SOCIO-ECONOMIC FEASIBILITY OF GREENING CAMPO GRANDE'S, ENTRECAMPOS' AND AVENIDA DA REPÚBLICA'S ROAD TUNNELS IN LISBON

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MARCH 2018

ABSTRACT

The green infrastructures have been widely spread with the purpose of countering the negative effects of urbanization, since they contribute with several benefits that go way beyond their aesthetical value. However, the variability of conclusions related to their economic feasibility generates discussion between researchers, investors and suppliers, leading to the need of cost-benefit analysis (CBA).
This dissertation proposes a methodology for an economic feasibility analysis of green systems in transport infrastructures. Such methodology is oriented according to the life cycle of those systems and organizes their costs and benefits via an incremental analysis, using economic appraisal components and transport infrastructures dimensions.
Applying this methodology to the road tunnels between the avenues of Campo Grande and Avenida da República, in Lisbon, five green solutions were evaluated. The CBA concludes that, for a time span of 40 to 50 years and a refresh rate of 4,79%, there is economic feasibility for four of these, for which the net present value (NPV) ranges from 33.961 € to 5.079.356 €.
Parameters like refresh and inflation rates, financial costs, interior noise reduction, creation of new areas and aesthetical improvement have a significant impact on the NPV, generating deviations between −27% and 16% for insider solutions and from −344% to 216% for outsider ones.

Keywords:
Transport Infrastructures
Road tunnels
Green roofs/walls
Economic Feasibility
Cost-Benefit Analysis

1. INTRODUCTION

1.1. Background and aim of the study

Urban environments have been experiencing a population increase, as well as a raise in what concerns to the movement of goods, causing the gradual replacement of green spaces with mostly impermeable surfaces [1]. Transport infrastructures, which are structural elements of urban centers, reveal essential functions, especially when most of the population works outside of their area of residence. These grow according to the population's mobility needs and keeping up with the cities' growth. The choice of private vehicles, not only increases the atmospheric and noise emissions, but also leads to traffic congestion, which heightens the social stress levels, endangering both the health and well-being of roadways' users and inhabitants of surrounding areas, ultimately damaging the surrounding ecosystems as well [2].
Green roofs and green walls, which have distinct installation plans and constructive methods [3; 4], have been gradually developed to counter the negative effects of urbanization, via the removal of atmospheric pollutants [5-7] and noise levels [8; 9] as well as an increase in the users' comfort [10]. Furthermore, they also contribute to the heat island effect mitigation [11; 12] and runoff management [13-16], positively affecting both the health and productivity of the citizens [8].
Even though these systems require additional initial charges when compared to conventional solutions, green infrastructures also include benefits such as aesthetical and functional improvements [17], the increase of the lifespans of waterproofing membrane, coatings and structural support [18-21], as well as the creation of jobs [22].
This dissertation intends to respond to the lack of studies related to the economic evaluation of green roofs/walls in transport infrastructures, especially road ones, through a CBA methodology applied to the road tunnels existent between the Campo Grande's avenues and Avenida da República, in the city of Lisbon, Portugal.

1.2. Transport infrastructures

This study focuses on roadways in which lower passages or road tunnels are included. The European transport system faces some obstacles mainly due to:

1) The different growth of the several types of transport, with the road ones being the most representative in transport of passengers (road - 79%, rail - 6% and air - 5%) and goods (road - 44%, maritime - 41%, rail - 8% and fluvial - 4%) [2];
2) Approximately 10% of Europe's road network being daily affected by congestion, with external costs of 0,5% of community gross domestic product (GDP) [2];
3) The large amount of fuels derived from petroleum that this sector consumes, which leads to a rise of atmospheric pollutants concentration that in 2014 registered the highest percentage of emissions in Europe (24,3%) when compared to other sectors [23]. Emissions of CO_2 represent 20% of all pollutants emitted,

with road transport possessing the highest percentage (71%) [2]. In Portugal, road transport systems are the leading source of CO emissions (about 60%) and NO_x (about 45%) [24];

4) The insecurity on roads, since road transports account for the largest number of accidents with the highest costs in human lives. In Portugal, since 2012, the number of road accidents has been steadily increasing, with the year 2017 registering 33 315 accidents with 378 human deaths [25].

1.3. Green infrastructures

Traditional green roofs have a multilayer disposal, composed by a waterproofing membrane, a root barrier, drainage and filter layers, as well as a growing medium for the plants. These solutions are generically classified according to their components and maintenance needs. Green roofs are classified as extensive, semi-intensive and intensive [3], whereas green walls can be living walls and direct or indirect green walls [4]. Extensive green roofs have a thin growing medium and a small variety of plants, therefore they require less maintenance and can be used in structures with lower load capacities. Hence, they generate lower costs during their use phase when compared to the intensive ones that, by including a wide diversity of plants due to the greater depth of substrate they present, require more recurring maintenance during their lifespan. The semi-intensive green roofs involve features between the extensive and intensive solutions [26; 27].
Direct green walls are the simplest and cheapest to set up, but they can be aggressive towards the support, damaging it during the maintenance of the system. With the indirect ones this situation does not occur, since cables or meshes of steel, wood, plastic or aluminum are used, keeping the roots of the plants away from it. Living walls are more complex, therefore more expensive than green walls, featuring configurations by means of prefabricated modules or felt layers [28].

1.4. Green urban transport infrastructures

Several researchers have performed CBAs on the installation of green infrastructures in buildings [8; 29-35]. Despite the results' variability, these studies highlight relevant benefits in long-term permanence, air-conditioned buildings. However, studies related to green systems applied on infrastructures such as road tunnels are scarce, and most of CBA conclusions presented in literature are unsuitable to this study, due to the fact that road tunnels do not require thermal insulation and refrigeration systems. Therefore, a methodology for CBA of greening road tunnels is presented, including relevant costs and benefits to this study, as seen in **section 2**.

2. Methodology

The proposed methodology (**Fig.1**) aims to discuss the economic feasibility of greening urban road tunnels by performing a CBA according to the green systems' life-cycle and categorising them into financial, economic and socioenvironmental components. Complementarily, the infrastructure, user and environmental dimensions are assessed independently according to the colours' gradation presented in **Fig.1**'s label. Both categories (economic analyses and transport dimensions) follow an incremental pattern.

