inter·noise 2009
innovations in practical noise control
2009 August 23-26
Ottawa, Canada

The true cost of road traffic noise in Portugal

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ABSTRACT

This paper presents some results of the ongoing investigation concerning the economical evaluation of road traffic noise. As the majority of the European countries, Portugal has part of its 10 million citizens exposed to excessive noise levels, according to the WHO suggested values. Considering the relevance of this subject and the constant increase in road traffic volume, it was recognized the importance of an economical valuation of this excessive noise levels, referred to three cost categories: *infrastructure* (increase in the infrastructure cost due to the constructions of noise mitigation measures), *noise externalities* (connected to social, real estate and health noise related costs) and *real estate income loss* (allied to the inability for construction in available land for construction based on excessive noise and the consequent reduction of the patrimonial value). This paper illustrates some of the investigation results for specific municipalities regarded as representative of the municipalities' majority according to its territorial, economical and urban planning characteristics.

1. INTRODUCTION

Since the approval of new statutory documents concerning the *third Portuguese Noise Code*[(1),] the *Real Estate Taxation Codes*[(2)], the *Territorial Management Systems*[(3)] and, lately, the *Strategic Environmental Assessment of Territorial Management Plans*[(4)], the relevance of environmental issues increased and most Portuguese municipalities began to explore the implications of this inconsiderateness.

Taking into account that almost all the cities are undertaking the revision of their Municipal Director Plans (MDP), these legal changes induced severe transformations on the scheduled work. They were obliged to produce Noise Maps and to classify the urban territory regarding

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noise sensitivity of present and expected uses and to perform the strategic environmental analysis of the upcoming MDP, including the concerns of the population that should be consulted through public participation mechanisms. One of the principal components of this strategic analysis is the preliminary detection of environmental concerns, which could be avoided with the adoption of mitigation measures of diverse types. Concerning noise, some of the questioned measures involve territorial management change (redistribution of incompatible uses), traffic reorganization and traffic calming measures or modification of the regular dressing surfaces (replacement for "*noise-friendly*" surfaces).

To define the "*best noise reduction procedures*" there is the need to identify all noise conflict areas, in each municipality, and to decide if the adequate measures depend on municipal actions or on private actions. To this investigation will be considered the mitigation actions already in-place either from public or private implementation.

2. NOISE LEGAL FRAMEWORK

Until 1987, when the *first Portuguese Noise Code* (RGR)[5] and the *Environmental Act*[6] were approved, the *Portuguese Constitution*[7] was the only statutory document where environment and welfare was mentioned. In fact, general concepts of welfare, quality of life, environmental rights, nature and environmental protection and natural resources protection were stated on articles 9, 66 and 81 and referred as National Authorities responsibilities.

Since then, was approved the *second Noise Code*[8] (RLPS) with the same scope of application but with a new acoustical parameter L_{Aeq}. The subsequent legal document was Decree-Law n.º 146/2006[9], which transposed the European Directive 2002/49/CE, 25th June into the Portuguese legislation, changed once more the acoustical reference parameter (from L_{Aeq} to L_{den}), introduced three reference periods: day (7 h – 20 h), evening (20 h – 23 h) and night (23 h – 7 h) and also strategic noise mapping, action plans and the obligation for public information and participation. Finally, in January 2007, the *third Noise Code*[1] was approved (RGR), harmonizing acoustical parameters, reference periods and noise limits as indicated on Table 1.

Table 1: Maximum Noise limits and Form of occupancy for Mixed and Sensitive zones[1]

Form of Occupancy	Full day period (0 h – 24 h)	Nighttime period (23 h – 7 h)
Mixed Zone	L_{den} = 65 dB(A)	L_n = 55 dB(A)
Sensitive Zone	L_{den} = 55 dB(A)	L_n = 45 dB(A)
Sensitive Zone *close to an existent MTI*	L_{den} = 65 dB(A)	L_n = 55 dB(A)
Sensitive Zone *close to a MTI during design stage (not for airports)*	L_{den} = 60 dB(A)	L_n = 50 dB(A)
Sensitive Zone *close to a major airport during design stage*	L_{den} = 65 dB(A)	L_n = 55 dB(A)
Sensitive Receivers on non classified zones	L_{den} = 63 dB(A)	L_n = 53 dB(A)

MTI - major transportation infra-structure

With this new RGR, municipalities were advised to produce noise maps (L_{den} and L_n, at 4 m height) as a supportive planning tool for the elaboration, alteration and revision of municipal director plans (MDP). It is stated that municipal director plans should guarantee environmental noise quality, promoting reasonable distribution of activities and noise sources as well as establishing noise classification areas (sensitive and mixed zones).

