ECONOMIC EVALUATION OF GREEN ROOFS INSTALLATION IN BUILDINGS

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ABSTRACT

Green roofs have been proposed as an efficient tool to combat urbanization problems, as they can help to achieve sustainable built environments and improve buildings performance. This paper uses assumptions based on a literature review to develop an economic evaluation of the life cycle of green roofs compared with the alternative scenario of a traditional roofing at a city and building level. This evaluation was made at 3 levels: financial, economic and socio-environmental analysis. The first level considers the construction, maintenance, replacement and demolition costs and private benefits as discount on fire insurance, energy consumption, improvement of photovoltaic performance and urban rooftop farming. The second level considers the economic gain associated with increase of property value, aesthetics, recreation and sound insulation. The third level considers social benefits related to storm water management (water quality enhancement and flood risk control), noise reduction, air pollution removal, mitigation of urban heat island effect, public health, ecological preservation and job creation.

The scale of this analysis required buildings classification in terms of age, roof type, use and repair needs. The study confirmed the economic feasibility of green roofs in long term at a social level but not at a private level. The net present value of the implementation of green roofs in Lisbon is about 3.369 million euros. A sensitivity analysis was performed to the parameters involved and it was concluded that the property value, aesthetics, recreation, sound insulation, discount rate and air quality have the highest influence.

Keywords: Green roofs, Economic evaluation, Comparative analysis, Traditional roofs, Lisbon.

1. INTRODUCTION

An intense urbanization process is causing serious environmental problems as it damages ecosystems, and therefore, affects the quality of people's lives [1]. The construction industry is responsible for a significant part of the world's energy consumption, which involves pollutant emissions and use of natural resources. Besides, urban areas are being built at the expense of green spaces, resulting in large impermeable surfaces [1–3]. To reduce the damage created, environmentally friendly practices have been introduced, including green roofs. Green roofs are a way of restore vegetated areas to the urban environment while improving buildings performance [2]. Green roofs are classified as extensive, semi-intensive and intensive according to their characteristics, purpose and type of vegetation [4]. Extensive roofs have a thin growing medium thickness, up to 20 cm thick, and small plants. Therefore, they are lighter and suitable for sloped roofs and structures with lower loading capacity, where the access to people is limited. As extensive roofs also assume self-maintenance and reduced irrigation needs, their costs become lower [2–4]. On the contrary, an intensive roof has a relatively deeper soil, usually higher than 15 cm. Thereby, their heavier weight may require a reinforced structure which is associated to additional costs [2]. It also implies a constant maintenance as it is often an accessible area [4]. Finally, the intermediate solution of semi-intensive roofs have a growing medium with thicknesses between 12 and 50 cm, which allows the application of a greater variety of plants than extensive and less than intensive roofs [4]. A multi-layer green roof system is more usual and it includes the following layers: vegetation, substrate, filter, drainage, membrane protection, root-resistant and waterproofing membrane and support. In some cases it can be added additional layers such as thermal insulation, irrigation system and other filters depending on the needs [2, 5].

Despite their benefits, greening the roofs requires costs that may make this solution less attractive to the building owner. This implies that benefits taken by both society and the private sector arise only from private investments. To assess whether the application of green roofs is economically valuable, all the operators should be taken into account. This way, this paper intends to develop a life-cycle cost-benefit analysis of green roofs systems in comparison to traditional roofs to determine which one of the solutions is more profitable. The economic evaluation was made at an urban and building level. At the urban level it was applied to a case study, the city of Lisbon.

2. COSTS AND BENEFITS OF GREEN ROOFS

Costs and benefits of green roofs depend on the scale of implementation in buildings and therefore can be distinguished as public and private costs and benefits.

Based on a literature review, those costs and benefits are presented and quantified below. The obtained results mainly differ due to parameters that influence the green roof's performance, particularly the location and climate.

2.1. Private costs and benefits

2.1.1. Installation cost

In a general way, extensive roofs are less expensive than intensive roofs. Apart from the roof type, installation cost also depends on the height of the building, construction method, labor and equipment cost, and location [3, 6]. This initial investment is significantly higher than traditional roofs, and therefore, represents a barrier to install green roofs [7]. The installation cost reduces as the roof area increases. It is important to note that if structural reinforcement it needed, additional costs will be expected.

2.1.2. Maintenance cost

A proper maintenance is required to ensure the expected performance and benefits of green roofs [6]. Similarly to the installation, the maintenance cost is higher in intensive roofs than in extensive roofs, associated to the irrigation needs [2, 6]. These costs are usually greater in the establishment period (growing seasons) during which this process is stricter [7].

2.1.3. Replacement cost

At the end of the roof's life, the waterproofing membrane is replaced and the majority of the other layers are recoverable. Therefore, the replacement cost becomes less expensive. Nevertheless, it depends on the roof type [7]. Some layers need to be replaced with some frequency as they have the following lifespan: insulation, 20 to 100 years; support, 30 to 50 years; and drainage system, 10 to 40 years [8].

2.1.4. Demolition cost:

Depends on roof's size, location, building characteristics and others. Some layers, such as the drainage system and the root-resistant membrane can be recycled [6].

2.1.5. Structural capacity

In a rehabilitation situation, the application of green roofs implies an additional weight that might exceed the load bearing capacity of the building structure. Considering that this may cause safety problems, it could be necessary to make some interventions involving extra costs. Those issues don't occur in reinforced concrete structures since they support 5 to 10 kN/m^2 extra loads (equivalent to a growing medium with 80 cm depth) [2]. The roof's slope, as well, has an important role in the technical viability of the green roof's installation. It has been recommended slopes no greater than 35º (only in extensive roofs) as they lead to substantial additional costs of installation [W1].

2.1.6. Energy consumption

Green roofs control the heat flow through the roof, therefore decreasing the energy needs [2]. The roof's energetic performance depends on the green substrate thickness, vegetation type, clime, precipitation, irrigation system, building characteristics as height, use and existent insulation [3, 9].