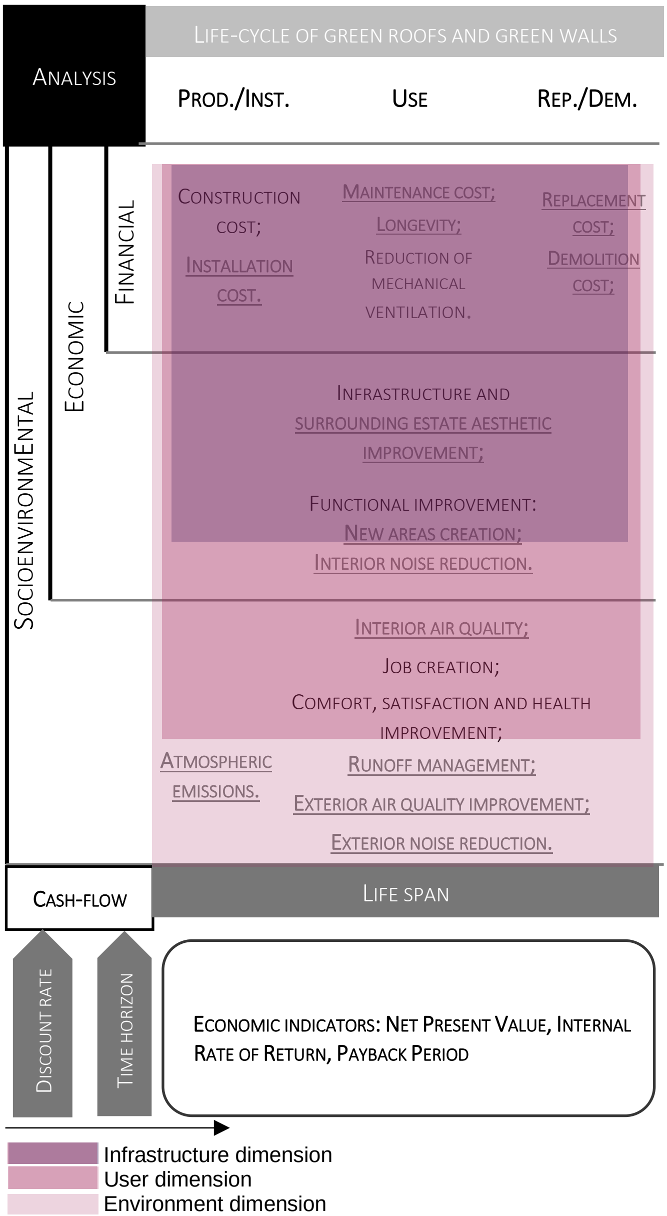


Fig.1 Methodology proposal for cost-benefit analysis

The previous costs and benefits (**Fig.1**) are described below, based on some researchers' conclusions.

Production and Installation phases

60 to 65% of the total sales of green roofs/walls come from the plants, growing medium, waterproofing and drainage layers production cost, meaning that only 35 to 40% is related to their installation [36]. Green roofs usually require a higher

initial investment when compared to the conventional ones, with the intensive green roofs being more expensive than the extensive ones [31]. However, variables such as geographic location, climatic conditions and the work's height should be considered, since more adverse climates require specific plant species and higher heights entail costs related to lifting, material transport and skilled labour [27]. The complexity of the system, as well as its size, are also important factors, with greater areas corresponding to lower installation costs per m^2 [26; 37]. On the other hand, the installation of green walls implies higher costs when compared to green roofs [38]. Even though indirect green walls usually have an installation cost lower than 75 $€/m^2$, living walls often assume values of more than 350 $€/m^2$ [39; 40].

Concerning atmospheric emissions, it was estimated that a CO_2 emission costs between 0,078 to 0,123 $€/m^2$ to produce extensive green roofs and between 0,033 and 0,078 $€/m^2$ for the intensive, while the NO_x emission costs vary between 13.133 to 20.734 $€/m^2$ the extensive solution and between 5.515 and 13 $€/m^2$ for the intensive one [41].

Use phase

Generally, green infrastructures require higher maintenance levels and costs than the conventional ones, with the living wall systems being the most expensive. Intensive green roofs imply more costs than the extensive ones, since they have a larger diversity of plant species [27; 35, 36, 42]. However, some researchers claim that the lifespan increase of the waterproofing membrane/coatings make up for these costs, given its lower exposure to aggressive agents, that may exceed two to three times the average of conventional infrastructures [18-20; 43-45].

Green infrastructures increase the value of real estate's rents and transport infrastructures with green roofs/walls tend to be valued due to benefits like aesthetical improvements [30, 46, 47], interior noise reduction [8, 32, 38] and the creation of new areas [30, 48]. These benefits vary according to the infrastructures' visibility and accessibility [49, 50]. Green areas also influence productivity and foster job creation, not only because of the construction, installation and maintenance processes, but also due to the new areas which are eventually created [8, 22, 51].

Several studies show that green spaces in urban environments mitigate people's illnesses by reducing anxiety and discomfort levels [8, 18-20], which are important parameters, given the stress caused by traffic levels near roadway tunnels. Besides, vegetation also enhances air quality, improving citizens' health [30, 53, 54].

Greening roadway tunnels attenuate noise on the surroundings, avoiding negative consequences for public health in the long term [8, 9] and contribute to both water quality improvement and runoff management, reducing expenses in drainage systems [8, 30].

Replacement or demolition phase

At the end of green infrastructure components' life cycle, they can be reused (except the waterproofing layer) [30, 35, 55] or landfilled [17, 30, 35, 18], according to the technological availability in cities.

3. CASE STUDIES

3.1 Main characteristics

The case studies to be analysed are the Campo Grande's, Entrecampos' and Avenida da República's road tunnels. These are important infrastructures since they are located near commercial and academic centres, parks, train stations and offices, allowing the simultaneous inbound and outbound flow of vehicles.

Despite being infrastructures with great value and located in the centre of the city, there are several problems mainly related to the lack of maintenance that can compromise their functionality, such as the coatings getting detached and worn out, as well as the presence of dirt, biological formations, invasive herbs and moss. In addition, graffiti, traffic congestion, underused areas and excessive atmospheric emissions inside the road tunnels are also observed.

Apart from the infrastructures' problems, there is also an uncomfortable atmosphere related to the high levels of exterior noise and polluted gases emitted mainly by the road traffic.