According to RGR, *licensing or authorizing new dwellings is forbidden, as well as new schools, hospitals or similar social equipments and leisure spaces, while the settled*

environmental noise limits are exceeded. The only exceptions are new housing, in "*consolidated urban areas*", with approved Municipal Noise Reduction Plan (MNRP) or where environmental noise limits are not exceed more than 5 dB(A). In this situation ought to be considered façade sound insulation reinforcement by 3 dB(A).

3. CASE STUDY MUNICIPALITIES

For the evaluation of road traffic noise cost were selected two cities in the north region of Portugal (Maia and Santa Maria da Feira) which can be consider as representatives of the great majority of the Portuguese counties. Thus, the municipality of ***Maia*** intends to represent cities with a strong services sector and reveals a significant industrial presence, given its proximity to major transportation infrastructures. The land use distribution demonstrates a dense urban occupation pattern (about 40% of the territory is classified as urban) and is densely populated (close to 1 700 hab/km^2). ***Santa Maria da Feira*** is a municipality with an extremely relevant industry sector, although the services sector is also present, and represents an important part of the municipal economy. As for land use characteristics, there is a dichotomy of occupation spite the consideration of 34% of the territory as urban. The western part of the municipality is more densely occupied and its inner part is dedicated to others forms of occupancy less populated.

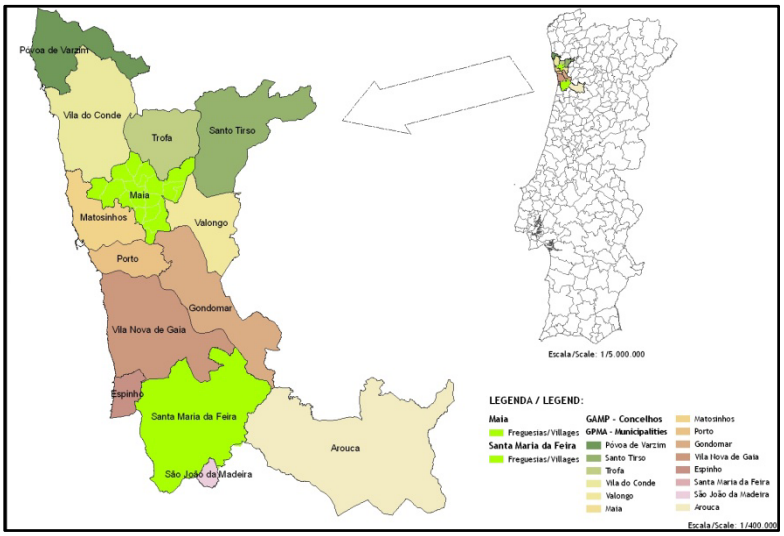


Figure 1: Case-study municipalities' location (Maia and Santa Maria da Feira)

Table 2: Summary table with characteristic indicators (2007) of Portugal and Case Study municipalities [10] [11] [12] [13]

Characteristics	Portugal	Maia	S.M. Feira
Population	**10 599 095**	138 226	146 367
Parishes ("*freguesias*")	**4 260**	17	31
Population density (inh/km^2)	**114**	1 663	680
National Road density (km/km^2)	**10**	0.3	0.2
Activity Sector (%GDP):			
Primary: agriculture/fishing	**2.4%**	0.1%	0.3%
Industries	**21.2%**	39.5%	65.5%
Services	**62.5%**	60.4%	34.2%
Actual MDP	**-**	2009	1993
Area (km^2)	**92 090**	83	215
Land use: urban (ha)	**481 082**	3 267 (39%)	7 359 (34%)

