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Design of a Noise Action Plan based on a Road Traffic Noise Map

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Summary

According to European Directive 2002/49/CE, EU state members had to compile a strategic noise map no later than 30 June 2007 and a corresponding action plan no later than 18 July 2008 for all agglomerations with more than 250,000 inhabitants and for all major airports, roads and railways. A study on environmental noise was thus conducted for the city of Palma de Mallorca (Spain) using a commercial noise prediction package. The noise level assessment reveals a troublesome situation that requires an urgent noise action plan. In this report, various noise mitigation measures are analysed considering not only the reduction of noise and the number of people that can benefit from these measures, but also the net monetary benefits generated. Given the possible options, it is clear that to achieve the best long-term solution, global noise abatement measures (i.e., traffic management) and local measures (i.e., noise screens) should be combined.

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1. Introduction

The recent concern with noise pollution is mainly due to the growing number of people exposed to high noise levels. Studies [1, 2] have estimated that more than 44% of European citizens of EU27 in 2000, or about 210 million of people, were exposed to road traffic noise with an equivalent total sound pressure level (L_{DEN}) exceeding 55 dBA.

It is necessary to start from the definition of “health” to better understand the effects of environmental noise on the population. The WHO states that: “*health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*” [3].

Therefore, a very noisy place could be detrimental to the quality of life and generate negative effects on human health. In fact, exposure to high noise levels – depending on physical and time features, such as the intensity and frequency composition – may cause not only auditory effects, such as hearing impairment, but also non-auditory effects, such as sleep disturbance, annoyance, mental illness, and problems with speech intelligibility, physical functioning and performance [4].

In fact, a recent study [5] demonstrated that road traffic noise exceeding 65 dBA during the day time increases the risk of heart attacks in men by 20%.

Furthermore, sleep disturbances caused by traffic noise may induce primary effects during sleep and secondary effects during the day after night-time noise exposure. Since

uninterrupted sleep is a prerequisite for good mental and physical functioning, the primary effects of sleep disturbance are difficulty in falling asleep, interruptions and alterations of sleep stages or depth, increased blood pressure and heart rate, vasoconstriction, changes in respiration, cardiac arrhythmia and increased body movements. The secondary effects are reduced perceived sleep quality, increased fatigue, depression and decreased performance [6, 7].

Apart from these motives to reduce the amount of environmental noise, the total external cost of noise gives rise to another and more comprehensive motive. International studies [1, 2] have examined the external cost of noise, and the estimates give a value of 45644 million Euros, or about 0.4% of the GDP of EU17 in 2000. However, the problem seems to be accelerating. In fact, from 1995 to 2000, a 25% increase in the cost of external noise has been estimated [2].

As a response to all these negative effects, the commission of the European community issued Directive 2002/49/CE [8]. With this legislative instrument, EU states sought to develop a common strategy to reduce noise pollution. The EU state members were required to compile a strategic noise map by no later than 30 June 2007 and corresponding action plans by no later than 18 July 2008 for all agglomerations with more than 250,000 inhabitants and for all major airports, roads and railways. The Directive recommends using harmonised noise indicators L_{night} (night equivalent noise rating level) and L_{DEN} (day-evening-night equivalent noise rating level). The equation given in the directive reads:

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$$L_{DEN} = 10 \log \left[\left(12 \cdot 10^{L_{\text{day}}/10} + 4 \cdot 10^{(L_{\text{evening}}+5)/10} + 8 \cdot 10^{(L_{\text{night}}+10)/10} \right) / 24 \right]$$

and the directive continues: in which

- L_{day} is the A-weighted long-term average sound level as defined in ISO 1996-2 [9], determined over day periods of a year;
- L_{evening} is the A-weighted long-term average level as defined in ISO 1996-2 [10], determined over all the evening periods of a year;
- L_{night} is the A-weighted long-term average sound level as defined in ISO 1996-2: 1987, determined over night periods of a year.

The default values for the day, evening and night time periods are 07:00 to 19:00, 19:00 to 23:00 and 23:00 to 07:00 respectively [8].

The purpose of this work is to analyse possible noise mitigation solutions in a study area located in Palma de Mallorca, Spain. In particular, we consider not only the reduction of noise levels and the number of people that can benefit from this reduction, but also an overall cost-benefit analysis. This could be a very useful instrument in decision-making progress because it helps to find the best long-term strategy and, furthermore, it ranks the mitigation measures.

2. Road traffic noise mapping: case study

The study area (Figure 1, bottom) is a part of Palma (Figure 1, middle), a major city and port located on the Spanish island of Mallorca (Figure 1, top) in the Mediterranean Sea, with more than 400,000 inhabitants. The case study has an area of approximately 3.7 km² with a population of 89,875 inhabitants. This study is based on a noise-mapping project [11] for the entire city of Palma de Mallorca that was previously elaborated by the Instrumentation and Applied Acoustic Research Group (I2A2) from Technical University of Madrid (UPM).

The noise maps were created with the commercial noise prediction package CadnaA. By assessing noise levels with simulations it is easier to evaluate possible mitigation plans and specify the different noise sources. Among all the calculation methods that CadnaA can handle, NMPB-Routes 96 [12, 13] was implemented since it was recommended by the European Commission to model road traffic noise [8].

The quality of a noise map is related to the accuracy of the input data [14, 15]. Thus, great attention must be paid in this step of the noise-mapping process.

All the input data used in this work were provided by the Palma City Council in the Geographic Information System (GIS) form. The digital terrain model was defined by 435 polylines with 1 m resolution and a range from 1 to 34 m above sea level. The geometry information for the



Figure 1. Top: Location of Mallorca island. Middle: Location of Palma de Mallorca. Bottom: District case study in Palma de Mallorca.

city's buildings was composed of 1235 polygons, and traffic data were provided in 1073 line segments, each representing the centreline of a road. In particular, the data for the traffic composition, flow and speed were given separately, depending on the weight (heavy and light) and the time period (day, evening and night). Annual meteorological information was provided by the Agencia estatal de meteorología (AEMET), and the population was calculated from the density of inhabitants of the different land use areas.