FIG.2: CAMPO GRANDE'S TUNNEL (A), ENTRECAMPOS' TUNNEL (B) AND AVENIDA DA REPÚBLICA'S TUNNEL (C)

3.2 Fieldwork

Short-term vehicle and pedestrian counts were performed at various strategic locations in the case studies, in order to clarify the users' preferred routes and achieve an optimal quantification of benefits (**section 4.2**). These counts, with an average duration of 15 minutes in each location, were performed in July, more precisely between the 14th and 27th of that month, at the period between 5 and 6 pm for the vehicles and between 8 and 9 am for the pedestrians.

Based on those short-term counts, the annual average daily traffic (AADT) was calculated, according to equation 1,

$$AADT_{estimated,i} = VOL_i \times 60 \times 24 \times F_{M,j} \times F_{D,j} \times F_{H,j} \quad (1)$$

where:

$V_{OL,i}$ – road or pedestrian volume traffic measured in one minute at location i;
$F_{M,j}$ – monthly adjustment factor for the roads' group j;
$F_{D,j}$ – daily adjustment factor for the roads' group j;
$F_{H,j}$ – hourly adjustment factor for the roads' group j;

The estimated AADT for each location is represented in **Fig.3.**

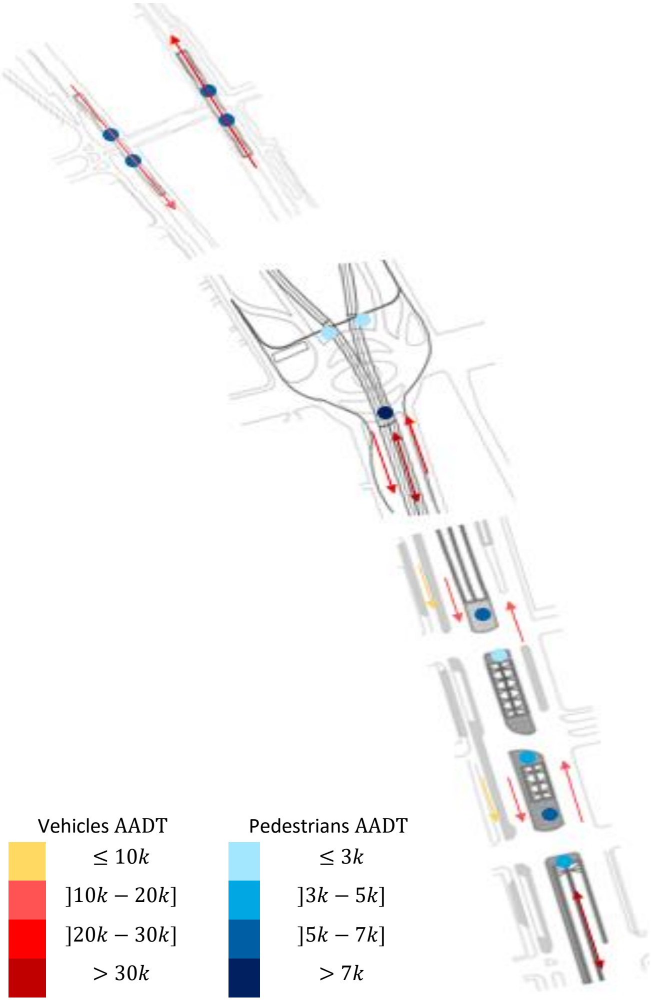


FIG.3: VEHICLES AND PEDESTRIANS DAILY FLOW

4. COST-BENEFIT ANALYSIS

The proposed methodology (**Fig. 1**) is adjusted to the parameters that are effectively analysed and quantified in the CBA of the case studies. Underlined parameters are valued due to their representativeness.

In the financial analysis, costs related to the construction of green infrastructures aren't considered since they are already included in the installation prices. Furthermore, benefits from the reduction in mechanical ventilation aren't considered either, due to the Portuguese legislation for urban road tunnels with lower extensions than 500 m [57] .

In socioenvironmental analysis, parameters related to comfort, satisfaction and health are not quantified, and neither is job creation, due to the subjectivity associated to external variables that are not the object of study.

4.1 Solutions proposal

According to the case studies performance and needs, five greening solutions are suggested, as seen in **Table 1**. Each solution includes two alternatives according to their typology: each vertical system (solutions I.2, III.1, III.2, III.4) is classified as a green wall (GW) or living wall (LW) and each roof greening system (solutions II.3) as extensive (EGR) or intensive (IGR) green roof. They have as main purposes the enhance of aesthetics, noise and atmospheric pollution removal, as well as the use of areas.

Solutions are selected by the representativeness of their benefits in two intervention areas: external or internal environment (**Table 1)**. Then, some assumptions are made based in Portuguese companies' data and literature review in order to quantify the green infrastructures' underlined costs and benefits, according to the proposed methodology (**Fig.1**). The quantification's summary is also presented in **Table 1**.

4.2 Methodology applied to the chosen solutions

Production and installation phases

Installation costs are based on data provided by companies such as Neoturf and Landlab (companies operating in Portugal, dedicated to greening areas), while pollutant emission costs are based on literature review. Both are punctual costs presented in the initial year.

Use phase

Maintenance costs are annual and quantified identically as the installation costs.

The longevity benefit, existing for the 35th year, is merely assumed for the vertical green solutions (I.2, III.1, III.2, III.4), since the limestone that covers Avenida da República's tunnel is durable.

Aesthetical improvement via green systems' installation is only quantified for the surrounding infrastructures, such as nearby buildings and the Entrecampos' station. Aesthetical improvement percentages from literature [30, 46, 47] associated with the average prices, in $€/m^2$ [19; 20], of the apartments near to solutions I.2 and II.3, leads to this benefit (presented only at the initial year). The aesthetical improvement value of Entrecampos' station is performed annually and is based in short-term counts [58]

The interior noise reduction was quantified based on the daily pedestrian flow near the critical noise sources (tunnels' openings). Therefore, using the AADT presented in **Fig. 3** and the decibel reductions performed via green infrastructures [8; 9], allied with the road noise costs per exposed pedestrian in Portugal [59], it is possible to quantify the benefits associated to solutions III.1, III.2 and III.4. In solutions I.2 and II.3, the external noise reduction leads to a lower investment in the intervention measures needed through Lisbon's city council [60].

