

Economic Benefits of Noise Reduction from Road Transport in Mountain Areas

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Abstract. Noise emissions are a relevant externality, which cause negative effects on affected population. Due to the topographic and physical characteristics of the geographical context, road transport in mountain areas is a main source of noise emissions. Adequate solutions have to be foreseen, able to reduce the impacts on affected population. First, this contribution describes alternative solutions to reduce the noise pressure along mountain roads. Then, it provides a method to evaluate their effectiveness based on a cost-effectiveness ratio and hedonic pricing. Two case studies located along a mountain road in South Tyrol (Italy) show the performances of different solutions in various contexts, suggesting the importance of evaluations that consider the territorial and settlement specificities. These results can be helpful for policy makers to define the most effective solutions to reduce transport externalities and to make mountain areas more liveable.

Keywords: Noise · Economic benefits · Transport externalities · Road transport · Mountain areas

1 Introduction

The impact of noise emissions at EU level is estimated at €1047B [1]. Together with global and local air pollution, accidents, congestion and habitat damage, noise is one of the main externalities generated by the transport sector [2]. Its effects on the affected population include physical and mental health problems, sleep disturbance hypertension, risk of stroke, diabetes and depression, agitation, stress, anxiety, and problems in children's cognitive development [3].

Some areas are more vulnerable than others under the same level of acoustic pressure. The mountain valleys are among them: here, sound can be amplified by topographic conditions, thermal inversion typical of cold months and nights, and the refraction of waves and wind, thus generating an amphitheatre effect that exacerbates the level of perceived sound and worsens the quality of life of the inhabitants [4]. Despite the temporary decrease in road and rail traffic volumes registered during the SARS-CoV-2 pandemic, traffic volumes along main roads are expected to increase, along with noise emissions, if adequate solutions are not implemented.

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This paper discusses about the impacts of alternative solutions for reducing noise emissions along mountain roads, by evaluating the variation in market values of affected buildings and relating them with the construction and implementation costs. The rest of the paper is organised as follows: in Sect. 2, potential measures for the reduction of noise emissions are presented. Section 3 describes a method to evaluate them, based on a cost-effectiveness ratio and hedonic prices (HP). Section 4 tests the method in two selected case studies, showing the importance of tailored solutions according to the territorial context. Some conclusions end the contribution.

2 Measures to Reduce Noise Emissions from Road Transport

Measures to mitigate noise emissions from road traffic are numerous and can be distinguished according to their scope. Three groups of measures can be identified: at-source, propagation path, and at-receptor [5]. The selection of the correct intervention depends also on the specific geographical context: in rough terms, solutions can be divided into urban and rural ones, here including also marginal areas. A third classification depends on the nature of the measure, which can be either management or physical. A list of these measures, with their main characteristics in terms of costs and acoustic benefits, is presented in Table 1.

As for the management solutions, noise pollution depends on vehicular speed (the average speed is related to the noise pressure by a logarithmic relation: [6]) and traffic volumes on the road. Urban solutions aim mainly at limiting the vehicular circulation or the travel speed through traffic management solutions. At speeds below 50 km/h, a 10-km/h reduction may lead to a reduction of 2–3 dB L_{eq} [7]. This solution implies the construction of physical elements to moderate speed vehicles, like gateways, horizontal or vertical deflections. Their costs are normally not high and, according to the evaluation available in several Italian territorial price lists, are included between 1,000 € and 10,000 € for every element.

Another management solution to reduce noise pollution is traffic calming, which can be either total or limited to heavy traffic. In the former case, this solution is found to be more effective, with a reduction up to 7 dB [7]. In the latter case, the reduction can be estimated up to 3 dB. This solution has low costs, but it implies an alternative road for the traffic, such as a bypass or a ring road. In urban contexts, alternative roads can be easily identified and this measure can be introduced in areas that are particularly critic. In case the alternative road is not available (this is mostly valid in non-urban context), the costs for building a new infrastructure have to be considered. As an initial reference value, the guidelines of the Autonomous Province of Bolzano [8] suggest considering 1,500 €/m, but this value can increase up to 20,000 €/m in case of gallery or other main infrastructural works, such as bridges or viaducts.