2.1.7. Sound insulation

As the roof's mass increases and the stiffness decreases, the green roof reduces the sound transmission through the roof. The substrate thickness is the most influencing parameter, but also the vegetation type [10], soil saturation [11] and the roof's previous insulation, especially in a rehabilitation context, since old buildings don't usually have that layer and so the increased insulation is more noticeable [12]. This benefit also depends on the urban environment, as they are useful near airports and under aircraft routes [10].

2.1.8. Roof's longevity

Green roofs increase the waterproofing membrane's life and efficiency, as they protect them from ultraviolet radiation, wind, impacts and temperature's variation [7]. With waterproofing membranes being the most important layers on roofs, as their lifespan increases, so does the roof's lifespan [2].

2.1.9. Fire performance

Green roofs are able, in certain conditions, to retard fire spread, mostly when saturated [4, 13]. This benefit depends on the roof type, substrate and vegetation characteristics like water retention capacity. Intensive roofs are more advantageous [4]. In that way, some companies apply a discount on the building's fire insurance, when roofs are greened [14].

2.1.10. Photovoltaic performance

Green roofs lower the temperature of the photovoltaic panels, increasing their efficiency. However, this benefit is not true when referring to intensive roofs due to excessive shading [15].

2.1.11. Urban rooftop farming

Taking advantage of the deep roofs substrate (reason why it isn't a benefit to extensive roofs), it's possible to grow vegetables and fruits such as: lettuce, kale, spinach, strawberry, blueberry, beans, and others [W2].

2.1.12. Building's sustainability

Due to most of the benefits already named and some named below, green roofs contributes to achieve buildings sustainable certifications [2].

2.2. Social costs and benefits

2.2.1. Storm water management

The green roof's substrate retains and delays the water runoff, since it is absorbed and then consumed, for irrigation, or evaporated. This benefit depends on the roof's slope, substrate thickness, precipitation regime and substrate saturation [16].

2.2.2. Water quality

The rainfall drained through the green roof is filtrated, the pollutants removed and the acid neutralized. This benefit depends on the roof's characteristics and age, precipitation's volume, and, especially, its maintenance [2, 16–18].

2.2.3. Urban noise

Like the sound insulation benefit (see 2.1.7) green roofs absorb the sound's energy, reducing it's propagation and the urban noise at street level [19]. The substrate's porosity, humidity and thickness, buildings characteristics like height and surroundings are important [19, 20].

2.2.4. Air quality

Green roofs improve air quality as they filter and remove carbon and pollutants, particularly in intensive roofs. This benefit results directly from the plants photosynthesis and indirectly from less energy needs, lowering emissions during the roof's production [2, 21, 22]. Resistant vegetative species are better as they resist all year.

2.2.5. Urban heat island effect

A general green roof installation allows to reduce the air's temperature associated to the release of latent heat. This is especially related to the roofs absorption and emissivity [2, 23].

2.2.6. Habitat creation and biodiversity preservation

As green roofs create spaces and conditions to develop wild life (like spiders, ants, bees, birds and regional flora) in urban areas where those spaces are rare [W3].

2.2.7. Public health and well-being

Green roofs improve public health by mitigating problems like urban heat island, pollution (that causes cardio-respiratory diseases) and decrease people's quality of life [7].

2.2.8. Property value, aesthetics and recreational space

The building's price rises because of attractive aspects and benefits that people are willing to pay for, like sound insulation. The recreational benefit is only applied to intensive roofs [24, W4]

2.2.9. Job creation and productivity

As the installation of green roofs requires labor. Also, green roofs are shown to decrease work's absence and increase productivity [25].

2.3. Costs and benefits summary

Taking in account all the conditioning aspects mentioned below, an extensive literature review was made to quantify green roofs costs and benefits. The following values (**Table 1**) are presented as intervals, as the analysis consists in a comparison between green and traditional roofs, being also referred to the Mediterranean climate (typical in Portugal).

Table 1: Green roofs costs and benefits compared to traditional roofs

			Extensive	Intensive
Private	Installation cost [7, 26, W5]	*Black*	75 to 132 €/m²	126 to 272 €/m²
		White	55 to 80 €/m²	
	Maintenance cost [27]		1 €/(m².year)	
	Drainage lifespan [8]		10 to 40 years	
	Replacement cost [7]		31 €/m²	
	Demolition cost [7]		0,18 €/m²	0,1 €/m²
	Weight [W1, W6, W7]		50 – 190 kg/m²	> 150 kg/m²
	Roof slope [W1]		Up to 35º	0º
	Energy consumption		See Table 2 and 3	
	Sound insulation [28]		2 to 20 dB	-
	Waterproof m. life [2, 29]		20 to 40 years	
	Roof's lifespan [7, 24, W8]		20 to 50 years	
	Fire insuran. discount [14]		10 a 20%	
	Photovoltaics perfor. [15]		1,29 to 3,33%	-
	Sustainability [W4]		40 LEED's credits	
Public	Storm water runoff retention [30, 31]		23 to 54%	69%
			74 to 89% pick	
	Stormw. runoff delay [31]		50 to 306 min	
	Storm water quality [32, 33]		34 - 97% Cu, 72 - 96% Zn, 62 - 92% Cd, 91 - 99% Pb, 80% NO_3 and 68 - 80% PO_4	
	Urban noise reduc [20, 34]		Up to 10 dB	3 to 6 dB
	Abs. air pollutants [22, 35]		72 to 85 kg/(ha.year)	
	Absorption of CO_2 [36, 37]		0,38 to 6,47 kg/(m².year)	
	CO_2 emissions [18]		2,54 to 3,57 kg/(m².year)	
	Urban heat island [38, 39]		0,3 to 4,2ºC	
	Public health [W9]		2,56€/(person.year)	
	Property value [24]		2 to 5%	10 to 20%
	Aesthetics value [24]		2 to 5%	5 to 8%
	Recreational value [40]			11%
	Job creation [41]		2,08 x 10^{-4} employees/m²	
	Productivity [42]		2,9%	