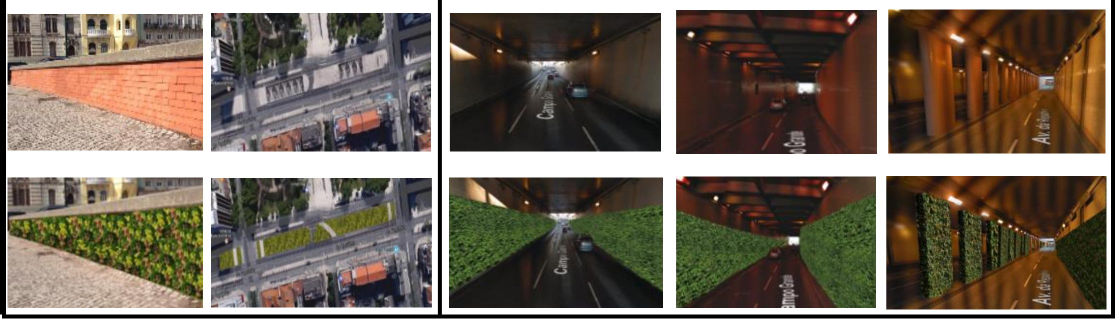
The benefit related to the creation of new areas is only associated to IGR solution. In order to quantify this benefit, the renting stores' cost are consulted [61]. Solutions III.1, III.2 and III.4 benefit the removal of pollutants and are obtained through the equivalent CO_2 price in The European Union Emissions Trading Scheme (EU-ETS), defined by the Kyoto Protocol [62]

Green roof solutions (II.3) prevent water inlet and leakage inside the tunnel. Based on data regarding precipitation episodes in Lisbon [63] one can obtain the volume of water retention. This amount of water does not intercept drainage systems, leading to lower costs [64].

Replacement or demolition phase

Replacement and demolitions costs are quantified similarly to the previous financial costs (installation and maintenance costs). Besides the integral replacement performed at the end of green infrastructures' life-cycle, punctual replacements are assumed. The drainage layer requires a replacement at the 25th year for solutions II.3 and in what concerns to vertical solutions (I.2, III.1, III.2, III.4), a certain amount of plant species need annual replacement.

TABLE 1: PROPOSED SOLUTIONS AND BENEFITS OBTAINED



			I.2		II.3		III.1		III.2		III.4	
SOLUTIONS	BEFORE / AFTER											
			EXTERNAL ENVIRONMENT				INTERNAL ENVIRONMENT					
BENEFITS			AESTHETICS IMPROVEMENT AIR RENEWAL FACADE PROTECTION		RUNOFF MANAGEMENT NOISE REDUCTION (OUTSIDE) SENSE OF COMFORT USER'S SATISFACTION		USER'S SATISFACTION NOISE REDUCTION (SOUND ABSORPTION) AIR RENEWAL				TRAFFIC CALM AESTHETICS IMPROVEMENT SENSE OF SECURITY FACADE PROTECTION	
AREA (m^2)			500		3033		595,2		960		936	
TYPOLOGY			GW	LW	EGR	IGR	GW	LW	GW	LW	GW	LW
Production/ Installation	Atmospheric emissions ($€/m^2$)	CO_2	0.056	0.1	0.123	0.078	0.056	0.1	0.056	0.1	0.056	0.1
		NO_x	10	15	20.734	13.133	10	15	10	15	10	15
	Installation costs ($€/m^2$)		90	600	50	120	90	600	90	600	90	600
Use	Maintenance costs ($€/(m^2.year)$)		3	36	3	9	3	36	3	36	3	36
	Longevity ($€/m^2$)		27	27			25	25	25	25	25	25
	Aesthetic improvement	Buildings ($€/m^2$)	106.42		183.13	244.17						
		Entrecampos' station ($€/year$)	258.8		887.29	1 183.06						
	New spaces ($€/ano$)					86 520						
	Interior noise reduction ($€/ano$)						94 307.63	235 769.08	25 364.33	63 410.82	48 369.76	120 924.41
	Runoff management ($€/ano$)				305.35	469.34						
	Interior air improvement ($€/ano$)	CO_2					0.012					
		NO_x					0.051					
	Exterior noise reduction ($€/m^2$)		2 811.32		14 056.58							
Rep./ Dem.	Replacement costs ($€/m^2$)		500	490	45	100	500	490	500	490	500	490
	Demolition costs ($€/m^2$)		120	200	20	70	120	200	120	200	120	200

*Demolition costs are not considered in analysis, since they are included in replacement costs

5. ECONOMIC FEASIBILITY STUDY: RESULTS AND DISCUSSION

Green infrastructures' costs and benefits are considered over their whole life-cycles. For vertical systems, a period of 50 years is analysed, whereas the green roof systems are studied over 40 years. The refresh rate is set at 4,79% (according to **Eq. 2**) to update the costs and benefits at the investment's time.

$$DR = (1 + r_{return})(1 + r_{risk})(1 + r_{inflation}) - 1 \qquad (2)$$

Rate of return, rate risk and inflation rate are, respectively:

r_{return}: 0.234% according to German bund, benchmark in Eurozone (usually used risk free interest rate) [65].

r_{risk}: 2.5% for a medium risk investment (annual risk premium) [66].

$r_{inflation}$: 1.5% according to 2019 prevision [67].

This feasibility study is performed for financial, economic and socioenvironmental analyses, and is based in the previously mentioned CBA. The analyses are presented separately according to the complexity of the green systems. The extensive green roof is named II.3.a and the green wall solutions are named I.2.a, III.1.a, III.2.a, III.4.a, whereas the intensive green roof solution is II.3.b and living wall solutions are I.2.b, III.1.b, III.2.b, III.4.b.

5.1 Financial analysis

Fig. 4 and **Fig. 5** show updated non-cumulative and cumulative cash flows, respectively. As expected, there is no financial feasibility in any of the studied solutions (**Fig. 5**), since most of the cash flows are negative, thus representing costs, except for the 35th year for the green wall solutions, due to their life period increase (**Fig.4 A**). This situation does not occur to the living wall systems, due to their requirements in annual maintenance and replacement (**Fig.4 B**). The green roof solutions, not having any financial benefit, do not present any positive inputs.

In general, the negative peaks are associated with the initial and final years, when the systems are installed and replaced, respectively, and at the 25th year for the green roof solutions, due to the drainage layer replacement.