The model lacked sufficient traffic data and several assumptions were made for the missing input data by using the “Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure”, as assigning default traffic values to dead-end-roads [16]. Assigning road types was done according to data provided by the Palma City Council, and adjusting it to different recommendations [16, 17, 18]. These recommendations may differ from the real circumstances existing in Palma de Mallorca. However, this general classification appeared to match the circumstances actually examined: “A” (Speedway), “B” (Highway) and “C” (Urban road).

2.1. Model validation

The simulation was verified to give feedback on the assumptions used in the model [19]. It is evident that if a noise map is found to be inaccurate, then any corresponding action plan should be brought into question.

A series of continuous samples during 10 days were measured at 4 locations in the study area (Figure 2). Many studies [19, 20] have shown that this sampling technique can properly establish the noise level average over a year.

All the measurements were carried out following the international references related to methodology, distances, precision, traceability and quality control [21, 22, 23, 24].

Furthermore, the locations of the measurements are representative of the different noise conditions taken into account the traffic data available for each road category, after the road categorization establishment [25, 17, 18]. All the locations were detailed chosen to measure mainly traffic noise at adjacent points to the different road categories with existing real traffic data.

Table I shows that all the deviations between the measured and calculated results are smaller than 2.2 dBA. In a recent study using a similar model, a simulation uncertainty [26] was estimated after carrying out an uncertainty analysis for the input data [27].

Analysing the uncertainty graphic (Figure 3), it is observed an overall uncertainty of ± 2.0 dB with a cover factor $k = 2$ and confidence level of 95.45% [28], thus the model is valid and properly represents the environmental noise of the study area [29, 30].

2.2. Noise level calculations

As recommended by the Directive, the EU state members must create maps showing the value of the noise indicators (L_{DEN} and L_{night}) at a height of 4 m and estimate the number of people exposed to the noise in these areas.

To create maps showing the values of the noise indicators, we constructed a grid of receptors spaced at 20 m at the recommended height (Figure 4). The estimation of people exposed to noise levels was carried out by distributing the receivers according to the German method [31] (Figure 5) and by associating an entire building's population with its maximum estimated noise level. Although this is not the method recommended by the European Commission [8], it is supposed to be the best estimation method [32].



Figure 2. Measurement sample locations.

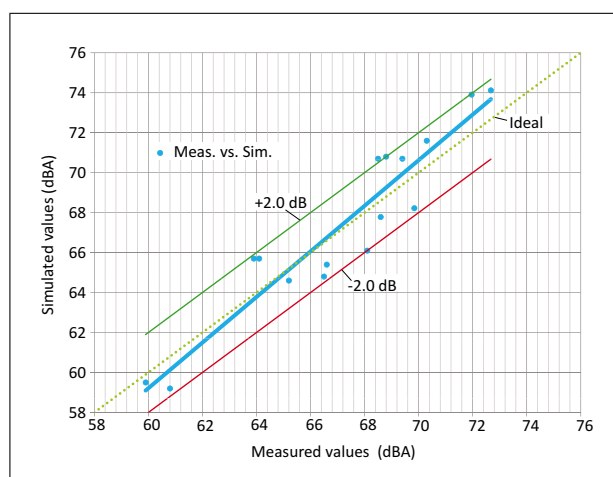


Figure 3. Uncertainty analysis.

2.3. Results of the simulations

As expected, the noise maps (Figure 6 and 7) show that the highest noise levels are found near the main roads and the highway.

About 99% of population is exposed to total noise levels (L_{DEN}) exceeding 55 dBA (Figure 8), and this situation does not improve at night (Figure 9). In fact, 99.9% of the population is exposed to night noise levels (L_{night}) exceeding 50 dBA.

The World Health Organization considers these values potentially harmful for human health [4, 33]. The Spanish legislation defines also an *acoustic quality objective* of 55 dBA for L_{night} in existing urban areas [34]. Therefore, it is evident that an action plan is necessary to reduce the number of inhabitants exposed to these undesired

Table I. Noise measurement data and calculation results [dBA] after calibration.

	Simulated				Measured				Simulated-Measured			
	L_{day}	$L_{evening}$	L_{night}	L_{DEN}	L_{day}	$L_{evening}$	L_{night}	L_{DEN}	L_{day}	$L_{evening}$	L_{night}	L_{DEN}
1	71.6	70.7	65.7	74.1	70.3	69.4	64.1	72.7	1.3	1.3	1.6	1.4
2	64.8	64.6	59.5	67.8	66.5	65.2	59.9	68.6	-1.7	-0.6	-0.4	-0.8
3	66.1	65.4	59.2	68.2	68.1	66.6	60.8	69.8	-2.0	-1.2	-1.6	-1.6
4	70.8	70.7	65.7	73.9	68.8	68.5	63.9	72.0	2.0	2.2	1.8	1.9

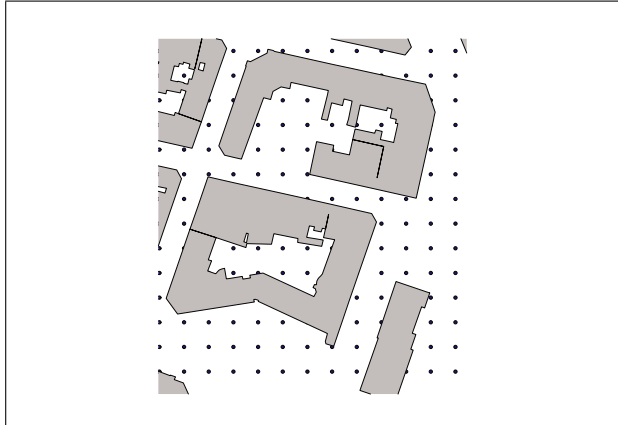


Figure 4. Grid evaluation.