Physical measures foresee other types of interventions to reduce noise impacts: installation of noise barriers, embankment, vegetation and realization of noise reducing asphalt pavement. Noise barriers are found to be more effective than vegetation, with an absorbing factor between 5 and 15 dB. They are effective only up to 100 m; if the distance is higher, the effect is negligible [5]. Unitary costs are equal to 1,000–1,500 €/m for a barrier that is up to 4 m high, with different values according to the typology and

construction materials [8]. The average operational life of this solution is about 20 years [9]. The application of these solutions may lead to several issues. Especially in delicate contexts (such as the mountain ones), influences on landscape must be considered and solved with adequate solutions that minimize the visual impact. Transparent barriers may be suitable for this purpose, but attention has to be paid to the effects on birds. The continuity of the structure is another issue. Along secondary roads, it cannot be always guaranteed for their entire length, due to the existence of the access to the buildings and to local roads. Fragmented barriers have a lower effect.

Embankment is a more natural type of noise barrier, with a potential effect estimated at 5–10 dB of noise reduction. The cost of this solution is not easily definable, as it is highly dependent from the morphology of the terrain and the required ground works. The main issue related to this solution is the large area required, which is rarely available. The cost for tree planting and for maintaining the vegetation has also to be foreseen. Vegetation can be also used without embankment, but its benefits are lower than noise barriers [5]. Hence, the planting should be foreseen as a technical solution for noise abatement only if expected emissions are slightly above the maximum threshold.

The tyre-road contact is the main noise source for both passenger cars and for heavy vehicles, respectively at speeds over 35 and 60 km/h [10]. Traditional noise reducing pavement can lower noise emissions up to 2–4 dB for light traffic and 2 dB for heavy traffic, considering the different average speeds of the two classes of vehicles. The use of special types of asphalt on roads with speeds equal or higher than 90 km/h can increase these values up to 6–8 dB and 4–5 dB, respectively. Costs for this solution are 15 €/m^2 for the first type, and 30 for the second [8]. The application of these asphalts is recommended for extra-urban roads, with an average speed not below 50 km/h. Conversely, in urban contexts, this solution is less effective. The estimated duration of this material is up to 10 years [11]. However, performances can progressively decrease and reach values only 1–2 dB lower than traditional asphalt values in five years, due to the accumulation of the pollutants in the asphalt pores.

Table 1. Measures to reduce acoustic emissions, benefits and implementation costs

Type	Measure	Geographical scope	Acoustic benefits	Costs
Management	Speed calming (physical elements)	Urban (speed limit < 50 km/h)	2–3 dB	1,000–10,000 €/each
Management	Traffic calming	Urban	3–7 dB	n.a.
Physic	Noise Barrier	Urban/rural	5–15 dB	1,000–1,500 €/m
Physic	Embarkment	Rural	5–10 dB	n.a.
Physic	Vegetation	Urban/rural	n.d.	n.a.
Physic	Traditional noise reducing pavement	Urban/rural (speed limit > 50 km/h)	2–4 dB	15 €/m^2
Physic	Special noise reducing pavement	Urban/rural (speed limit > 90 km/h)	6–8 dB	30 €/m^2

Finally, noise abatement solutions may be also directly related to the source (i.e., the vehicles), including the reduction of noise from engine and other vehicle noises. In this sense, the diffusion of zero-emission vehicles (powered by electricity or hydrogen) or hybrid vehicles in the vehicular fleet may represent a valid support in the reduction of noise emissions. However, except for few public vehicles, this measure is mostly related to private citizens and firms; furthermore, it requires a long temporal horizon to be effective, due to the slow dynamics in the renewal of the vehicular fleet [12]. As such, policymakers can intervene only indirectly, by introducing subsidies or other incentives to encourage the shift towards these vehicles.

3 Methodology

To verify the impacts of selected measures in terms of noise reduction, HP is a possible solution [13]. HP calculates a variation in the market value of buildings as a consequence of the variation in noise emissions perceived by such buildings. The relationship is inverse: a decrease in perceived noise determines an increase in market values, and vice versa. This variation has to be compared to the installation/construction costs to realize the proposed interventions. To this aim, a cost-effectiveness ratio can be adopted, which is referred to a single year z, as in Formula (1):

$$CE_x^z = \frac{C_x^z}{B_x^z} \tag{1}$$

where CE is the cost-effectiveness ratio of a specific solution x, C are the implementation costs and B are the benefits, expressed as economic variation of market values after the introduction of x. Since each x has a different temporal horizon (for instance, the installation of a noise barrier is effective for a longer period than the pavement of a road with noise reducing pavement), it is appropriate to divide the implementation costs and the benefits by the years y of expected life, as in Formula (2) and (3), to obtain a yearly average value:

$$C_x^z = \frac{C_x}{y} \tag{2}$$

$$B_x^z = \frac{B_h + B_{com} + B_{ind} + B_{acc}}{y} \tag{3}$$

The comparison of CE from alternative solutions x allows determining the most effective solution in terms of noise reduction.