Characteristics	Portugal	Maia	S.M. Feira
Land use: industrial (ha)	**75 151**	769 (9%)	530 (2%)
Land use: public equipments and parks (ha)	**37 837**	982 (12%)	419 (2%)
IMI Tax		0.50%	0.50%
IMI income		€ 16 840 361	€ 11 361 210
Percentage of total revenue		20%	19%

4. INFRA-STRUCTURE COST

The evaluation of the ***infrastructure cost surplus*** was conducted through the analysis of all the investments performed by road concession holders with the purpose of eliminating the existent noise conflicts, both in the 24 h period (L_{den}) and in the nighttime period (L_n).

From the available noise alleviation measures, both concession owners chose to implement measures in the noise source (noise-improved pavements) and on the noise path (noise barriers) for a better protection of the receivers, mostly in dwellings, with the guaranty of an effective environmental noise reduction.

The unitary cost of these measures is summarized in Table 3, together with the *global additional cost* (Δ) for the construction and *global cost* for renewal of special noise reduction pavements (considering as reference surface: *dense asphalt concrete*) and the *full investment cost* for noise barriers. The average renewal price is referred to the construction year through the consideration of discount rates in order to achieve the Present Value (PV)[14]:

$$PV = \left[\frac{1}{(1+i)^n} \right] \quad (1)$$

where:
i – discount rate
n – year of expenditure (pavement rehabilitation)

The *regular maintenance operations cost* both for noise barriers and noise-reducing pavements were not considered, as there is no standard enforcement for these procedures.

Table 3: Summary table with the implemented noise mitigation measures [15], [16]

Characteristics	€/m²	Maia	S.M. Feira
Pavement with improved Acoustical performance			
Reference Surface: DAC (dense asphalt concrete)	3 - 4		
PAC (porous asphalt concrete)	5 - 6	356.250 m² Δ = € 710.500	287.834 m² Δ = € 575.668
PERS (poro-elastic road surface)	4 - 5	472.450 m² Δ = € 472.450	-
Average cost for pavement renewal (each)	6 - 8	€ 2.493.750	€ 2.014.838
Noise Barriers			
Leca block wall with absorption (*Leca®Mursom*)	70 - 80	143.702 m² € 10.777.650	-
Metallic with absorption	120 - 140	-	17.622 m² € 2.290.860
Acrylic	140 - 150	1.650 m² € 239.250	1950 m² € 282.750

5. NOISE EXTERNALITIES

The ***noise externalities*** were estimated taking into consideration two primary aspects: *Health Impairment* and *Annoyance*, usually supported by the population in general and, in particular, by those who experience directly those negative impacts.

Concerning *health impairment*, excessive traffic noise levels can motivate different health effects, for instance, *sleep disorders*; *weaken concentration* skills and related *working injuries* or *reduced productivity*; *diminished learning and understanding* aptitude; *hearing damage*, *stress episodes* (leading to change of heart beat frequency, increase of blood pressure and hormonal variations) and even an increasing risk of *cardiovascular diseases* and *psychiatric disorders*. These health costs might be evaluated through medical costs, productivity and working time loss or raised mortality costs. An estimate performed by CE Delft[17] for T&E, evidenced average social costs, due to excessive traffic noise levels, over € 40 billion per year on EU22 countries, mainly derived from road traffic (90%).

With reference to *annoyance*, the "*feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them' or 'a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when noise interferes with someone's thoughts, feelings or daily activities'* "[18], the evaluated impacts refers to the mentioned disturbance experienced by citizens exposed traffic noise.

Taking into consideration the quality of data, it was not possible to perform all the initially expected calculations. As so, it was considered an alternative estimate method, for which all the anticipated information was available. The elected method was the one defined on the European Project HEATCO (Developing **H**armonised **E**uropean **A**pproaches for **T**ransport **Co**sting and Project Assessment) for the evaluation of environmental costs and, in particular, costs related to noise.