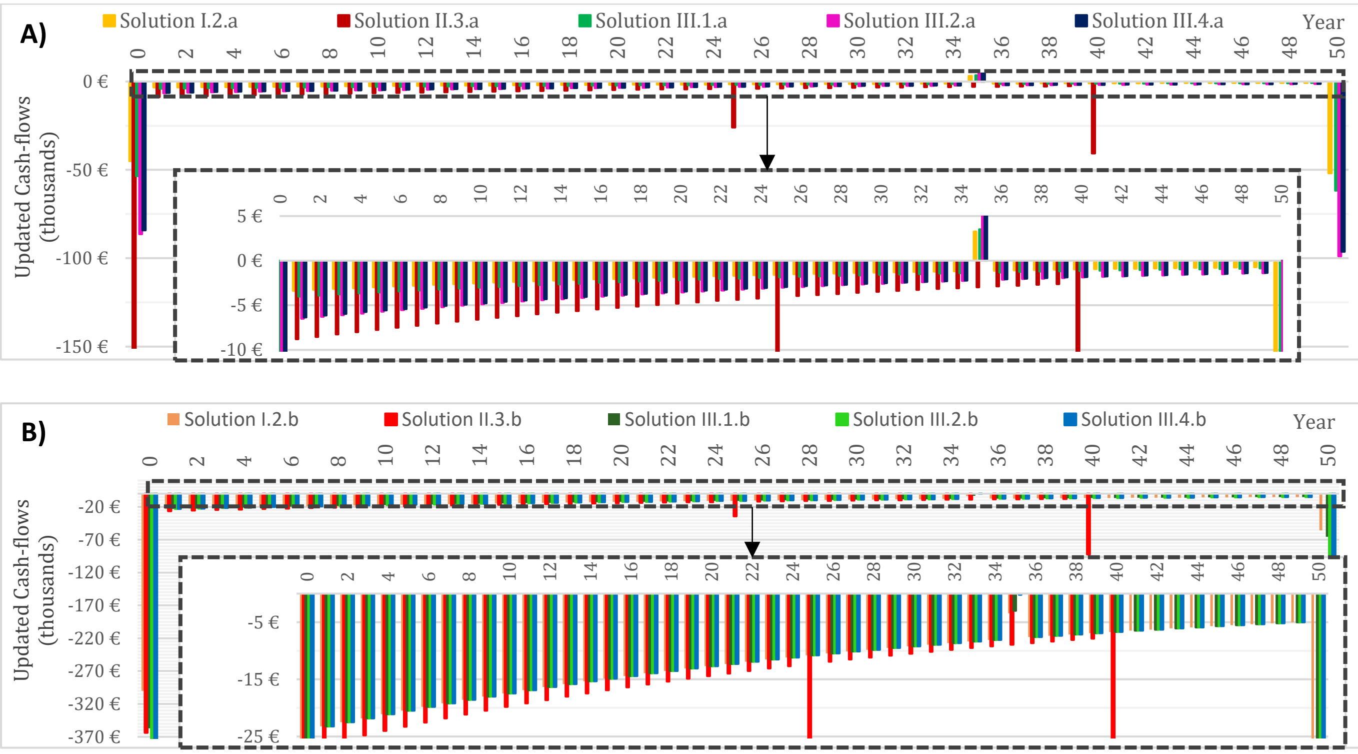


FIG.4: UPDATED NON-CUMULATIVE CASH FLOWS OF THE FINANCIAL ANALYSIS

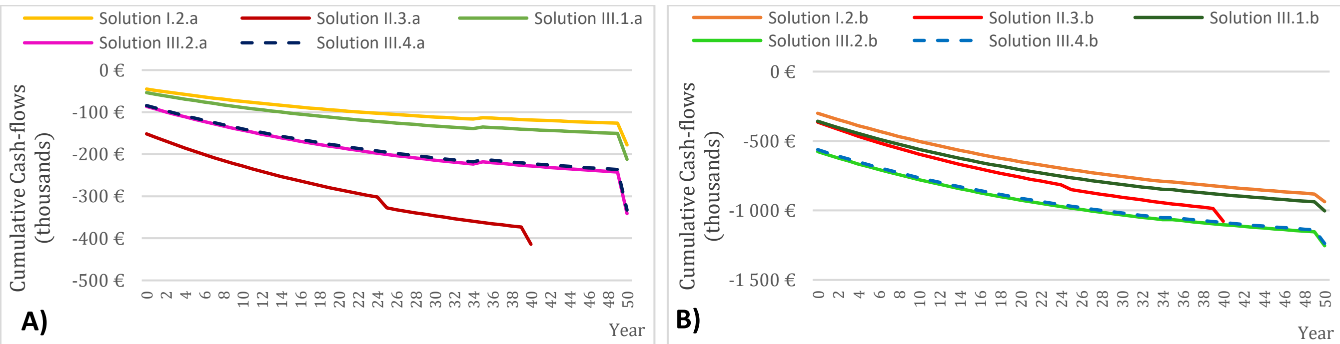


FIG.5: UPDATED CUMULATIVE CASH FLOWS OF THE FINANCIAL ANALYSIS

5.2 Economic analysis

Unlike **Fig. 4**, the updated non-cumulative cash flows of the economic analysis (**Fig. 6)** shows mostly positive inputs, representing benefits for the majority of the solutions.

It is seen in **Fig. 6** that solutions with green roofs only present a positive input in the initial year, due to the aesthetical improvement benefit that they provide in the surrounding buildings. However, considering that this is a punctual benefit, both alternative solutions (II.3.a, II.3.b) only present negative updated cash-flows in the remaining years of the life-cycle. In opposition, apart from solutions I.2, every proposal present positive inputs during its life-cycle, due to the inner noise reduction benefit. Therefore, as shown in **Fig. 7,** only solutions I.2 reveal their economic infeasibility, which means that even the green roof solutions, with mostly negative updated non-cumulative cash flows (**Fig. 6)**, make up for the financial costs through the aesthetical improvement and recreational benefits.

5.3 Socioenvironmental analysis

The socioenvironmental analysis involves both social and environmental values. **Fig. 8** and **Fig. 9** represent updated non-cumulative and cumulative cash flows, respectively, and its trend and cash flows are similar to the previous economic analysis, which denote the higher weight of economic parameters.

As shown in figures (**Fig. 8** and **Fig. 9)** solutions I.2 continue to present negative updated cash flows in the socioenvironmental analysis (except in the initial year for solution I.2.a), meaning that these are the only solutions that are not viable at the end of their 50 year life-cycles.