C_x can be calculated through parametric values given by territorial price lists, as provided by regional or provincial institutions, local Chambers of Commerce or equivalent institutions. The most complex aspect in Formula (1) is the calculation of B_x, which has to consider the different uses of involved buildings [14]. To this aim, we can distinguish among residential (h), commercial (com), industrial (ind) buildings, and accommodation and facilities (acc). They need to be analysed separately (Formulas 4–7), according to their average market prices (AP, expressed as €/m^2). These values have to be multiplied by the commercial area S of the buildings affected by noise (calculated as the sum of all

surfaces of a building), by a noise sensitivity appreciation index (*NSAI*), defined as the percentage appreciation in prices per dB decrease in noise level, and by the reduction of noise *RNP* that is guaranteed by *x* for each building *i*. *NSAI* is theoretically different for each function: for instance, the variation in dB for residential buildings is expected to be more important than industrial areas, considering the type of activities performed. For the sake of simplicity, instead of considering the value of *RNP* for the single building, bands with a similar reduction of noise can be defined.

$$B_h = \sum_{i=1}^{n_h} AP_h \cdot S_h \cdot RNP_{i,x} \cdot NSAI_h \tag{4}$$

$$B_{com} = \sum_{i=1}^{n_{com}} AP_{com} \cdot S_{com} \cdot RNP_{i,x} \cdot NSAI_{com} \tag{5}$$

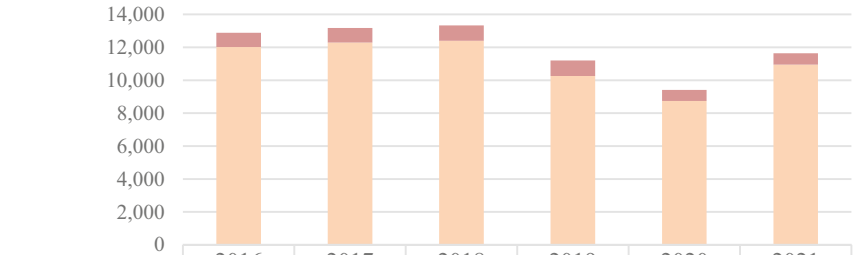
$$B_{ind} = \sum_{i=1}^{n_{ind}} AP_{ind} \cdot S_{ind} \cdot RNP_{i,x} \cdot NSAI_{ind} \tag{6}$$

$$B_{acc} = \sum_{i=1}^{n_{acc}} AP_{acc} \cdot S_{acc} \cdot RNP_{i,x} \cdot NSAI_{acc} \tag{7}$$

4 Impacts of Alternative Solutions on Noise Reduction: Two Case Studies from S.S.38 (Italy)

Strada Statale (S.S.) 38 dello Stelvio has been selected as location of two distinct case studies. This road is a typical mountain motorway, which connects Bolzano (South Tyrol) to Valtellina (Lombardy) through the Stelvio pass. Road traffic from S.S. 38 is one of the main sources of noise pressure in the area and object of specific monitoring by the Autonomous Province of Bolzano. The average traffic registered at the detection point of Laces in 2021 was equal to 11,642 vehicles/day, with the heavy component counting for roughly 6% of the total (687 veh/day) [15]. Before the SARS-CoV-2 pandemic, average values were higher, with more than 13.000 veh/day (Fig. 1). Traffic data are incomplete for years 2019 and 2020 (the detection point did not work properly between November 2019 and January 2020).

Impacts deriving from road traffic are represented by some noise maps elaborated by the Environmental Agency of the Province of Bolzano, according to the European standards with the L_{den} indicator, as foreseen by the Italian Legislative Decree 194/2005 [8]. These maps represent noise generated by road traffic, dividing their surroundings in areas of 5 dB intervals, comprised between 50 and 80 dB. Only major roads (i.e., roads with a yearly traffic volume higher than 3M vehicles) are mapped. This allows identifying those stretches of the provincial road where buildings are affected by a higher noise pressure. Values provided by these maps have then been assigned to the buildings located close to the motorway thanks to the software QGis. A unique noise exposition has been assigned to each building included in the two study areas (the red rectangle in Fig. 2 and Fig. 3). If a building lies between two acoustic zones, the highest value has been considered. Recalling the methodology presented in the section above, geometric and typological information of buildings have also to be collected. The surfaces of the buildings are provided by the digital cadastral geometries, which are published on the



