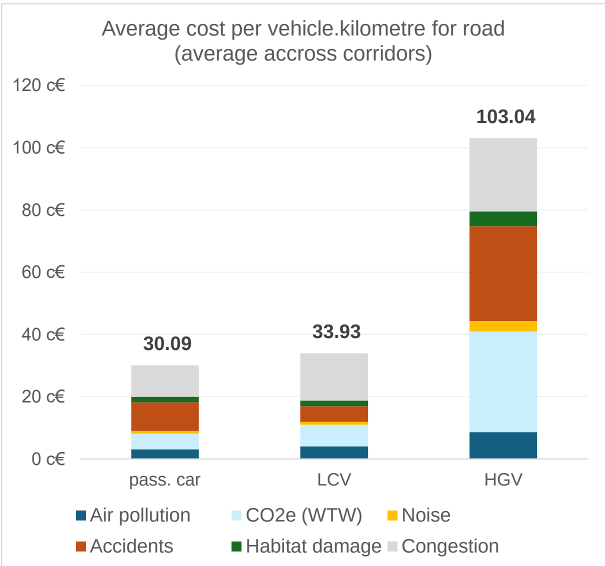


Figure 45: Average cost per vehicle kilometre of road

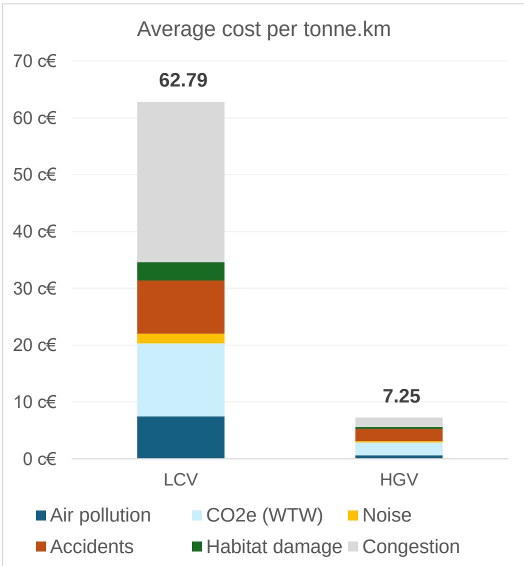


Figure 46: Average cost per tonne.kilometre of road per type of vehicle

6.5. Rail external costs per type of service

For rail, the costs per type of train (passenger or freight) is presented in the chart below. It should be noted that there are many different sub-types of trains for each category, and that we lack data and assumptions to carry out a finer analysis.

For example, regenerative braking allows electric trains to recover energy from braking. This is a potentially key question for passenger trains, and it is especially important in an Alpine context where slopes are numerous and often steep. But this aspect could not be taken into account in the present study.

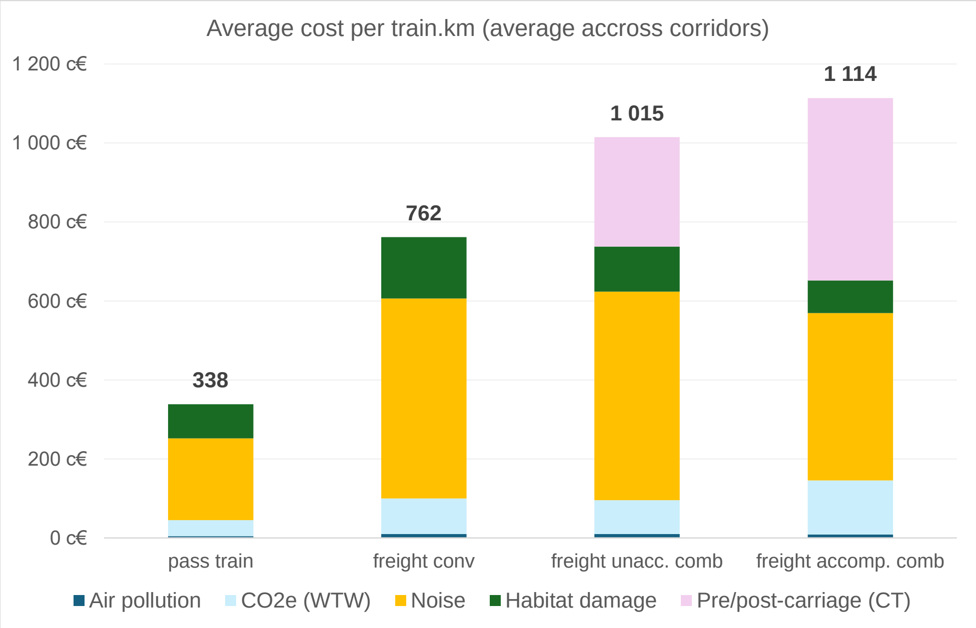


Figure 47: External costs of rail per type of train (passenger and freight)

7. CONCLUSIONS

This study is the first comprehensive estimation of external costs of land transport on Alpine corridors. It is based on the most recent data and studies available in 2025 and relies heavily on the following studies:

- European handbook on external costs (CE Delft 2019), which is currently being updated,
- Noise of road transport in an Alpine environment (Cerema 2018),
- The value of climate action (France Stratégie, Quinet 2025).

An extensive GIS analysis of the corridors was carried out for a finer calculation taking into account:

- Population density along each corridor,
- Infrastructure characteristics (speed, number of lanes, gradient, altitude),
- Distinction of type of natural environment (plain / Alpine foothills / Coastal Alpine foothills / Alpine).

This work still presents limits due to some areas of uncertainty. First, there is a lack of publicly available data and assumptions on rail transport in terms of energy consumption per train.kilometre, noise impact in an Alpine environment, and passenger demand. Some external costs are also less well known, with uncertainties regarding the Alpine factor to be applied for noise as well as congestion on transalpine roads.

Finally, this study focuses on land modes of transport and does not evaluate external costs from air transport (some 10 million passengers flew between Germany and Italy in 2023 according to Eurostat) or from maritime transport, which is used massively on some routes such as Spain – Italy (for which there are also road and rail flows).

The following table sums-up the authors' perception on the limits and level of confidence for each external cost calculated.

Table 13: Level of confidence in the estimated external costs

External cost	Level of confidence			
	Road		Rail	
Air pollution	***	Good knowledge of vehicle emissions	*	No assumptions on extra-braking due to gradient
Climate change (CO_2e, WTW)	***	Question of CO2 value, but otherwise good knowledge of vehicle emissions	**	Few studies and data on pax train energy consumption
Noise	*	Divergent conclusions between GRACE 2006 and CEREMA 2018	*	Conclusions of road studies applied to rail
Accidents	**	Data analysis unconclusive. Question of infrastructure costs.	/	Not relevant
Habitat damage	**	Depends on local environement	**	Depends on local environement
Congestion	*	Lack of data on time lost at cross-alpine bottlenecks	/	Not relevant
Pre/post-carriage (rail CT)	/	Not relevant	*	Uncertainty regarding distances of CT services and pre/post carriage

Level of confidence

***	High level
**	Medium level
*	Low level
/	Not relevant