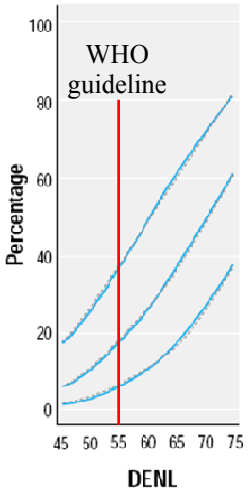
The assessment methodology was the ***Impact Pathway Approach*** (IPA)[19]. This method involved the consideration of noise dispersion models (including emission and propagation mechanisms) and the associated noise levels on the receivers, both in the Initial Situation (Do-nothing situation) and the Final Situation (Do-something situation: Noise mitigation measures), whose results are indicated in Table 4.

Table 4: Summary table for exposed population *before* and *after* the execution of noise mitigation measures (NMM)

Noise Classes	Exposed population in Maia		Exposed population in S.M. Feira	
	Before NMM	*After NMM*	*Before NMM*	*After NMM*
$L_{den} \geq 75$ dB(A)	5192	3894	36	27
$65 \leq L_{den} < 75$ dB(A)	25 747	24528	8 869	8 449
$55 \leq L_{den} < 65$ dB(A)	49 656	44691	18 473	15 458
$45 \leq L_{den} < 55$ dB(A)	26154	31385	30 794	32 728
$L_{den} < 45$ dB(A)	*5471*	*7722*	*71 906*	*73 416*
$L_n \geq 75$ dB(A)	360	270	0	0
$65 \leq L_n < 75$ dB(A)	8 650	7353	21	2
$55 \leq L_n < 65$ dB(A)	30 719	24575	5 702	4 832
$45 \leq L_n < 55$ dB(A)	52701	55336	22 749	19 466
$L_n < 45$ dB(A)	*19790*	*24686*	*101 606*	*105 778*

This variation on environmental noise levels was assessed in terms of welfare changes (health impacts and annoyance) and, later, quantified through concepts of monetary valuation, namely, *willingness-to-pay* for noise reduction, which allowed determining *Noise Costs*.

This line of action followed the subsequent steps: *calculation of noise exposure* for the initial situation without noise reduction procedures; calculation of *annoyed and sleep-disturbed persons* with exposure-response functions (ERF) and *monetary valuation* of those impacts. Then, reapply the same procedure for the final situation incorporating the implemented mitigation measures. The results of these procedures are graphically revealed in Figure 2 and Figure 3.



Percentage of "*Little Annoyed*" persons

$$\%LA = -6.235\times10^{-4}\,(L_{den}-32)^3 + 5.509\times10^{-2}\,(L_{den}-32)^2 + 0.6693\,(L_{den}-32) \quad (2)$$

Percentage of "*Annoyed*" persons

$$\%A = 1.795\times10^{-4}\,(L_{den}-37)^3 + 2.110\times10^{-2}\,(L_{den}-37)^2 + 0.5353\,(L_{den}-37) \quad (3)$$

Percentage of "*Highly Annoyed*" persons

$$\%HA = 9.868\times10^{-4}\,(L_{den}-42)^3 - 1.436\times10^{-2}\,(L_{den}-42)^2 + 0.5118\,(L_{den}-42) \quad (4)$$

Percentage of "*Highly Sleep Disturbed*" persons

$$\%HSD = 20.8 - 1.05L_{night} + 0.01486L_{night}^2 \quad (5)$$

Percentage of "*Sleep Disturbed*" persons

$$\%SD = 13.8 - 0.85L_{night} + 0.01670L_{night}^2 \quad (6)$$

Percentage of "*Little Sleep Disturbed*" persons

$$\%LSD = -8.4 + 0.16L_{night} + 0.01081L_{night}^2 \quad (7)$$

Figure 2: Estimated curves and polynomial approximations for L_{den} and L_{night}, regarding *annoyance* [20], [21] and *sleep disturbance* [22] for road traffic noise