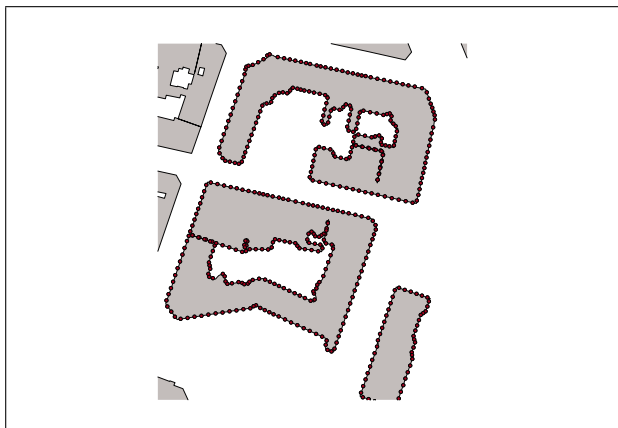


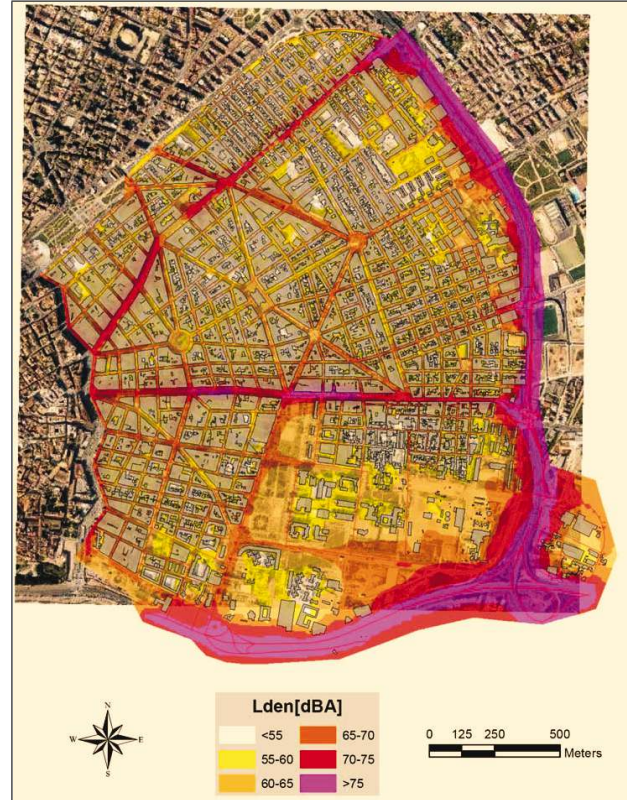
Figure 5. Façade building evaluation.

noise levels. The current noise map will be referred to as scenario 0 below.

3. Noise action plan

3.1. Methodology

Many studies and articles [35, 36, 37] show that the most effective and also the most cost-effective measure is to reduce or to avoid noise at its source via strategies such as road traffic management, traffic calming, and low-noise tires. Sometimes these global measures may not solve the problem completely, leaving a significant percentage of the population exposed to very high noise levels. Therefore, we can combine global actions with local actions,

Figure 6. Road traffic noise map for L_{DEN} .

such as noise screening. The aim of noise screens or barriers is to reduce the propagation of noise as close as possible to the noise source. If it is not possible to use this source based local measure, it is necessary to consider measures at the receptor such as sound insulation.

In this study only measures concerned with the source or with the propagation of noise are considered as suggested to be the first and best solution to carry out [37].

3.2. Proposed measures

The area studied here can be split in two parts depending on local characteristics. The first part is the centre of the city (Figure 10), where the road traffic is composed of up to 10% of heavy vehicles (HVs), the maximum vehicle speed is around 50 km/h and the maximum daily total number of vehicles is about 46,000. On the other hand, the highway (Figure 11) has up to 15% HVs, the maximum vehicle speed is around 90 km/h and the maximum daily total number of vehicles is about 140,000.

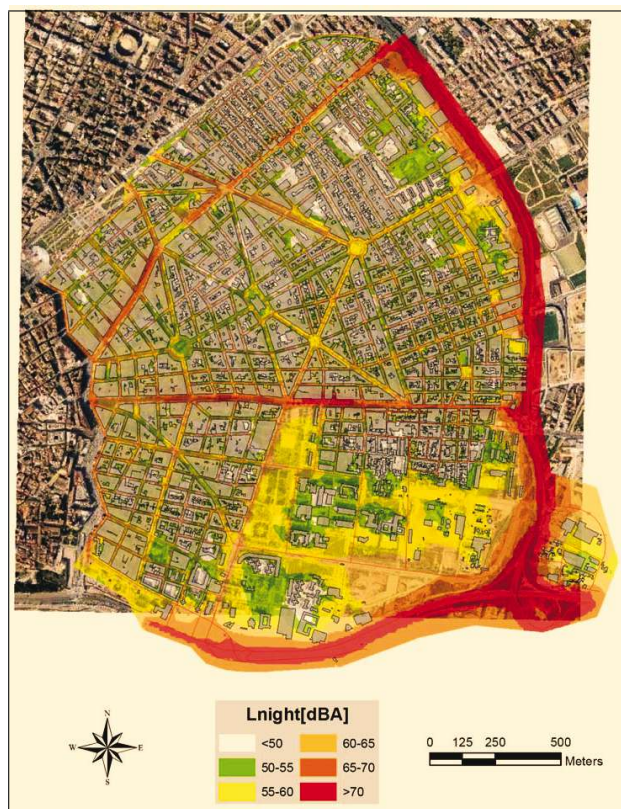


Figure 7. Road traffic noise map for L_{night} .