	2016	2017	2018	2019	2020	2021
Heavy vehicles	859	881	930	942	674	687
Light vehicles	12,024	12291	12402	10263	8,741	10,954

Fig. 1. Evolution of average daily traffic along S.S. 38, years 2016–2021 [15]

Geoportal of the Province of Bolzano [16]; whereas destination and number of floors of the buildings have been provided manually, with a visual analysis made through Google Street View. These values have been subsequently inserted in the attributes of the digital cadastral geometries.

If values registered along the road overcome the thresholds imposed by the Italian National Law (L. 447/95) and no compensation measures have been yet introduced, the impacts of alternative solutions can be evaluated in terms of effectiveness and acoustic benefits generated on the territory. Two stretches of S.S. 38 seem particularly interesting for the evaluation: they are located in the South Tyrolean municipalities of Laces and Castelbello-Ciardes. Practically, we limit our evaluation only on those areas with buildings, where the acoustic maps reveal a noise pressure higher than 55 dB. Indeed, under this value the national legislation for residential areas is respected and the adoption of such solutions does not provide significant marginal acoustic benefits to the exposed population. In both case studies, interventions under evaluation include a) the installation of noise barriers on the side(s) of the road where buildings are exposed to noise pressure (scenario 1); the pavement of the road surface with a noise reducing pavement (scenario 2); and the two measures adopted jointly (scenario 3). Theoretically, the number of alternative solutions to reduce noise pressure from road traffic is higher. For instance, the speed traffic moderation or the limitation of the circulation for heavy vehicles are possible alternatives, but it seems more appropriate in urban contexts or in areas where an alternative road network is available (see Sect. 2).

4.1 Laces

The portion of considered territory is an urbanized area located between the centre of Laces and the S.S.38. It includes 2- or 3-floor residential buildings, a petrol station with a mini-market discount, and a hotel with camping structure (Fig. 1). The accommodation facilities and the petrol station are at the same level of the road, and are directly accessible from it, while the residential zone is depressed and divided from the road by a river and some vegetation. Despite this, acoustic values registered in this area overcome the threshold value of 55 dB, with some peaks (up to 75 dB) in the band that is closer to

the road and hosts non-residential buildings. Hence, the evaluation of the alternative measures is important to identify the most effective solutions.

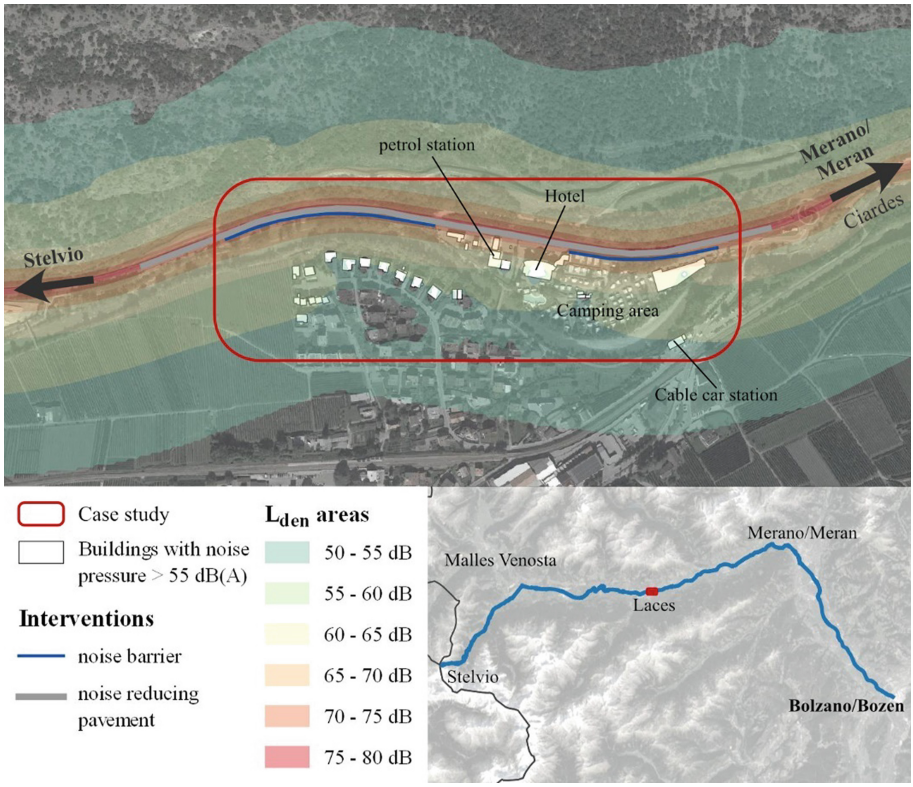


Fig. 2. Laces: noise pressure from road transport, buildings considered and proposed measures. Background map: [17]