Table 2: Energy consumption of green roofs in comparison to traditional black roofs [26, 38, 43–47]

		Black			
		Insulated		Non insulated	
		Residential	*Commercial*	*Residential*	*Commercial*
Exten	Heat	-8 to 15	8 to 53	2 to 16	45 to 48
	Cool	-5 to 53	-26 to 0	4 to 54	7 to 45
	Total	1,2 to 32	-7 to 2	0,8 to 12	31 to 44
Inten	Heat	Non referred	-3 to 36	Non referred	48
	Cool		8 to 71		84
	Total		8 to 60		72

Table 3: Energy consumption of green roofs in comparison to traditional white roofs [26, 38, 43–47]

		White			
		Insulated		Non insulated	
		Residential	*Commercial*	*Residential*	*Commercial*
Exten	Heat	20 to 36	35 to 73	1 to 39	71
	Cool	-84 to -193	-14 to -297	-500 to 2,2	-315
	Total	-14 to 13	-7 to -41	-1 to 21	-6
Inten	Heat	Non referred	26 to 62	Non referred	71
	Cool		-5 to 7		29
	Total		-1 to 46		63

3. COST BENEFIT ANALYSIS

Economic evaluations are a good tool to determinate the feasibility of an investment, considering all the costs and benefits of the project's life cycle. An initially expensive investment doesn't mean that it isn't profitable in long-term. An economic evaluation has 3 levels: financial, economic and socio-environmental analysis. The first level considers cash-flows directly associated to the investor. The second level considers the project's contributes to the local economy as the third level has into account aspects related to social equity and environmental protection. A literature review was made associated to the economic evaluation of green roofs comparatively to traditional roofs (**Table 4**).

In a general, the researches concluded that green roofs are an investment with no profits to the building's owner. Considering the social benefits and costs, green roofs may be feasible. On the other hand, intensive roof have higher net present value (NPV), yet, longer payback periods (PR).

4. METHODOLOGY

The economic evaluation concerns two alternative scenarios, being the hypotheses: replacing an existing traditional roof for a green roof or maintaining the first solution. The evaluation is applied to the city of Lisbon, therefore cash-flows were estimated based on the literature review (see 2) considering specific local constraint. As said before, the evaluation is an incremental process, like represented in (**Fig 1**) that involves 3 levels: financial, economic and socio-environmental level. Each level considers the costs and benefits indicated in **Fig. 1** (those highlighted are affected by inflation).

Table 4: Economic comparative evaluations between green and traditional roofs

Ref	Scenario	Green roof	Period and DR	Analysis		Results	
[48]	Urban - 600 mil m² (commercial and residential buildings)	Not referred	30 years 5%	**Socio-environmental:** Energy consumption, urban heat island, air quality, storm water runoff.		**Building**: Non feasible	**Urban:** Feasible
[1]	Urban – 176.234 m² Building - (commercial and residential) - 929 m²	Extensive	40 years 4%	**Financial / Socio-environmental:** Installation, maintenance, storm water management, energy consumption, air quality.		**Building:** NPV 18,87% higher	**Urban:** NPV 12,14% higher
[29]	Urban - 1700 ha	Extensive non accessible	40 years 3%	**Financial / Socio-environmental:** Installation, longevity, sound insulation, air quality, storm water management, energy consumption.		**Building:** Non feasible	**Urban:** Feasible
[49]	Residential (55, 125 and 270 m²) and commercial buildings (1795 m²)	Extensive	40 years 2,8%	**Financial / Socio-environmental**: Storm water management, energy consumption, energy related emissions, public health, longevity		**Building:** NPV 25% lower; PR 7 years	**Urban:** NPV 5-15% lower; PR < 7 years
[26]	Commercial insulated buildings - 986 m²	Extensive, Semi-intensive and Intensive	Not referred 0%	**Financial:** Installation, energy consumption, maintenance	Tenerife, Seville, Rome, London	**Economies**	**Payback**
						-6 a -7%	Negative
					Amsterdam	-5 a 2%	Neg to 489 years
					Oslo	3 a 5%	237 to 140 years
[24]	Not referred	Extensive and Intensive	40 to 50 years 2 a 8%	**Financial / Economic/ Socio-environmental**		**Building**	**Urban**
				Production, installation, operation, demolition	Extensive	NPV 255 €/m² PR 4,6 years	NPV 351 €/m² PR 4,2 years
					Intensive	NPV 536 €/m² PR 6 years	NPV 610 €/m² PR 12,8 years
[7]	22 roofs (black and white) - 455 a 9290 m²	Not referred	50 years 3%	**Financial / Economic/ Socio-environmental**		**NPV (Black roof)**	**NPV (White roof)**
				installation, maintenance, operation, replacement		-84 €/m²	-62 €/m²

The application to the city of Lisbon required a building's classification to determine those that can support a green roof installation.

The economic indicators estimated were: net present value (NPV), internal rate of return (IRR) and payback period (PR), as they are the most popular. At last, based on the economic evaluation, a sensitive analysis was made to study the parameters influence in the NPV.