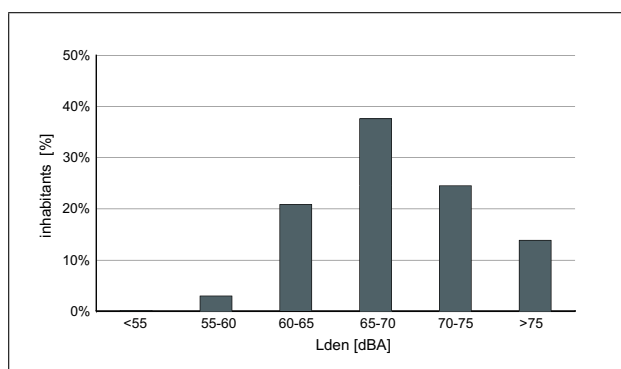


Figure 8. Population exposed to L_{DEN} .

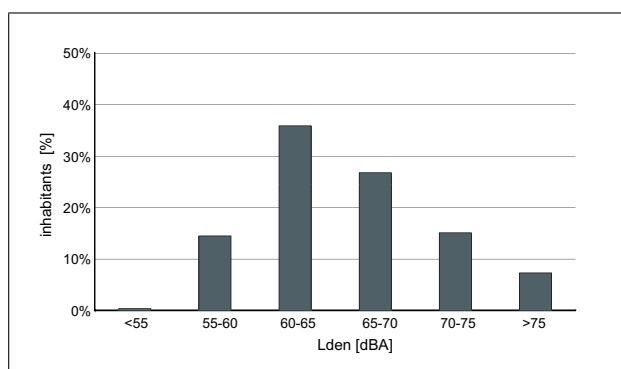


Figure 9. Population exposed to L_{night} .

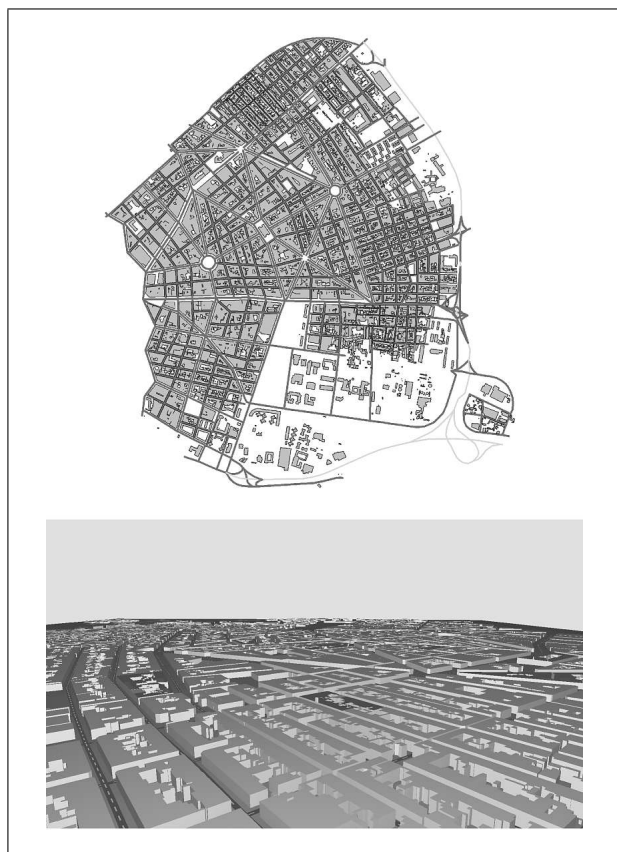


Figure 10. 2D and 3D views of the centre of the city.

Given the features of the noise sources in the different areas, the following solutions were proposed:

- in the centre of the city, global measures should include the reduction of road traffic volume and a local measure should be the construction of a tunnel;
- on the highway, global measures should include a reduced cruising speed and a local measure could be a noise screen.

3.3. Tackling noise: possible scenarios

In order to assess the impact of the proposed measures on the noise levels, a total of four scenarios were analysed. These scenarios were created by combining the possible solutions mentioned above. Scenarios analysed were:

1. a 50% reduction of HVs at the city's centre and a speed reduction (from 90 to 70 km/h) on the highway;
2. a 50% reduction of all vehicles at the city's centre and speed reduction (from 90 to 60 km/h) of HVs and a speed reduction of light vehicles (from 90 to 70 km/h) on the highway;
3. a 75% reduction of HVs and 50% of light vehicles at the city's centre, a speed reduction (from 90 to 60 km/h) of HVs, a speed reduction of light vehicles (from 90 to 70 km/h) and noise barriers on the highway;
4. tunnels and noise barriers.

Note that the noise reduction estimation not only refers to the reduction of the noise level, but it also estimates the number of people that benefit from the noise reduction.