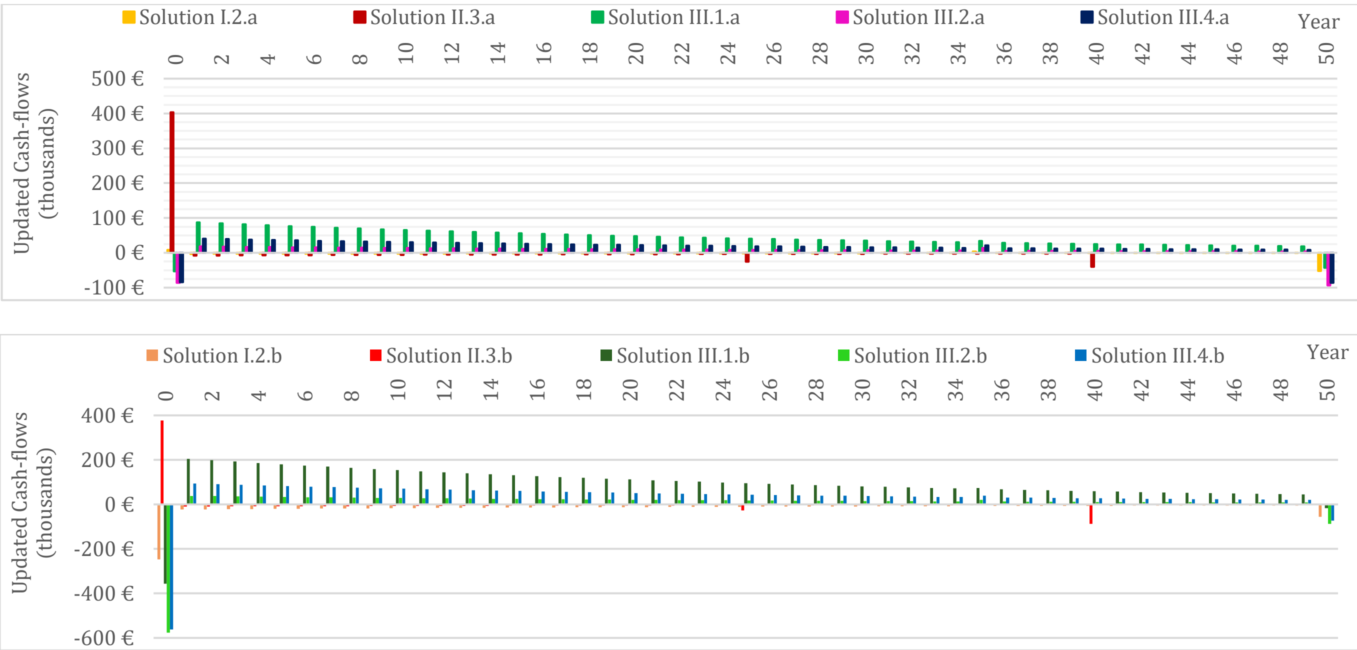


FIG.6: UPDATED NON-CUMULATIVE CASH FLOWS OF THE ECONOMIC ANALYSIS

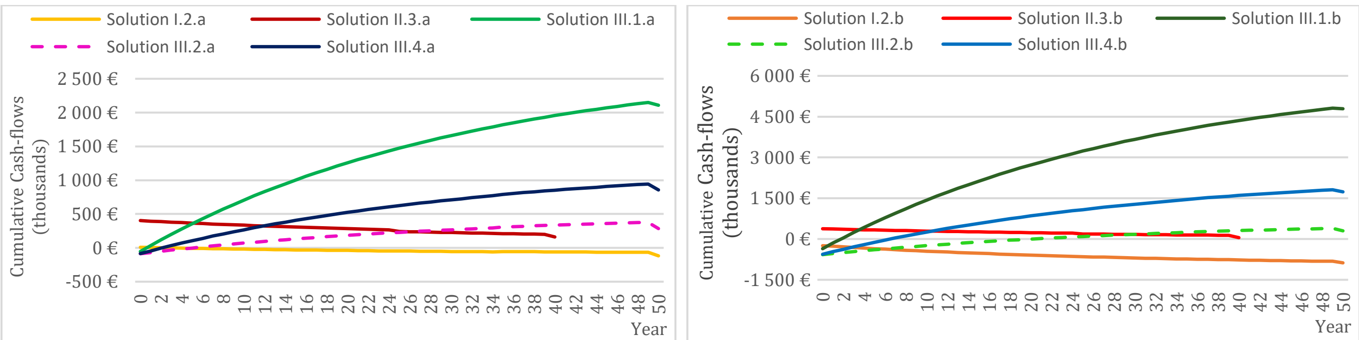
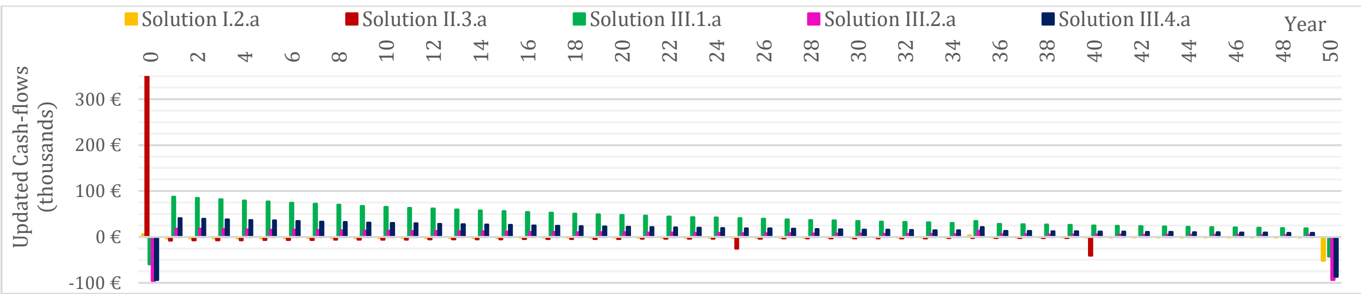