Scenario 1 (NB_La) foresees the installation of two noise barriers. The first one is between the road and the bike lane along the Adige River, whereas the second is in substitution of the fence of the camping. These two barriers are interrupted to allow the access to the petrol station, hotel and camping. Total length of the two barriers is about 325 m. Assuming a parametric cost of 1,500 €/m [8], total construction costs are about 580,000 €. The effect of this solution is limited to 13 residential buildings and on the camping area. The range of noise reduction estimated in the second paragraph for this type of solution varies between 5 and 15 dB, according to the technical characteristics. To be cautionary, in the first band (the closest to the road, with an average noise pressure of 65 dB or more), we assume an intermediate reduction of 10 dB thanks also to the favourable conditions of the terrain and a reduction of 6 dB for the buildings subjected to a noise pressure of 60 dB, that are also situated further from the barrier. The benefits of this solution are expected to be valid at least for 20 years from the construction [9].

Scenario 2 (RA_La) proposes the substitution of the road pavement in simple asphalt, with a noise reducing pavement for a length of 860 m and a width of 8 m. The new road pavement is not limited to the place where buildings are located, but includes a broader part of the road, where the line is straight, and the travel speed of vehicles is higher. The total cost is about 100,000 € (assuming a unitary cost for the asphalt equal to 15 €/mq [8]). The impacts of this solution, which is expected to be operational 10 years [11] and requires two cycles of pavement for the period of 20 years under evaluation, involve all 24 buildings considered. With this solution, a potential noise reduction on light traffic from 2 to 4 dB, and 2 dB on heavy traffic may be obtained. As in scenario 1, we assume two different values for the buildings subjected to a noise pressure equal to 60 dB and 65 dB or more (respectively, green, light green and oranges colours in Fig. 2). Reduction is estimated at 2 and 3 dB, considering the reduced component of heavy traffic along the road and the speed limit of 90 km/h (the efficiency of noise reducing asphalt pavement increases with increasing speeds).

Scenario 3 (NB/RA_La) sums the costs and benefits deriving from the two scenarios previously described.

Table 2 and Table 3 present for each scenario the construction costs and the acoustic benefits, expressed as variation in the real estate according to Formulas 4–7. The market value of buildings is given as the average unitary values for residential, retail and accommodations in the municipality of Laces as derived from [18] and multiplied by the floor area of the buildings distinguished by destination. In other scenarios, we have assumed an appreciation index equal to 0.05%/dB for each function, according to [19]. This value has to be multiplied by the noise reduction described above.

Table 2. Laces: construction costs of acoustic measures in different scenarios

Scenario	Measure	Unitary cost*	Quantity	Total costs** €	Average costs €
Scenario 1: NB_La	Noise barrier	1,500 €/m	385 m	577,500	28,875
Scenario 2: RA_La	Noise reducing pavement	15 €/m^2	6,880 m^2	206,400***	10,320
Scenario 3: NB/RA_La	Noise barrier	1,500 €/m	385 m	577,500	39,195
	Noise reducing pavement	15 €/m^2	6,880 m^2	206,400***	

Note: *Source: [8]
**Referred to a period of 20 years for all measures
***Noise reducing pavement has to be renewed every 10 years

In absolute terms, scenario 3 presents highest values both in terms of yearly costs and benefits (with about 39,000 and 46,000 €/year, respectively); whereas the most economical solution is given by scenario 2 (10,320 and 18,750 €/year of costs and benefits). The installation of noise barriers only (Scenario 1) lies in the middle. Table 4 demonstrates that, despite the lower economic benefits, scenario 2 presents the most