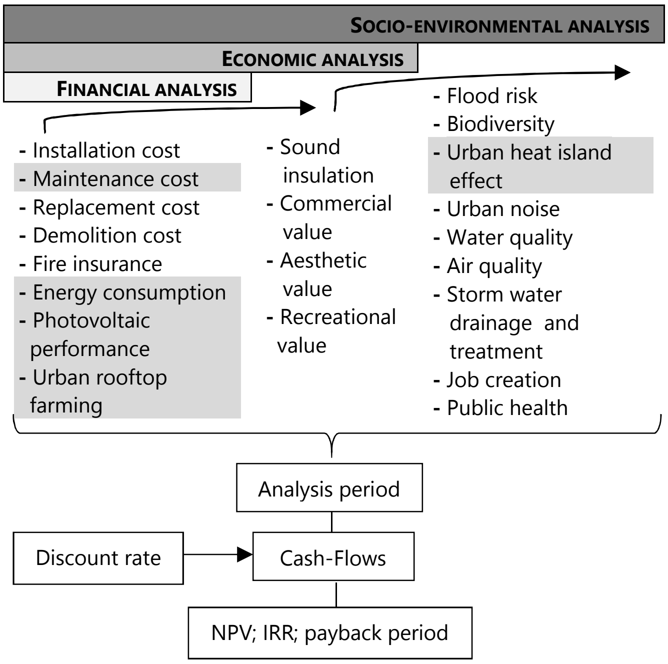


Fig. 1: Methodology proposal

5. AN APPLICATION TO THE CITY OF LISBON

5.1. Building classification

It was necessary to determine the buildings in Lisbon capable of receiving a green roof (associated to the structure's load capacity). Knowing the construction history of the city and the buildings main characteristics, the available building types were defined (**Table 5**), based on structure and roof type, roof's slope, repair needs, existence of insulation and year of construction.

Table 5: Building types integrated in the analysis

Building type			Analysis considerations
I	Structure:	Mixed	**1946 to 2005** Only buildings with considerable repair needs
	Roof:	Slopped, non insulated	
II	Structure:	Concrete	**1946 to 2005** Lightly slopped (up to 20º)
	Roof:	Slopped, non insulated	
III	Structure:	Concrete	**1946 to 2005** No specifications
	Roof:	Flat, non insulated	
IV	Structure:	Mixed	**2005 to 2011** Only buildings with considerable repair needs
	Roof:	Slopped, insulated	
V	Structure:	Concrete	**2005 to 2011** No specifications
	Roof:	Slopped, insulated	
VI	Structure:	Concrete	
	Roof:	Flat, insulated	

5.2. Assumptions

5.2.1. Financial parameters

5.2.1.1. Analysis period

It was assumed a traditional roof's service life of 20 years and 40 years to green (see 2.1.8). To include longevity benefits and the replacement cost, the comparative economic evaluation covered a 40 year period (assumed as the green roof's service life).

5.2.1.2. Discount rate

As the life cycle analysis considers initial and future expenditures, the economic evaluation usually incorporates a discounting method. An 8% discount rate was determined by the following equation, where $R_{inflation}$ is the inflation, obtained from [W10], taken as an 3,9%; R_{risk} is the risk premium that, considering green roofs as a low risk investment, adopts the value of 1% [W11]; R_{yield} is the yield rate, that is assumed to be 3%.

$$R_{discount} = \left(1 + R_{inflation}\right) * \left(1 + R_{risk}\right) * \left(1 + R_{yield}\right) - 1$$

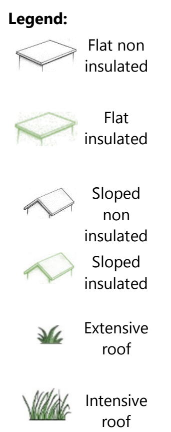
5.2.1.3. Inflation

Since the analysis uses a constant euros approach it means that the purchasing power that an euro had in a particular year is the same in the future. However, the rate of increase in prices of individual items over a given period must not be neglected. Therefore, the following inflation rates, based on [W12], were assumed: 4,9 %, 1,4% and 2,0%.for energy, agricultural products and maintenance, respectively.

5.2.2. Scenarios analysed

Table 6: Scenarios analysed

Buildings		Scenario	Existing building			Green roof to install
Nº	Area (m^2)		Building type	Use	Existing roof	
113	16 782	**1**	I e II	Commercial		
5505	822 333	**2**		Residential		
11	1 603	**3**	IV e V	Commercial		
526	78 546	**4**		Residential		
41	6 127	**5**	III	Commercial		
2009	300 203	**6**		Residential		
5	687	**7**	VI	Commercial		
225	33 673	**8**		Residential		
41	6 127	**9**	III	Commercial		
2009	300 203	**10**		Residential		
5	687	**11**	VI	Commercial		
225	33 673	**12**		Residential		



Scenarios with different building and roofing characteristics were analysed (**Table 6**). From data collected in [W13], those scenarios were quantified in terms of the number of existing buildings in Lisbon and their respective area (established from the average roof surface of buildings).

5.2.3. Building scale

5.2.3.1. Installation cost

The installation cost of green roofs and traditional roofs in Portugal was consulted in [W13]. Both costs were compared, with the difference in value being presented in **Table 7**. This comparison was made between similar roofs so that the cover (green or tile) would be the only reason for the price's variation.

This value was counted in years 0 and 40 (associated to roof's replacement). Was assumed that if the previous roofs didn't have insulation, the green roof installed wouldn't have as well, and otherwise.

5.2.3.2. Maintenance cost

A 10-year maintenance cost was also consulted and compared between green and traditional roofs (**Table 7**).

Table 7: Increased 10-year maintenance and installation cost (€/m^2)

		Maintenance		Installation	
		Non insulated	Insulated	Non Insulated	Insulated
Extens.	Flat	-	5,31	-	21,01
	Slopped	12,09	8,03	41,49	29,34
Intens.	Flat	-	103,03	-	95,01

5.2.3.3. Replacement cost

The vegetation was assumed to have an 8 year lifespan while the drainage layer resists 24 years (so both would be replaced at once, thus avoiding additional costs). Demolition and installation costs were consulted [W13] for these layers and the final amount (the replacement cost) is indicated as $10{,}80\,€/m^2$ to vegetation in extensive roofs, $11{,}45\,€/m^2$ to vegetation in intensive roofs and $16{,}03\,€/m^2$ to drainage layer to green roofs in general.