FIG. 7: CUMULATIVE CASH FLOWS OF THE ECONOMIC ANALYSIS



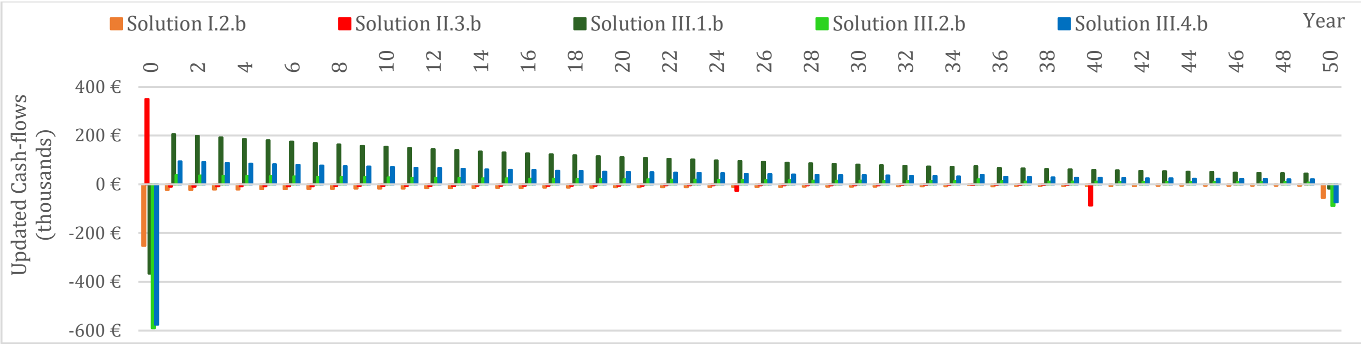


FIG. 8: UPDATED NON-CUMULATIVE CASH FLOWS OF THE SOCIOENVIRONMENTAL ANALYSIS

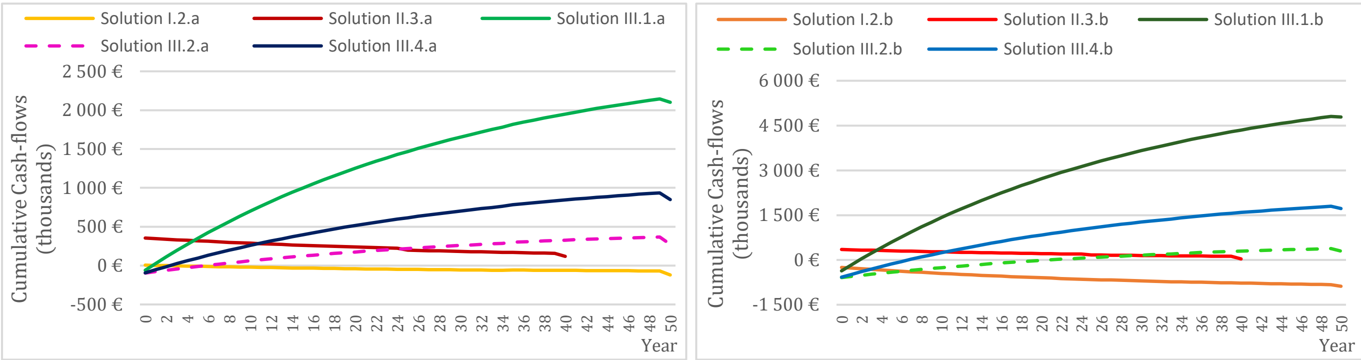


FIG. 9: CUMULATIVE CASH FLOWS OF THE SOCIOENVIRONMENTAL ANALYSIS

5.4 *Summary discussion*

Fig.10 summarises the NPV of all the analysed solutions. Presented values include both benefits and costs for all studied life-cycle phas es (installation, use and replacement or demolition) and dimensions (infrastructure, user and environment).

	I.2		II.3		III.1		III.2		III.4	
	I.2.a	I.2.b	II.3.a	II.3.b	III.1.a	III.1.b	III.2.a	III.2.b	III.4.a	III.4.b
Financial Analysis	-177 839	−936 870	−414 021	−1 077 629	−212 089	−1 003 005	−341 218	−1 253 830	−332 688	−1 237 240
Economic Analysis	-118 064	−877 096	161 146	49 538	2 107 182	4 795 173	282 557	305 607	856 851	1 736 607
Socioenvironmental Analysis	-120 281	−881 834	118 734	33 961	2 102 119	4 787 108	274 390	292 599	848 889	1 723 924

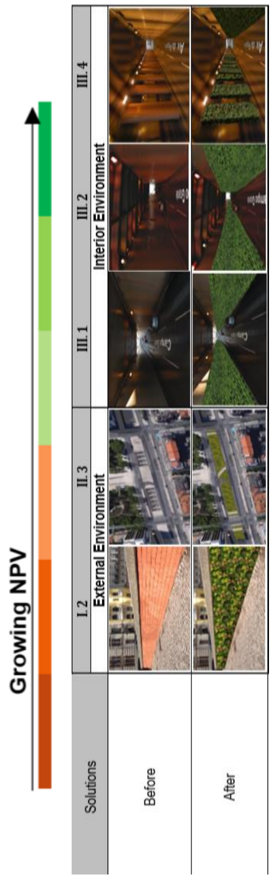


FIG.10: NPVS, IN €, OF PROPOSAL SOLUTIONS

According to section **5.1**, and as presented in **Fig.10**, there are no positive financial NPVs in any of the proposed solutions, since the parameters of this analysis are mainly costs. However, in economic terms, most of the solutions are viable, since the existing benefits outweigh the costs observed in the financial analysis, with the vertical solutions inside the road tunnels (III.1, III.2, III.4) being the holders of most significant NPV values. As seen in **Fig.10**, solution III.1.b is the one with the highest NPV (of about 4,8 million euros) due to the interior noise reduction benefit (user dimension) associated with the highest flow of daily pedestrians (**Fig.** 3). In fact, the absence of this benefit in solutions I.2 makes these proposals economically unviable, since the benefits resulting from aesthetical improvement (environment dimension) do not make up for the investment, maintenance and replacement costs. In addition, since these present negative socioenvironmental NPVs, they reveal themselves as not feasible at the end of their life-cycles (50th year).

The living wall solutions inside the road tunnels (III.1.b, III.2.b, III.4.b) are those with the higher NPV values and, therefore, higher absolute gains when compared to their alternative ones, (e.g. solution III.1.a is an alternative to solution III.1.b). However, the solutions with green walls are those that present the most significant relative gains, in comparison to their alternatives. III.1.a is the most representative solution, with socioenvironmental gains about 39 times higher than the corresponding investment. This means that NPV only indicates whether or not a solution is viable based on its income and costs, obtaining different conclusions regarding the profitability of the project when other economic indicators are used. Hence, opting for solutions with greater absolute or relative gains depends on the investor's objectives as well as his initial budget.

The cost difference between intensive (II.3.b) and extensive (II.3.a) green roofs is 663 608 €, while social and environmental gains are about 3.5 times higher for the extensive typology, meaning that the benefits of aesthetical improvement and creation of new areas on solution II.3.b do not have such a significant weight, considering the additional costs involved. Additionally, the cumulative cash-flows from the socioenvironmental analysis of these solutions tend to decrease over the years, as seen in **Fig. 9.** This is a result of considering the benefit of aesthetical improvement of surrounding buildings in the installation year, instead of annually, leading to future negative cash-flows in the following years.