Table 3. Laces: acoustic benefits in different scenarios

Scenario	Destination	Unitary value* €/m^2	RNP	Surface m^2	Benefits** €	Yearly benefits €
Scenario 1: NB_La	Residential	2,204	10 dB	724	79,718	3,986
		2,204	6 dB	4,975	328,884	16,444
	Commercial	1,557	6 dB	256	11,992	600
	Accommodation and facilities	1,693	10 dB	1,425	120,612	6,031
		1,693	6 dB	136	6,860	343
	Total			**7,516**	**548,066**	**27,403**
Scenario 2: RA_La	Residential	2,204	3 dB	724	23,915	1,196
		2,204	2 dB	6,706	147,803	7,390
	Commercial	1,557	3 dB	894	20,857	1,043
		1,557	2 dB	256	3,997	200
	Accommodation and facilities	1,693	3 dB	6,936	176,129	8,806
		1,693	2 dB	136	2,287	115
	Total			**15,652**	**374,988**	**18,749**
Scenario 3: NB/RA_La	Residential	2,204	13 dB	724	103,635	5,182
		2,204	8 dB	4,975	438,511	21,926
		2,204	2 dB	1,731	38,176	1,909
	Commercial	1,557	8 dB	256	15,989	799
		1,557	3 dB	894	20,857	1,043
	Accommodation and facilities	1,693	13 dB	1425	156,795	7,840
		1,693	8 dB	136	9,145	457
		1,693	3 dB	5,511	139,945	6,997
	Total			**15,652**	**923,053**	**46,153**

Notes: * Source: [18]
**Benefits are calculated for 20 years. NSAI is 0.05% for each destination and each scenario

Table 4. Laces: cost/effectiveness ratio of different scenarios

Scenario	Yearly costs of intervention €	Yearly acoustic benefits €	Cost-benefit ratio
Scenario 1: NB_La	28,875	27,403	1.05
Scenario 2: RA_La	10,320	18,750	0.55
Scenario 3: NB/RA_La	39,195	46,153	0.85

effective performance: economic benefits are nearly the double of the yearly construction costs, due to the fact that the benefits involve all buildings (differently from Scenario 1). The combined adoption of measures (Scenario 3) presents also a good cost-benefit ratio, which suggests the adoption of both technologies in case of higher initial pressure. The installation of noise barriers alone (scenario 1) seems not effective (cost-benefit ratio greater than 1).

As for the single destinations, some considerations can be useful. Residential buildings have a considerably appreciation, due to the high number of these buildings in the band that is the closest to the infrastructure. Accommodation facilities have a similar benefit in both scenarios 1 and 2: indeed, the camping benefits from the installation of noise barriers, whereas the noise adsorbing asphalt produces an increase of value also for the hotel. The joint adoption of the two solutions determines a high benefit on this type of destination (+305,885 €). In absolute terms, values of commercial buildings are negligible compared to other destinations. The petrol station and related commercial activities benefit somehow from the road pavement substitution. Conversely, the only building that registers a reduction of noise pressure originated by the noise barriers is a small activity situated next to the cable car station.

4.2 Ciardes

The second case study along the S.S. 38 is a small area near Ciardes, for which we investigate the same alternative measures and scenarios as in Laces. Here, the main destination of buildings is residential, with few manufacturing or rural activities (reported as "industrial" in Table 5 and Table 6). Differently from Laces, buildings are located on both sides of the road (mostly southward) and are depressed. The limit of the study area is given by the territorial context. At the western side, the boundary is coincident with the beginning of the urban area: here, the 50-km/h speed limit makes the noise reducing pavement ineffective; furthermore, in urban areas it is not possible to install noise barriers. At the eastern side, we consider the presence of a road tunnel as the natural boundary of our evaluations.

Scenario 1 (NB_Ci) foresees the installation of a noise barrier to protect 9 residential buildings on the southern side of the road. Other 16 buildings in the east area cannot be protected with a similar efficacy, because they have a direct access to the S.S. 38 through local roads. This prevents from the construction of a continuous barrier. The total length of the barrier is about 265 m, the construction cost is about 397,500 € and the expected effect on the buildings is a reduction of noise pressure by 10 dB. In this case, no differences in noise reductions are considered among buildings, because all of them are located in the proximity of the road and are all subjected to values of noise pressure between 65 and 75 dB. The considered operational lifetime of this infrastructure is 20 years.

In Scenario 2 (RA_Ci), the noise reducing pavement is extended for a length of 650 m and a width of 8 m, which means a construction cost equal to 78,000€. As in Lacies, this intervention has to be repeated two times in the 20 years, which is the temporal horizon of the analysis. The expected effect is the reduction of noise pressure by 2 dB. This value is lower than in the previous case study, due to the lower speed limit on this section of the road (70 km/h against 90 km/h in Laces).