5.2.3.4. Demolition cost

The consulted demolition cost was not available for slopped roofs, so the decreased cost was assumed the same as flat roofs. A value of 5,12 and $5{,}11\,€/m^2$ for non-insulated and insulated extensive roofs, and 4,46 and $4{,}47\,€/m^2$ for non-insulated and insulated intensive roofs was applied in the end of green roof's life (year 40).

5.2.3.5. Roof's longevity

Assuming that the green roof's life doubles comparing to traditional roof's (20 years), it must be accounted the cost avoided in the replacement of the green roof. This cost sums the increased installation cost and the decreased demolition cost but, instead of being a cost, it represents a gain.

5.2.3.6. Fire insurance

In Portugal, building's fire insurance is required. Consulting annual costs for a residential building and knowing that green roofs reduce the insurance from 10 to 20%, an average gain of 0,09 and $0{,}08\,€/m^2$ was estimated to construction years until and from 2006 [W14]. To commercial buildings, the insurance corresponds to 60% of the residences insurance, meaning discounts of 0,06 and $0{,}05\,€/m^2$.

5.2.3.7. Energy consumption

Based in [W15], the annual cooling and heating needs for commercial and residential buildings were determined. Since the main energy consumed for heating and cooling is natural gas and electricity, their price was collected from [W16], as $0{,}06\,€/kWh$ and $0{,}16\,€/kWh$. Considering the increase or decrease of energy consumption, depending on the scenario (see **Table 6**), the following annual costs and economies were calculated (**Table 8**).

Table 8: Energy consumption costs and savings

		Extensive (€/m^2)		Intensive (€/m^2)	
		Heat	Cool	Heat	Cool
Residential	Insulated	0,06	-0,25	0,35	0,46
	Non insulated	0,17	-0,62	0,40	0,54
Commercial	Insulated	0,76	-0,51	0,49	0,31
	Non insulated	0,96	-0,21	0,56	0,37

5.2.3.8. Sound insulation

A research [27] concluded that when the sound insulation increases 1 dB, the property's value increases 0,6%. Knowing that green roofs can provide a sound insulation from 2 to 20 dB and from the average property price in Lisbon [W17] the following gains were obtained (**Table 9**).

Table 9: Increased property's price

		Average property's price (€/m^2)	Increased value (€/m^2)
Extensive	Residential	3.318,00	199,08
	Commercial	2.103,22	126,19
Intensive	Residential	3.318,00	398,16
	Commercial	2.103,22	252,39

5.2.3.9. Photovoltaic performance

Lisbon, being a city with high solar exposure, is investing in photovoltaics. Knowing that green roofs increase the efficiency of photovoltaic panels in 1,29 to 3,33% (see 2.1.10), it was estimated that a building with a green roof produces 0,18 to $0{,}70\,kWh/m^2$ more electricity than with a traditional roof. This value was based on the probable electricity production of the panels consulted in [W15] and assuming that the benefit was despised to the heating season. Either to use or sell, this benefit represents an annual average profit of $0{,}07\,€/m^2$, based on electricity's price of $0{,}16\,€/kWh$ [W16]. Note this benefit only applies to extensive roofs.

5.2.3.10. Urban rooftop farming

The produced cultures can be for personal consumption or for sell. In either ways, the gain is the product's price. From the minimal production productivity [W18] of some of the food named before in 2.1.11. and their price [consulted in W19], an average profit of $4{,}48\,€/m^2$ was obtained, only available to intensive roofs.

5.2.3.11. Property, aesthetics and recreational value

The commercial value of the properties was estimated based on the average price of buildings in Lisbon [W17] and their valorization set on the literature review (see 2.3) (**Table 10**). The recreational value is only available to intensive roofs. Note that the property's price refers to the roof surface and the valorization to the whole building. Therefore, the gain must be multiplied by the medium number of floors (3,73 floors, consulted in [W12].

Table 10: Increased property, aesthetics and recreational value (€/m^2)

		Price	Recreational	Aesthetics	Property
Extensive	Residential	3.318,00	0,00	464,52	464,52
	Commercial	2.103,22	0,00	294,45	294,45
Intensive	Residential	3.318,00	1.459,92	862,68	1.990,80
	Commercial	2.103,00	1.682,58	546,84	1.261,93

5.2.4. Urban scale

5.2.4.1. Storm water drainage and treatment

Lisbon's drainage system is mostly combined. Therefore, rainfall is drained and treated as wastewater. This storm water management involves costs (an average $0{,}04\,€/m^3$ [W20]), which are avoided by the green roof's retention capacity. The value indicated corresponds to the total volume drained. To determine the value associated only with storm water management, the part of volume referent to drained precipitation (1,2%) was calculated, based on the [W15]. That way, an annual cost of $0{,}004\,€/m^3$ was obtained. A total annual average precipitation of $0{,}922\,m^3/m^2$ was set by information available in [W10]. According to these data and the retention capacity of green roofs, the annual avoided costs are 0,002 and $0{,}003\,€/m^2$ for extensive and intensive roofs, respectively.

5.2.4.2. Flood risk

After the serious floods occurred in 2014, Lisbon's city hall (CML in portuguese) reviewed the drainage plan (PDGL in Portuguese), resulting in an intervention proposal to resolve the drainage issues. The intervention's actions, expected to be done until 2030, are focused in rainfall flow deviation. Green roofs are able as well to retain part of the precipitation. Corresponding the green roofs benefits to the intervention proposal, the investment of the proposal (**Table 11**) was associated to the Lisbon's impermeable surface. Since green roofs reduce the pick flow in 84%, annual economies of $0{,}01\,€/m^2$ were estimated to the flood risk attenuation due to green roofs installation.