It is verified that the interior noise reduction is the variable that represents the benefit with the highest order of magnitude (in the order of millions of euros), that belongs to the user dimension.

It should also be pointed out that these projects tend to have higher internal rate of return and low return on investment, due to the existence of significant returns in the first year, when parameters with some subjectivity are considered (user and environment dimensions).

5.5 Sensibility analysis

Even with detailed market research, economic feasibility studies will always include some uncertainties. Therefore, sensibility analyses are carried out in order to achieve higher safety margins. A -10% to 10% fluctuation is attributed to each parameter considered in the CBA for each studied solution, observing that the refresh and inflation rates, financial costs, interior noise reduction (for the inner solutions), creation of new areas (for the intensive green roof) and aesthetical improvement (for the outer solutions) have a significant impact on the NPV.

Fig. 11 and Fig. 12 show two examples of socioenvironmental influence in NPV for solution II.3.b (intensive green roof) and solution III.1.b (living wall solution).

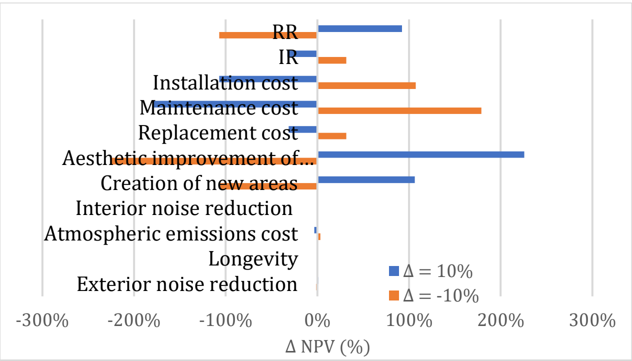


FIG.11: SOCIOENVIRONMENTAL PARAMETERS' INFLUENCE ON NPV OF SOLUTION II.3.B (OUTER SOLUTION)

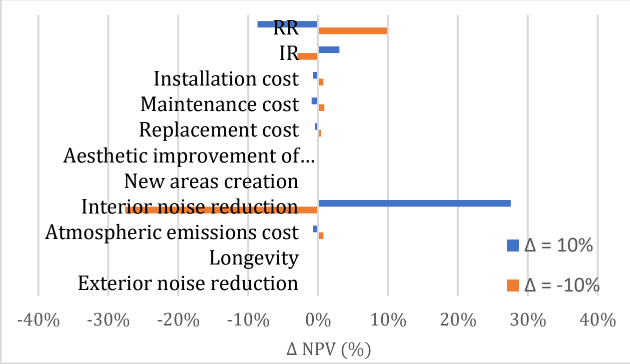


FIG.12: SOCIOENVIRONMENTAL PARAMETERS' INFLUENCE ON NPV OF SOLUTION III.1.B (INNER SOLUTION)

Based on the more elastic parameters, three different scenarios are established: most probable (base scenario), optimistic and pessimistic, as seen in **Fig. 13**. It is verified that the solutions I.2, even in an optimistic scenario, are still unfeasible and that solutions II.3 reveal themselves as no longer viable in a pessimistic one. The remaining solutions do not present modifications that could compromise their feasibility in any of the scenarios.

Thus, there's an average NPV reduction of 27% from the base scenario to the pessimistic one and the same indicator presents a 16% increase when switching from the base scenario to the optimistic one, when referring to inner green wall solutions (III.1, III.2 and III.4).

Outer solutions (I.2 and II.3) imply an NPV reduction of 344% and an increase of 216%, when switching from the base scenario to the pessimistic one, or to the optimistic scenario, respectively. This high fluctuation is observed due to the fact that a very high aesthetic value benefit is considered in the later solutions, mainly II.3.

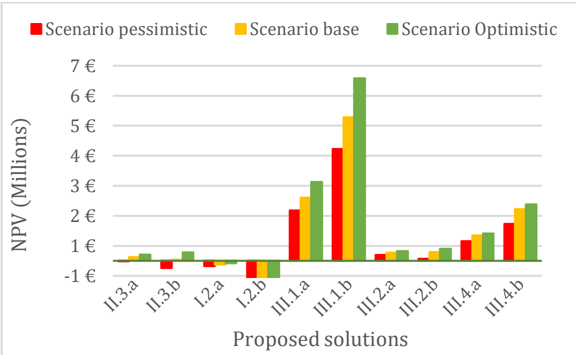


FIG. 13: SOCIOENVIRONMENTAL NPV FOR EACH SCENARIO

6. CONCLUSIONS

The proposed methodology for the feasibility study of greening the roadway tunnels between Campo Grande's avenues and Avenida da República is functional for four of the five solutions studied. Financially, all solutions are unfeasible, with costs ranging from 177 839 € (I.2.a) to 1 253 830 € (II.3.b). In economic terms, costs range from 118 064 € (I.2.a) to 877 096 € (I.2.b) whereas gains fluctuate between 49 538 € (II.3.b) and 4 795 173 € (III.1.b). In a socioenvironmental analysis, costs are between 120 281 € (I.2.a) and 881 834 € (I.2.b) and gains range from

33 961 € (II.3.b) to 4 787 108 € (III.1.b). It is therefore concluded that, at the end of their life-cycles, only solutions I.2 do not present socioenvironmental feasibility. The variable referring to the interior noise reduction (user dimension) provides gains after 50 years with the highest order of magnitude, in the order of millions of euros, followed by the creation of new areas (infrastructure dimension) and aesthetical improvement (environment dimension), both in the order of thousands of euros.

The living wall solutions have higher NPVs and therefore more significant absolute gains, when compared to their respective alternatives. The solution which stands out the most is the one that involves the use of living walls inside the tunnel of Campo Grande (III.1.b), with an absolute gain of about 4,8 million euros. On the other hand, it is its alternative solution with green walls (III.1.a) that represents the highest relative gains, which are around 39 times higher than the corresponding costs. Thus, opting for the solution which has the higher absolute or relative gains depends on the investor's objectives and initial budget. In what concerns to solutions with green roofs (II.3), it is verified that the intensive one (II.3.b) possesses the lowest NPV.

Parameters like refresh and inflation rate, financial costs, interior noise reduction, recreation and aesthetical improvement have a significant impact on the NPV, generating deviations between -27% and 16% for insider solutions and from -344% to 216% for outsider ones.

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