Scenario 3 (NB/RA_Ci) is the sum of the measures adopted in NB_Ci and RA_Ci.

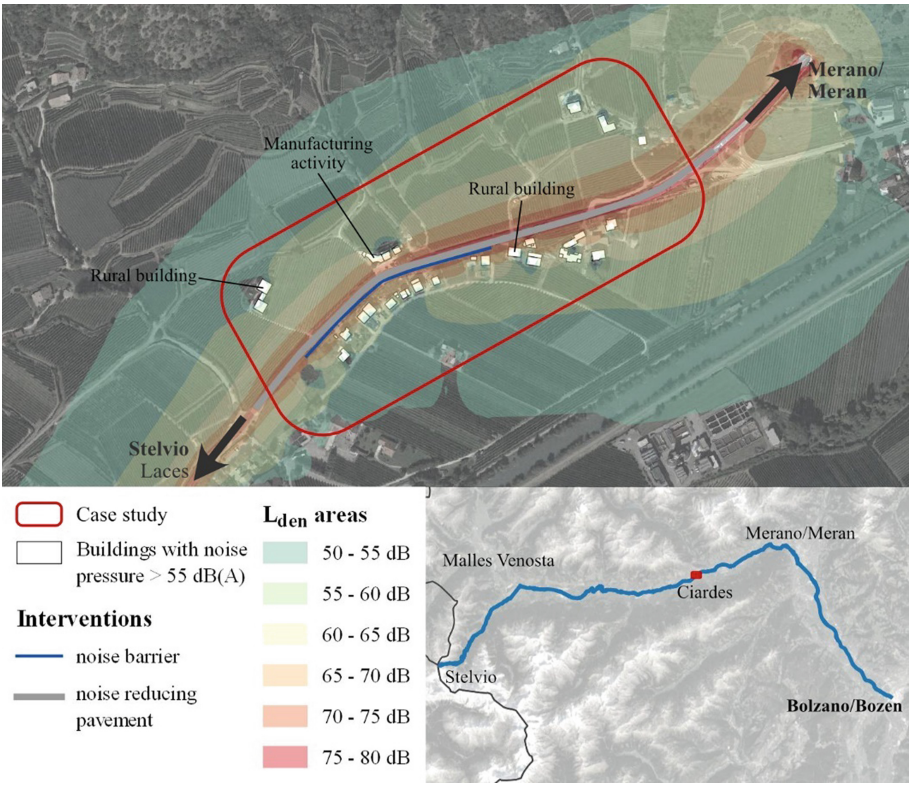


Fig. 3. Ciardes: noise pressure from road transport, buildings considered and proposed measures. Background map: [17]

Results deriving from the adoption of the different measures are quite clear: even though the installation of the noise barrier (scenario 1) is the solution that allows the highest benefits in absolute terms (see Table 6), the adoption of noise reducing pavement is the most effective solution. The cost-benefit ratio equal to 0.75 means that the introduction of this measure is convenient compared to the implementation costs. Differently from the previous case study, Scenario 3 has a cost-benefit ratio slightly greater than 1, which would suggest a cautionary approach in the adoption of joint measures as the technical solution to limit the noise pressure for the residential buildings that are close to the road (Table 7).

As for the single destinations, residential buildings are those that benefit the most (almost exclusively) from the introduction of the noise barrier and/or noise reducing pavement. In Scenario 2 and 3, no benefits for industrial buildings are visible because the surfaces, and hence their market values, are too limited to have an appreciable benefit for this destination.

Table 5. Ciardes: construction costs of acoustic measures in different scenarios

Scenario	Measure	Unitary cost*	Quantity	Total costs** €	Average costs €
Scenario 1: NB_Ci	Noise barrier	1,500 €/m	265 m	397,500	19,875
Scenario 2: RA_Ci	Noise reducing pavement	15 €/m^2	5,200 m^2	156,000***	7,800
Scenario 3: NB/RA_Ci	Noise barrier	1,500 €/m	265 m	397,500	27,675
	Noise reducing pavement	15 €/m^2	5,200 m^2	156,000***	

Note: * Source: [8]
**Total costs refer to a period of 20 years for all measures
***Noise reducing pavement has to be renewed every 10 years