Table 11: PGDL's intervention investments

	2016	2017	2018	2019	2020	2021 to 2030
Investment (€)	12.800	24.753	24.779	23.383	11.638	71.771
Maintenance	1.043.000 (€/year)					

5.2.4.3. Water quality

Green roofs reduce almost entirely the main pollutants of drained storm water. It was assumed that these "clean" waters avoid the respective treatment costs. The cost named before of $0{,}004\,€/m^3$ involves both storm and wastewater. Assuming that half of the value is designated to storm water, and consequently associated to the storm water drained (not retained), an annual economy of $0{,}001\,€/m^2$ was determined. This value considered the not retained rainfall, ranging between 46 and 76% of the total annual precipitation for extensive and 31% for intensive roofs (see percentages in 2.3).

5.2.4.4. Air quality

To limit pollutant emissions, the Kyoto Protocol developed an emissions trading system known as the carbon market. Certified emission reductions (CERs), known as carbon credits, are commercialized, being equivalent to a ton of CO_2 reduced or removed. This commodity's price of 4,95 € [W21] can be associated to another removed greenhouse gases (GEE), through their conversion in carbon dioxide equivalent (CO_2e), in which those emissions are expressed by their global warming potential (GWP). Of all the pollutants absorbed by green roofs (referend in 2.3) it was only found the value of GWP for NO_2 [W22], equal to $298\,kg$ of CO_2e. The green roof's potential to reduce GEE results from the group of pollutants and CO_2 absorption, and decrease of CO_2 emissions related to the processes of installing the roof (see 2.3). This being said, the green roof's profits providing from CERs are 15,89 and $33{,}71\,€/(m^2.year)$ to extensive and intensive roofs.

5.2.4.5. Urban heat island effect

A research indicates that for each $0{,}6\,°C$ increase air temperature, the cooling needs are 1,5 to 2% higher [50]. Knowing that a general installation of green roofs reduces urban temperature by an average of $2{,}25°C$, the energy consumption reduces about 6,6%, meaning a profit of 0,10 and $0{,}13\,€/m^2$ to residential and commercial buildings, respectively. This is based on the energy consumption quantified in 5.2.3.7.

5.2.4.6. Urban noise

CML presented a plan of action [W15] to reduce urban noise by $10\,dB$. Green roofs can achieve the same goal. This plan reaches 33 000 people, equivalent to $1{,}3\,km^2$. Based on this area and the plan's investment, the following gains were established (**Table 12**).

Table 12: PAR's investment plan

	Year 1	Year 6	Year 11
Investment (€)	2.997.735,00	3.198.600,00	3.057.052,00
Investment (€/m^2)	2,31	2,46	2,35

These gains were associated to intensive roofs and just 80% to extensive roofs as their benefit aren't the same.

Note that this isn't a completely realistic approach since buildings have different noise exposure in Lisbon.

5.2.4.7. Habitat creation and biodiversity preservation

CML has committed to increase Lisbon's potential to preserve biodiversity until 2020 and presented a budget of 46.319.898 € in 2010 to this end [W15]. Assuming this budget was kept in the following years, an annual cost of $2{,}72\,€/m^2$ is avoided with the installation of green roofs. However, since green roofs probably don't provide the same benefit, this value was reduced by 80% and 40% in extensive and intensive roofs, resulting in economies of 0,54 and $1{,}63\,€/m^2$).

5.2.4.8. Public health and well-being

As previously mentioned, people are willing to pay $26{,}56\,€/year$ to reduce 0,001% the risk of early death due to problems related to pollution. That was the benefit assumed to the installation of green roofs in Lisbon, since this is a value difficult to quantify. An annual gain of $0{,}68\,€/m^2$ was identified to intensive roofs and only 50% was assumed to extensive roofs ($0{,}33\,€/m^2$), since their pollutant's removal capacity is lower.

5.2.4.9. Job creation and productivity

Based on the gross domestic product of 179.378,88 $million$ € and the 4 548 700 employed people in 2015 in Portugal (GDP available in [W10]), the annual value of $39.435{,}20\,€/employee$ was estimated as the richness that each employee represents to the country. Green roofs employ $2{,}08 \times 10^{-4}\,people/m^2$ a year, therefore provides an annual profit of $8{,}19\,€/m^2$.

5.3. Results

Compiling all the costs and benefits associated with the possible scenarios allows to perform an NPV analysis. Using the discount rate and the inflation over a 40 year period, the economic evaluation was performed at 3 levels: financial, economic and socio-environmental analysis, at building and urban scale.

5.3.1. Financial analysis

The private analysis shows that green roofs are relatively more costly for the building owner when compared to traditional roofs (**Fig. 3** and **Fig. 5**). Nevertheless, related to minor costs of installation, maintenance and replacement, flat green roofs (scenarios 5, 6, 7 and 8 shown in the figures) becomes less expensive. Green roof type is the parameter with bigger influence in the results, since intensive roofs involve relevant costs compared to not so relevant benefits as energy savings, higher photovoltaic performance and urban rooftop farming (**Fig. 2** and **Fig. 4**). However, the farming benefit, non-existent in extensive roofs, leads to a faster investment recovery in intensive roofs.

There is no doubt that intensive roofs provide energy consumption savings; therefore, an application in old buildings is more convenient. However, this isn't so evident in extensive roofs. In general, extensive roofs increase energy consumption in residences and decrease in commercial buildings (significant only for non-insulated roofs – scenarios 1 and 5) (**Fig. 2** and **Fig. 4**). This way, installing extensive roofs is more interesting in insulated roofs for residential buildings. On the opposite, for commercial buildings it is preferred to install roofs with no insulation. This is not noticeable in scenario 1 (**Fig. 2**) since it is a slopped roof and, for lack of data, its installation and maintenance cost was assumed the same as a flat roof. That's why this high cost conceals the energy savings. However, both scenarios 1 and 5 show a certain recovery of investment costs. It is important to say that the thermal insulation provided by green roofs, and the consequent consumption savings, represent some of the data, based on the literature review, with more variability. Thus, more research was needed, mostly in Mediterranean climate, to provide more reliable results

Also note that maintenance costs in the year 20 are partially amortized by the cost avoided with the unnecessary replacement of the traditional roof existent on the alternative solution.