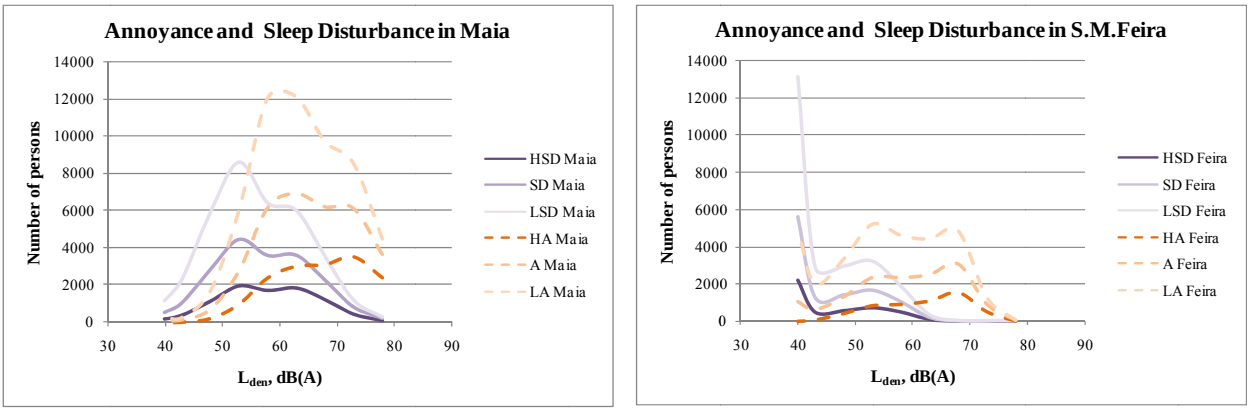


Figure 3: Estimated number of people *A-annoyed* (L_{den}) or SD-*Sleep Disturbed* (L_{night}) due to road traffic noise exposure, in Maia and Santa Maria da Feira

For the monetary comparison were applied the *HEATCO noise cost factor tables* derived for Portugal[23], [24], [25], by person and by year, to the highly annoyed population in the Initial Situation (IS) and in the Final Situation (FS). These tables include both health and annoyance costs in two situations: "*New approach*" (health and annoyance was based on dose-response functions); "*Central value*" (health and direct WTP for reducing annoyance based on 'stated preference' studies) and the results are indicated in Figure 4.

L_{den}		n.º persons	Noise Cost	Δ persons	Δ noise cost
"*New approach* "	*Road*				
Maia	IS	107 684	€ 2 341 238	-1 863	-€ 192 543
	FS	105 821	€ 2 148 695		
S.M.Feira	IS	64 016	€ 727 971	-851	-€ 44 916
	FS	63 165	€ 683 055		
"*Central values* "	**Road**				
Maia	IS	204 607	€ 8 255 116	-6 324	-€ 736 129
	FS	198 283	€ 7 518 987		
S.M.Feira	IS	104 036	€ 2 426 814	-4 781	-€ 215 638
	FS	99 255	€ 2 211 176		

Figure 4: Estimated global Noise External costs per year in Maia and Santa Maria da Feira

6. REAL ESTATE COST

The ***noise indirect effects on municipal taxes income*** were modeled in view of three main areas: *Territorial Management*, *Noise* and *Real Estate Taxation*.

Regarding ***territorial management***, was collected all the significant data on municipal territorial partition like urban space characteristics, present constructions, most relevant activities, *spatial distribution of uses* and *construction potential coefficient* (CPC) by use; and the effective *constraints* as ecological, natural and agricultural reserves, forest and wood production areas, protection area to the transportation infra-structures (airport, aerodrome, railway, metro and road), preservation area to patrimonial constructions, etc.. In fact, there was a common constraint between territorial management and noise, *Noise Classification Zones*.

With reference to ***noise***, was gathered all the information related to the previous noise map and was introduced and calculated the new L_{den} and L_n parameters. With this information congregated with territorial planning guidelines were designed the municipal noise classification zones. Subsequently, it was possible to determine the presence of *conflict areas*[c] and the related *degree of conflict* (how many dB(A) exceeding the legal noise limits).