Table 6. Ciardes: acoustic benefits in different scenarios

Scenario	Destination	Unit value* €/m^2	RNP	Surface m^2	Benefits** €	Yearly benefits €
Scenario 1: NB_Ci	Residential	1,596	10 dB	3,000	330,601	16,530
	Industrial	626	10 dB	–	–	–
	Total			**3,000**	**330,601**	**16,530**
Scenario 2: RA_Ci	Residential	1,596	2 dB	9,239	203,644	10,182
		561	2 dB	626	3,588	179
	Total			**9,865**	**207,232**	**10,362**
Scenario 3: NB/RA_Ci	Residential	1,596	12 dB	3,000	396,718	19,836
		1,596	2 dB	6,239	137,523	6,876
	Industrial	561	2 dB	626	3,588	179
	Total			**9,865**	**537,829**	**26,891**

Notes: * Source: [18] ** Benefits are calculated for 20 years. NSAI is 0.05% for each destination and each scenario

Table 7. Ciardes: cost/effectiveness ratio of different scenarios

Scenario	Yearly costs of intervention €	Yearly acoustic benefits €	Cost-benefit ratio
Scenario 1: NB_Ci	19,875	16,530	1.20
Scenario 2: RA_Ci	7,800	10,361	0.75
Scenario 3: NB/RA_Ci	27,675	26,891	1.02

5 Conclusions

Noise emissions are one of the most important transport externalities, as they affect population living close to the infrastructures, with direct impacts on their physical and mental status. This paper has presented and evaluated some technical solutions to reduce the perceived noise along mountain roads, which are known as critical areas characterized by high acoustic pressures. The evaluation is based on a cost-effectiveness ratio that compares the installation costs with the expected benefits of inhabitants, which in turn are calculated with the hedonic pricing method. Two case studies located along S.S. 38 in South Tyrol reveal the importance of tailored solutions, which need to be based on the morphological and settlement characteristics of the area.

This research derives from a change in the paradigm of development for mountain areas. In the past, the well-being of inhabitants of the valleys was often sacrificed in favour of the economic benefits deriving from tourists, with all related negative externalities (here including the noise and air pollution). However, in last years, this vision has been modified. This is not only due to an increased concern about environmental aspects, but also as a consequence of the tourist market, which seeks more and more genuine and less car-dependent products. Hence, the perspective of inhabitants and the added value that they can obtain regarding the market values of their properties can be used not only as indicator of the social benefit, but also as an indicator related to the tourist attractiveness of a region.

Other contributions revealed the importance of addressing the noise emissions from mountain roads, thus confirming the results of our evaluation: [20] measured noise emissions along an urban expressway in the mountainous city of Chongqing (China). A survey to local inhabitants revealed that acoustic environment was the priority environmental factor to be improved. [21] analysed the variation of traffic-related noise emissions from 1990 to 2016 in Bielsko-Biała, a mountainous city in Poland. Despite the improvement in the vehicle fleet, directing transit traffic to the city beltways, as well as the local use of noise barriers, the level of noise intensity increased at night-time, due to the increased road traffic. [22] made a literature review of noise abatement actions, finding that noise barriers are the most effective direct measure, whereas quieter pavements could have an important supporting role.

Some aspects need to be evaluated with a higher accuracy, starting from the adoption of a noise sensitivity appreciation index that is more tailored to the specificities of the context and continuing with the real reductions of noise guaranteed by alternative solutions. Moreover, costs based on parametric values may be helpful for a preliminary evaluation, but when coming to a more executive phase, analytical evaluations have to be provided. The analysis of future noise emissions should also consider the technological evolution: as recalled in Sect. 2, the increase in the number of electric vehicles, as well as the improvement of materials could contribute to the reduction of noise emissions. Finally, the two case studies presented in Sect. 4 have analysed the payback period of the interventions, without considering the issue of discounting. An analysis that includes also the discounted payback period may be helpful, paying particular attention to the choice of the rate that best represents the intervention from a social perspective. Issues related to discount rates and transport externalities may be a very delicate issue, as

visible from the numerous criticalities raised during the evaluation of the impacts from greenhouse gas emissions [23].

Despite the need of deepening these methodological aspects, this paper has demonstrated that mountain sites with a limited number of buildings but crossed by important road infrastructures can obtain appreciable benefits in terms of noise reduction with the application of relatively economical measures. This aspect is fundamental in terms of policy and equity perspectives: indeed, targeted interventions may contribute to improving the quality of life for citizens living in such peripheral and rural contexts, and to avoiding negative consequences in terms of ageing, depopulation and significative tourism losses [24, 25].

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