A comparative analysis between commercial and residential buildings (previous figures and **Table 13** and **Table 14**) revealed that the first ones are less expensive, again related to the energy consumption. This is more obvious for extensive roofs. Extensive roofs are more expensive when applied to residences between 9,41 and 26,63 $€/m^2$. The NPV in intensive roofs is very similar in both building types.

To conclude, green roofs are not a viable investment to the owner of the building, as they require constant investment, so profits are not expected. It was also concluded that, after the roof type, the slope is the parameter with most influence in the NPV, as flat roofs cause less expenditures.

Table 13: NPV of the financial analysis to commercial buildings

	Commercial buildings (- €/m²)					
Scenario	1	3	5	7	9	11
NPV	41,55	39,38	18,81	30,02	103,59	106,60

Table 14: NPV of the financial analysis to residential buildings

	Residential buildings (- €/m²)					
Scenario	2	4	6	8	10	12
NPV	68,18	48,79	45,08	39,43	103,01	106,02

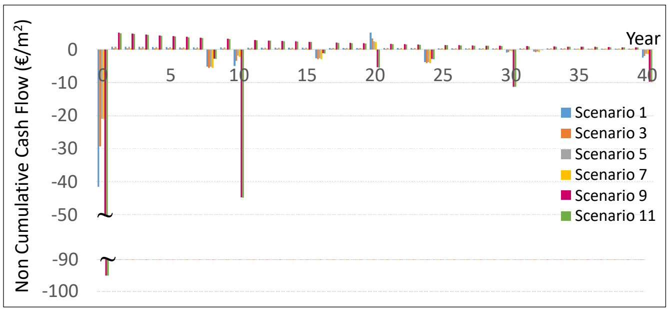


Fig. 2: Non-cumulative cash flows to commercial buildings

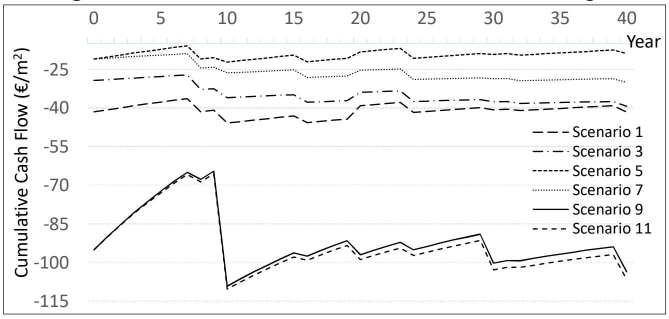


Fig. 3: Cumulative cash flows to commercial buildings

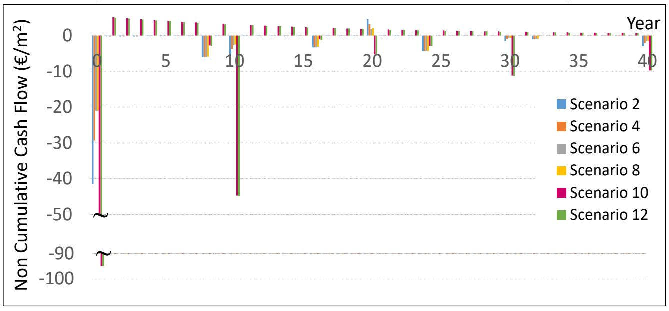


Fig. 4: Non-cumulative cash flows to residential buildings

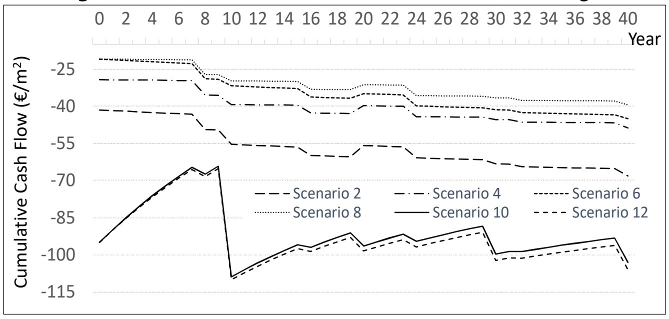


Fig. 5: Cumulative cash flows to residential buildings

5.3.2. Economic analysis

Despite being an unattractive investment to the private sector, green roofs are very likely profitably at an economic level (**Fig. 7** and **Fig. 9**). This is mostly because of the property's valuation. Even though intensive roofs are the most expensive, they have also more benefits since they consider the recreational benefit, non-included in the extensive roofs analysis. More benefits result from the application in a context of rehabilitation, being the absence of insulation the parameter with more influence after the roof type. The economic analysis is less sensitive to the roof slope, meaning that the results of a sloped and flat roof are similar, when maintaining the remaining characteristics.

As the property's valuation benefit is taken in account when the system is installed (**Fig. 6** and **Fig. 8**), the profits tend to reduce over time, as happens in the financial analysis. This occurs more rapidly in extensive roofs because they do not benefit from the urban farming as the intensive roofs do.

Despite the worse results showed in the financial analysis, in the economic analysis the green roofs, when applied to residential buildings, have higher NPV. This is related to their highest property price in Lisbon when compared to commercial buildings, resulting therefore in a greater valorization. Extensive roofs are more profitable when applied to residences between 331 and 287 $€/m^2$.comparatively to commercial buildings .This increase can be up to 970 $€/m^2$ in intensive roofs (**Table 15** and **Table 16**).