Concerning the ***real estate taxation model***, the new IMI Code[(2)] (2003 and revised in 2006) was the primary working material. The calculation of *equivalent area* (A) and the definition of the *location coefficients* were the most important tasks, especially as there was no data available. All the data had to be calculated or determined through indirect techniques. The first information needed refers to vacant building area. The analysis of the present situation, in terms of construction, revealed the status of land occupation. Joining that information with building restrictions was calculated the *vacant land for construction*, according to the future activities and class of use.

However, for the purpose of this study, the interesting vacant land for construction did not refer to its total extent. In fact, the relevant area for analysis was the one under a noise conflict. Therefore, the following step was area selection. From all the vacant land for construction, it was only essential to consider *noise conflict influenced areas* whose primary occupation would be noise susceptible, as housing.

Afterwards, as the patrimonial value depends on the construction area, it was required to estimate the maximum achievable total construction area. In the Municipal Director Plan (MDP) regulations and in line with the possible uses of each class of urban space, are specified the construction parameters, which allowed the calculation of the expected *total construction area of*

[c] Human occupied areas where environmental noise surpasses the correspondent ***noise limit***.

the municipality under noise conflict.

The computation of *equivalent area* (A) involved the observation of complementary information with diverse nature. On one side, there is the evaluation of the possible construction area (A_a and A_b) and, on the other, the remaining area of the allotment (A_c and A_d). The influence of taxation model arises at this point with the *location coefficient for land value* (% T) and, afterwards, with *housing location coefficient* ($C_{L\ housing}$). These two factors along with the *construction value* (V_c), *area function* (C_a) and *quality and comfort coefficients* (C_q) will consent to the estimate of the total patrimonial value as a ***regular urban property***.

$$V_{t\ regular\ urban\ property} = V_c \times A \times C_a \times C_{L\ housing} \times C_q \quad (8)$$

$$A = (A_a + 0.3\,A_b) \times \%\,T + (0.025\,A_c + 0.005\,A_d) \quad (9)$$

This process was reapplied, in the context of "other" urban property, but now the important factors were the *construction value* (V_c), *housing location coefficient* ($C_{L\ housing}$) and the *allotment area* (A_T) which will determine the new patrimonial value as ***other urban property***.

$$V_{t\ other\ urban\ property} = V_c \times A_T \times C_{L\ housing} \times 0.005 \quad (10)$$

The last procedure refers to the real estate tax calculation – IMI value.

Each municipality has an individual tax with a maximum of 0.5% whose application to the calculated patrimonial values will endorse the estimate of municipal tax income loss.

Table 5: Assessment table for real estate cost related to excessive environmental noise levels

Characteristics	Maia	S.M. Feira
A (m^2)	1 407 554	62 463
V_c (€/m^2)	615	615
C_a (average)	0.97	1.00
C_q	1.00	1.00
$C_{L\ dwellings}$ (average)	1.19	0.96
$C_{L\ land\ for\ construction}$ (average)	0.25	0.19
Patrimonial value (Vt): Land for construction	€ 1 027 600 375	€ 36 529 805
Patrimonial value (Vt): Other properties	€ 27 144 811	€ 1 056 362
IMI tax (2007)	*0.50%*	*0.50%*
IMI revenue: Land for construction	€ 5 086 640	€ 182 252
IMI revenue: Other properties	€ 133 189	€ 4 918
IMI revenue variation	***€ 4 953 451***	***€ 177 334***

7. RESULTS

In Table 6 are presented the preliminary results of this study for an expected lifetime of 20 years (standard horizon for the road network in Portugal).

During this time frame for the *noise mitigation measures*, the noise-improved surface is expected to require two renewals (compared with dense asphalt concrete), noise barriers are considered to be in place and effective for the overall period. In both cases, no maintenance operations are expected.