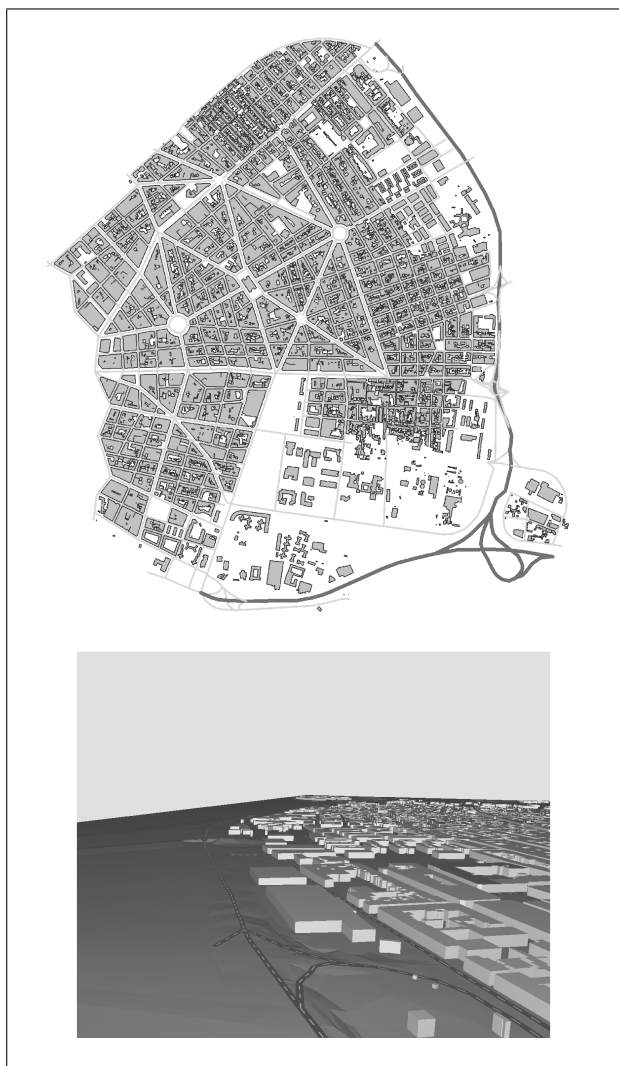


Figure 11. 2D and 3D views of the highway.

3.3.1. Scenario 1

At the centre of the city, we considered a 50% reduction in HVs. This can be achieved with the alternate number plate action, which has already been done in many Italian cities like Verona, Milano, Trento, Palermo, and Roma [38]. This measure usually serves other objectives as well, such as improving road safety and air quality, and it may raise noise awareness since drivers need to optimise every journey into the city to comply with the restriction. It is notable that this measure is only effective in terms of noise reduction if speeds are kept low and driving patterns do not change in a negative way [37].

For the highway we propose reducing a vehicle's speed from 90 to 70 km/h, which can be achieved with variable signs for posting speed limits and informing drivers of their speed [37]. One side effect of this change is that it would raise a driver's awareness of the current or changed speed limit, thus causing more drivers to observe the limit [39]. Other ways to control drivers' speeds include automatic traffic control and police enforcement. In many cities, such as Barcelona [40], Bristol, Munich [41], Glasgow, Edinburgh, Leicester [42], speed reduction has al-

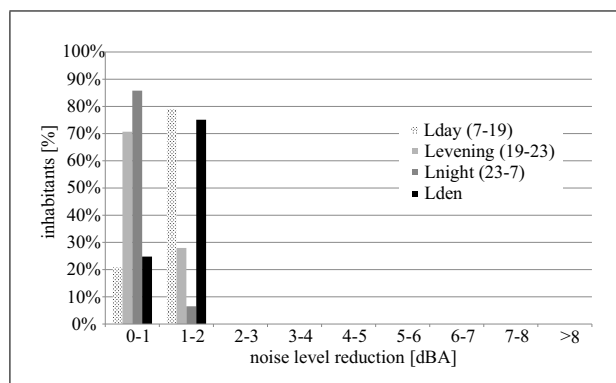


Figure 12. The percentage of people that benefit from the noise reduction in the scenario 1.

ready been considered as a possible solution to noise pollution. In general, reducing the speed limit will also contribute to road safety and improve the air quality. Note that the drivers should decrease their speeds without changing to a lower gear, which could increase noise levels.

In Scenario 1, noise levels are reduced up to 2 dBA (Figure 12). The difference between day-evening-night levels is explained by the difference in the percentage of HVs, as the number of HVs decreases during the day.

3.3.2. Scenario 2

Although heavy vehicles comprise only a small percentage of the total traffic volume (up to 10% in main roads), these vehicles have a great impact on noise pollution [41, 36, 16, 43, 44]. At the centre of the city we considered a 50% reduction in all type of vehicles to verify this conclusion. A possible way to implement this measure is the alternate number plate method.

For the highway we considered reducing the speed from 90 to 70 km/h for light vehicles and reducing the speed from 90 to 60 km/h for heavy vehicles. This measure can be achieved via interactive speed signs, automatic traffic control and police enforcement [39].

In the Scenario 2 noise levels are reduced up to 3–4 dBA (Figure 13). There is only a little difference between day-evening-night noise levels, because the different restrictions for light and heavy vehicles are applied on the highway.

3.3.3. Scenario 3

Scenario 2 highlights the great impact of HVs on noise pollution, because the 50% reduction of the light vehicles, which compose 90% of the total traffic volume, only doubles the noise reduction. Therefore, in this case we considered a 75% reduction of HVs and a 50% reduction of light vehicles at the city's centre. These measures can be achieved with the alternate number plate restriction for light vehicles and permission limits for HVs. For the HVs, the driver must supply the registration number of the truck as well as details of the destination and the number of stops required; the aim of this strategy is to ensure that permits are only issued to vehicles with a legitimate need to travel to the centre of the city and to enable careful monitoring

Table II. Noise Barriers description.

Barrier	Length [m]	Height [m]	Top of barrier
1	218	4	Cantilever (1m H, 1m V)
2	940	4	Cantilever (1m H, 1m V)
3	295	4	Cantilever (1m H, 1m V)
4	70	4	Cantilever (1m H, 1m V)

of the numbers and use of permits being issued. A similar measure has been already carried out in Dublin [45]. Of course, this restriction should be analyzed in detail as the situation differs in a small island as Palma compared to the case studied in Dublin. So, this 75% reduction of HVs is for illustrative purposes.

Global measures like those implemented in scenario 2, decrease the number of individuals exposed to very high noise levels by a large amount, but the noise pollution problem is not solved in the area near the highway. Therefore, for this third scenario we added the local measure of requiring noise screens to the global measures for instances where the building façade total noise levels (L_{DEN}) exceed 75 dBA. Noise barriers can have significant impact on noise abatement. Unlike a sound insulated window, they also offer noise protection for outside areas like balconies and gardens. However, note that noise screens affect the visual aesthetics of the area and they can block air flow, which might negatively impact the local air quality [46].

We propose cantilevered noise barriers (Table II) because it is the simplest solution to the problem of reducing barrier height, as the top section of this type of barrier is angled towards the traffic. This enables the diffracting edge of the barrier to be placed considerably closer to the source of the noise than in the case of a vertical barrier [47]. The height of the barrier was optimised to achieve a reasonable noise level (4 m).

Furthermore, we propose building the barriers with reflective material as the reflected sound that can reach the buildings on the other side of the highway is negligible [48].

In Scenario 3 the noise levels are reduced up to 5 dBA. The difference between day-evening-night levels can be explained by the various activities of HVs for these different times, as the number of HVs decreases during the day. Note that the noise reduction is over 8 dBA as a result of the noise barriers and it concerns about 0.6 % of the population (Figure 14). To calculate the new noise levels with noise barriers, also VBEB method was used to assure a good estimation of the new population exposed to those noise levels.

3.3.4. Scenario 4

Although scenario 3 decreases the number of individuals exposed to high noise levels by a large amount, people are still exposed to very high noise levels near the main roads. A further reduction in heavy vehicles beyond 75% seems unrealistic; therefore, possible options include local measures like noise barriers or tunnels. Using noise barriers is

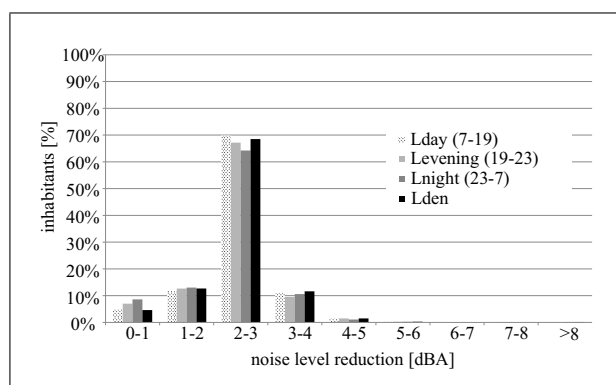


Figure 13. The percentage of people that benefit from the noise reduction in the scenario 2.

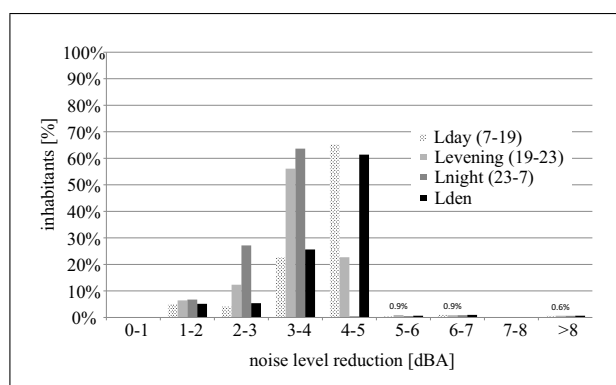


Figure 14. The percentage of people that benefit from the noise reduction in the scenario 3.

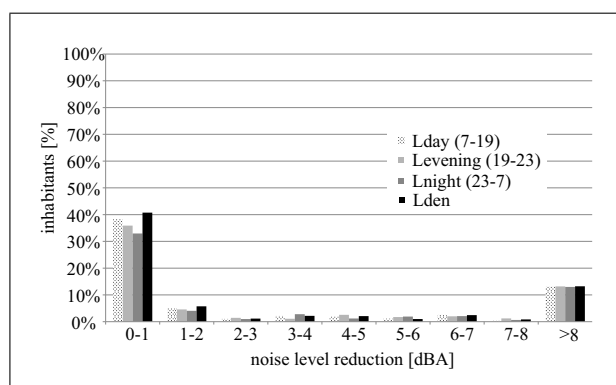


Figure 15. The percentage of people that benefit from the noise reduction in the scenario 4.

obviously unfeasible at the centre of the city because they are not aesthetic and they may cause security problems [37]. The use of tunnels can improve air quality and they can motivate environmental requalification [37], therefore two tunnels were simulated on scenario 4. Tunnels details can be observed in Figure 16a.

For the highway, we only considered using noise barriers since reducing the speed limit from 90 to 70 km/h only decreases the total noise levels by a maximum of 2 dBA (Figure 12).

It is notable that only 13% of the total population benefits from a reduction in noise levels greater than 8 dBA,