Table 6: Summary results for road traffic noise related costs

	"New approach"		"Central values"	
	Maia	**S.M. Feira**	**Maia**	**S.M. Feira**
	L_{den}		L_{den}	
Noise externalities with no noise-reduction actions (20 years)	*€ 46 824 760*	*€ 14 559 420*	*€ 165 102 320*	*€ 48 536 280*
Health costs (per year)	€ 2 341 238	€ 727 971	€ 8 255 116	€ 2 426 814
Annoyance cost (per year)				
Real Estate Cost with no noise-reduction actions (20 years)	*€ 99 069 020*	*€ 3 546 680*	*€ 99 069 020*	*€ 3 546 680*
reduction municipal IMI income (per year)	€ 4 953 451	€ 177 334	€ 4 953 451	€ 177 334
	€ 145 893 780	***€ 18 106 100***	***€ 264 171 340***	***€ 52 082 960***
Noise externalities with noise-reduction actions (20 years)	*€ 42 973 900*	*€ 13 661 100*	*€ 150 379 740*	*€ 44 223 520*
Health costs (per year)	€ 2 148 695	€ 683 055	€ 7 518 987	€ 2 211 176
Annoyance cost (per year)				
Real Estate Cost with no noise-reduction actions (expected for 20 years)	*€ 66 046 013*	*€ 1 773 340*	*€ 66 046 013*	*€ 1 773 340*
reduction in municipal IMI income (per year)	€ 3 302 301	€ 88 667	€ 3 302 301	€ 88 667
	€ 109 019 913	***€ 15 434 440***	***€ 216 425 753***	***€ 45 996 860***
Additional infrastructure cost				
Pavement (including 2 renewals)	€ 6 170 450	€ 4 605 344	€ 6 170 450	€ 4 605 344
Noise Barriers	€ 11 016 900	€ 2 573 610	€ 11 016 900	€ 2 573 610
	€ 17 187 350	***€ 7 178 954***	***€ 17 187 350***	***€ 7 178 954***
Population (inhabitants per municipality)	112 220	130 078	112 220	130 078
Initial Noise Externalities and reduction IMI income (by inhabitant)	€ 1 300	€ 139	€ 2 354	€ 400
Investment in noise mitigation measures (by inhabitant)	€ 153	€ 55	€ 153	€ 55
Remaining Noise Externalities and reduction IMI income (by inhabitant)	€ 971	€ 119	€ 1 929	€ 354
True Cost of Road Traffic Mitigation (by inhabitant)	***€ 175***	***-€ 35***	***€ 272***	***-€ 8***

Regarding *noise-exposed population*, were calculated the expected noise externalities (health and annoyance costs) according to HEATCO procedures for the Do-nothing and Do-something Situations. For *real estate costs* was also calculated the expected reduction in municipal IMI income for both situations. Finally, was evaluated the difference between the noise related costs in the initial situation and after the investment and implementation in noise mitigation actions.

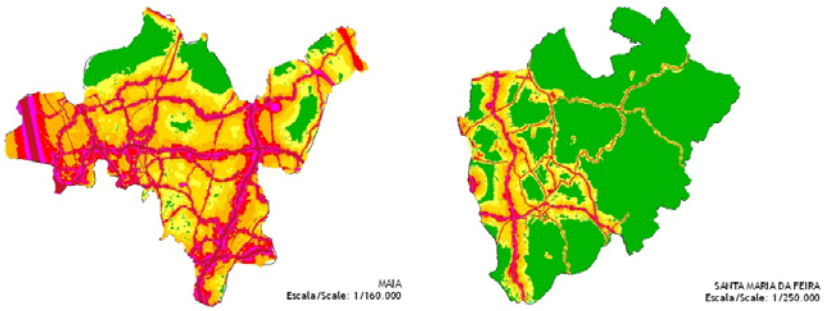


Figure 5: Noise Maps (L_{den}) from Maia and Santa Maria da Feira

As it can also be seen in Figure 5, the situation is not similar for the two municipalities. In fact, there is a significant disparity between them and one of the most probable reasons might well be the "*urbanity*" of Maia contrasting with Santa Maria da Feira. **Maia** is a municipality with all noise sources possible and with an important part of its territory already occupied (housing, services, public facilities, diverse modes of transportation and an important industrial area) on the other hand; **Santa Maria da Feira** has a considerable part of the territory (almost two thirds) dedicated to natural reserves, thermal-water areas and yet to be built zones, where one primary mode of transportation: road network and multiple industrial plants not concentrated in industrial areas.

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