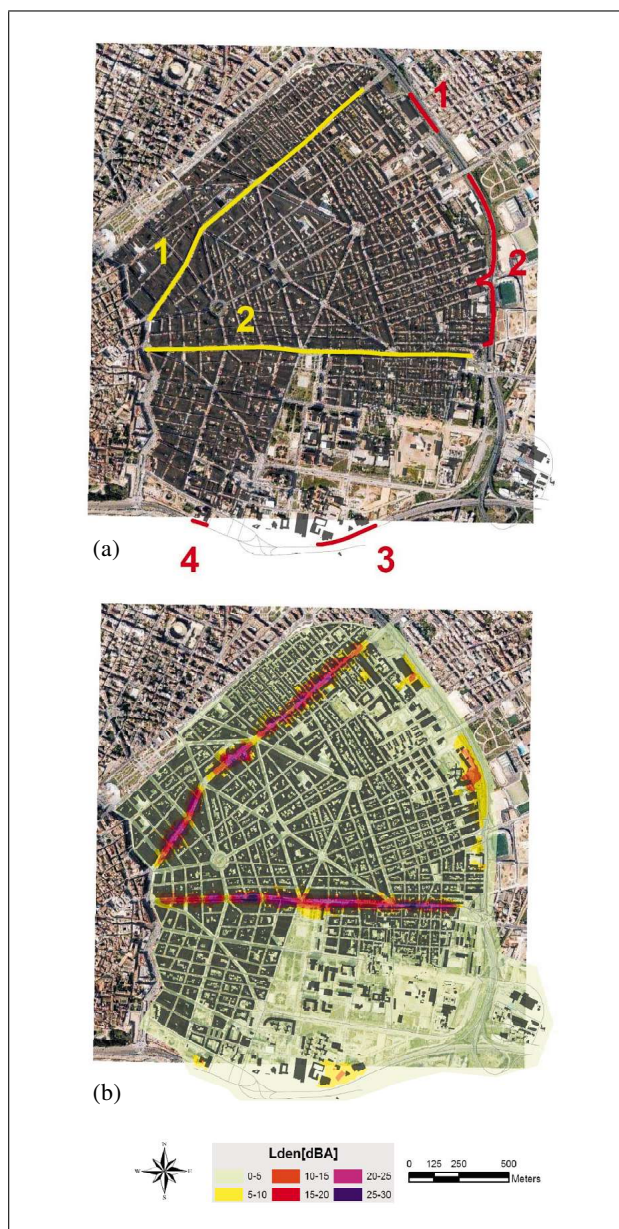


Figure 16. a. Noise barriers and tunnels simulated in scenario 4. b. The reduction of the total noise levels (L_{DEN}) in scenario 4.

while the majority of the people (about 40%) experience a reduction in noise levels lower than 1 dBA (Figure 15). In particular, for the main roads the tunnels reduce the noise levels up to 30 dBA and for the highway the noise screens decrease noise levels by up to 15 dBA (Figure 16). These results indicate that although scenario 4 is based on several local measures, it can decrease number of people exposed to the highest noise levels.

3.4. Comparing scenarios

To find out the best strategy all the scenarios are compared to scenario 0 (Figure 17). Note that a negative percentage implies a reduction of population exposed to that noise level while a positive variation implies an increase. Therefore, benefits of each scenario can be evaluated and quan-

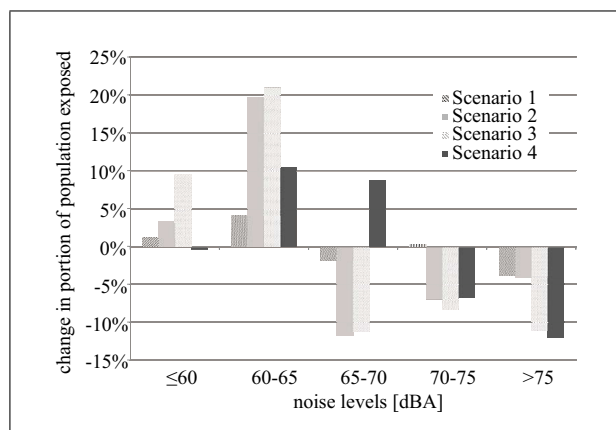


Figure 17. The change in the portion of the population exposed to high noise levels (L_{DEN}) compared to scenario 0.

tified in terms of percentage of people exposed to certain noise levels.

All of the scenarios decrease the number of people exposed to the highest noise levels and increase them at lower noise levels (Figure 17). In particular, the results show that:

- global measures (Scenarios 2) reduce the portion of inhabitants exposed to levels exceeding 65 dBA by 23%;
- global and local measures (Scenario 3) cause a 31% reduction in the portion of the population exposed to levels exceeding 65 dBA. A bigger portion of the people (11%) experience a reduction in noise levels higher than 75 dBA in Scenario 3 compared to Scenario 2.
- local measures (Scenario 4) give a 19% reduction in the portion of inhabitants exposed to noise levels exceeding 70 dBA. A bigger portion of the people (12%) experience a reduction in noise levels higher than 75 dBA in Scenario 4 compared to Scenario 3.

4. Cost-benefit analysis

The Working Group on Health and Socio-Economic Aspects states that it is possible to develop a proper noise action plan with a well-conducted cost-benefit analysis. This type of analysis can help to prioritise noise reduction plans so as to ensure that limited funds produce the best effect. This group produced a position paper on road transportation that recommends that households spend Å25 per dB (L_{DEN}) on noise reduction, per household per year. The range of the validity of this value is between 50/55 L_{DEN} and 70/75 L_{DEN} , and it should be adjusted as soon as new research on this topic becomes available [49].

This value was estimated using two different methods to evaluate the benefits of noise reduction. The first method (Stated Preference) refers to the people's willingness to pay to reduce their noise exposure. The second method (Hedonic pricing) is based on price differences in the housing market that result from traffic noise. It is notable that these methods are likely to represent only a reasonable valuation of the perceived noise effects. This value might

Table III. Cost-benefit analysis of the different scenarios.

Scenario	Benefits[€/year]	Construction costs [€]
1	635,617	43,160
2	1,853,108	43,160
3	2,821,076	2,221,560
4	1,791,512	14,897,850

represent a lower bound, as an extra element for unperceived impacts needs to be added in order to better represent the benefits generated from noise reduction [49].

Many European price lists [48, 50] were consulted to estimate the overall cost of the different measures of noise mitigation. We only considered the direct costs of implementation, disregarding the maintenance and the indirect and hidden costs. In particular, the construction costs include (Table III):

- static signs for the alternate number plate action, static and interactive speed signs for the speed reduction and labour costs for the implementation (Scenario 1 and 2);
- static signs for the alternate number plate action, static and interactive speed signs for the speed reduction, reflective noise barriers and labour costs for the implementation (Scenario 3);
- tunnels, reflective noise barriers and labour costs for the implementation (Scenario 4).

According to Table III, three out of four scenarios produce annual benefits that are higher than the costs to construct noise mitigation devices (although maintenance and indirect costs have not been taken into account). For scenarios 1, 2 and 3, the difference between these two values is large enough to support the proposed noise mitigation plan even considering the possible errors generated from the assumptions used.

In particular, Table III shows that:

- global measures (Scenarios 1 and 2) are the cheapest options;
- global-local measures (Scenario 3) produce annual benefits higher than the construction costs;
- local measures (Scenario 4) are used in the only option that presents a construction cost that is higher than the annual benefits.

The problem now is to determine whether it is better that a large number of people benefit from a lower noise reduction (Scenario 1 and 2), or if it is better that a lower number of people benefit from a higher noise reduction (Scenario 4). For the best long-term solution, these two methods should not be considered separately, but they should be combined (Scenario 3). This conclusion is supported by a temporal analysis of the net monetary benefits (Figure 18), which considers only the construction costs (in the first year) and the annual benefits (Table III). In this case, we considered 5 year period of analysis, as required by the END for noise action plan [8]. It is important to note that the omission of maintenance, indirect and hidden costs could have a material impact upon the assessment;

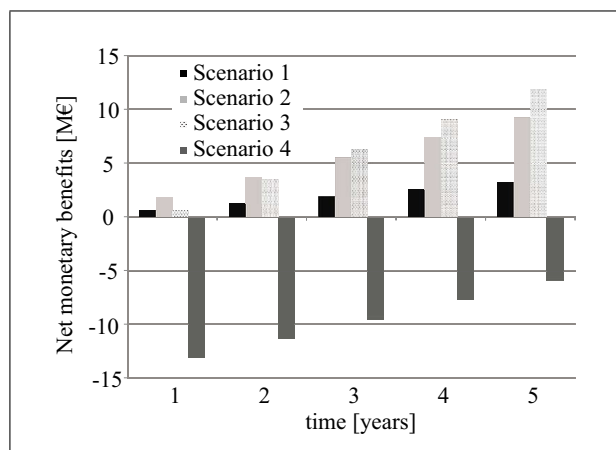


Figure 18. Net monetary benefits of the different scenarios over a five year period.

although several noise reduction actions as speed reduction and reduction in both light and heavy vehicles imply low implementation and maintenance costs [51].

Over this period of time, the choice of the best action plan is different than over a single year. In fact, while scenario 2 (global measures) presents an immediate monetary benefit, especially because of the low initial costs of mitigation, from the third year on scenario 3 (global and local measures) is the best choice (Figure 18). Therefore, it is evident that a long-term period must be considered in order to better understand the effects of a given noise action plan.

5. Conclusion

The results of this study reveal that the noise levels defined by WHO are widely exceeded in the study area: the city of Palma de Mallorca. It is clear that measures to mitigate noise pollution are needed.

The proposed solutions have shown that it is possible to greatly reduce the number of people exposed to harmful noise levels with global measures like traffic management (Scenario 1 and 2). Furthermore, as shown by the cost-benefit analysis, global solutions are cheaper than local solutions (Table III). Another advantage to global solutions is increased public awareness. As a matter of fact, global measures like alternative number plate or permission limit systems for HVs, with a corresponding explanation for the reasons of implementation, can develop noise awareness. These strategies force people to think about noise problems, since they have to optimise every journey into the city to comply with the restrictions [37].

Occasionally, global measures may not completely solve the problem, leaving some groups of people exposed to very high noise levels. In these cases, we should combine global actions with local actions like noise screening. Although this option is quite expensive, it can produce the highest net positive monetary benefits over a long-term period (Scenario 3). We should take care when implementing local measures because they can quickly increase the cost

of construction without an equally large benefit, as shown by scenario 4 (Figure 18).

In particular, the different scenarios indicate the influence of heavy vehicles on environmental noise in urban areas. In scenario 1, the 50% reduction in HVs, which consist of a maximum of 10% of all traffic volume, decreases noise levels by up to 2 dBA, whereas a 50% reduction of all the vehicles decreases the noise by up to 3 dBA (Scenario 2). Therefore, traffic plans that directly affect HVs, such as a permit limit system, should take priority. It is notable that this measure is only effective in terms of noise reduction if speeds are kept low and driving patterns do not change in a negative way, because HV reduction could imply an increase of light vehicle mean speed [37]. After that, the reduction in light vehicles is the most important mitigation option, while decreasing speed limits only slightly reduces noise levels (Figure 12).

Regarding local measures, tunnels are the most effective noise reduction measure. In this study, it was estimated that noise is reduced by 30 dBA near the tunnels. Another option is a noise screen, which, according to this study, yields a reduction of up to 15 dBA (Figure 16).

Some measures designed to tackle the noise problem interfere with other objectives, such as road safety, energy consumption, air quality and congestion. All these effects must be taken into account to assess a holistic noise action plan. Research is needed to evaluate the monetary benefits of these secondary effects; such a study could greatly help the decision makers prioritise the different noise mitigation plans available. For example: Access restriction may of course be expensive to implement because of other measures that have to be taken, as new parking lots, public transport and system to enforce the restriction. On the other hand the measure is extremely efficient, as its efficiency depends on to what extent the restrictions are taken. If you completely eliminate the traffic you obviously also completely eliminate the traffic noise [52]. Anyway, to carry out a holistic environmental impact assessment, almost all Internal Stakeholders should be involved as: Transport planning; Road maintenance; Urban planning; Air quality; Health; Land use planning; Urban renewal; Municipal waste; Management and Local police [37].

As stated above, noise pollution is growing and it is causing more harmful effects on human health. Therefore, noise problems should be studied further to develop a holistic environmental impact assessment, as they imply also environmental improvements such as less emission of air pollution [52].

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