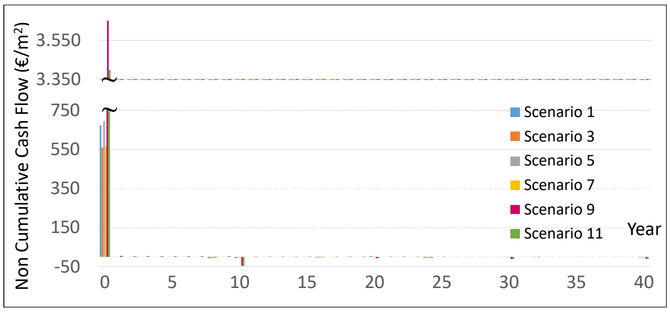


Fig. 6: Non-cumulative cash flows to commercial buildings

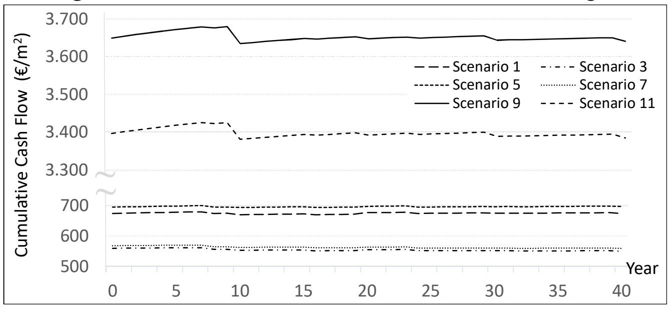


Fig. 7: Cumulative cash flows to commercial buildings

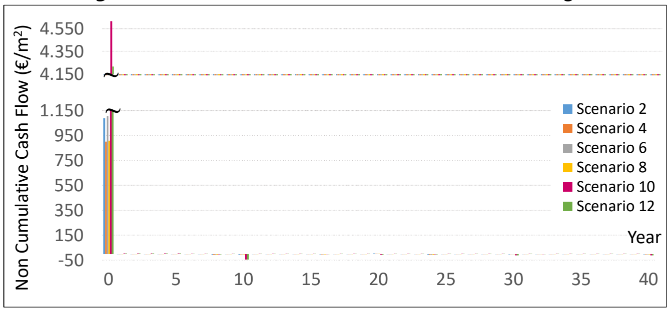


Fig. 8: Non-cumulative cash flows to residential buildings

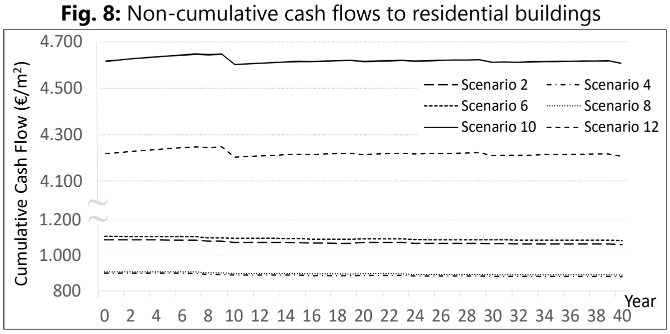


Fig. 9: Cumulative cash flows to residential buildings

Table 15: NPV of the economic analysis to commercial buildings

	Commercial buildings (€/m²)					
Scenario	1	3	5	7	9	11
NPV	673,54	549,52	696,28	558,88	3.640,15	3.384,75

Table 16: NPV of the economic analysis to residential buildings

	Residential buildings (€/m²)					
Scenario	2	4	6	8	10	12
NPV	1.060,82	880,25	1.083,04	889,61	4.608,55	4.207,38

5.3.3. Socio-environmental analysis

Although involving more benefits than the economic analysis, the socio-environmental analysis profits result mostly from the property valorization (**Fig. 10** and **Fig. 12**). This said, the cash flows of both analysis are very similar. Yet, at this level, the profits do not tend to depreciate, as it happened at the economic analysis. On the contrary, the obtained from the air quality benefit result in increasing cash flows over time (**Fig. 11** and **Fig. 13**). Therefore, installing green roofs instead of traditional roofs is clearly a feasible long-term investment in a social and environmental level (particularly intensive roofs). The roof's slope is, once again, not expected to influence the NPV result, being the age of the building the second most important parameter, after the roof type.

As in the economic analysis, when installed in residential buildings, green roofs are more profitable. As mentioned before, the results in both analysis are similar. Therefore, a comparison between residential and commercial buildings (**Table 17** and **Table 18**) leads to the same conclusions.

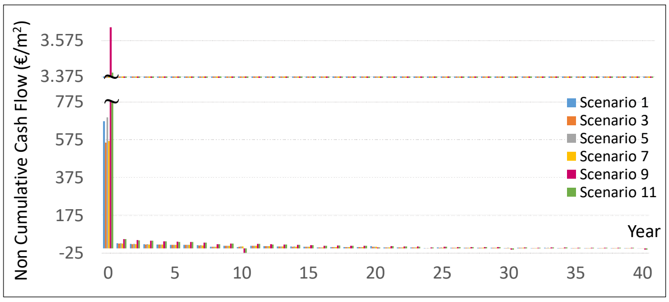


Fig. 10: Non-cumulative cash flows to commercial buildings

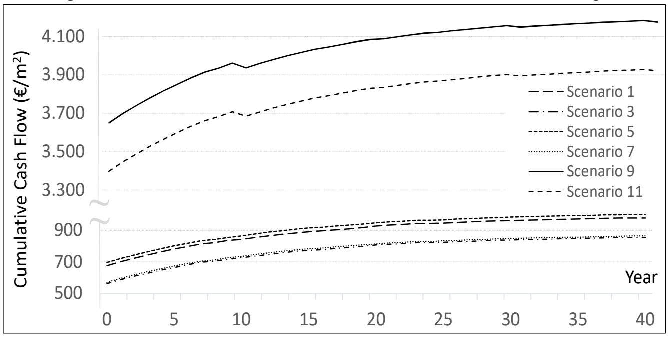


Fig. 11: Cumulative cash flows to commercial buildings

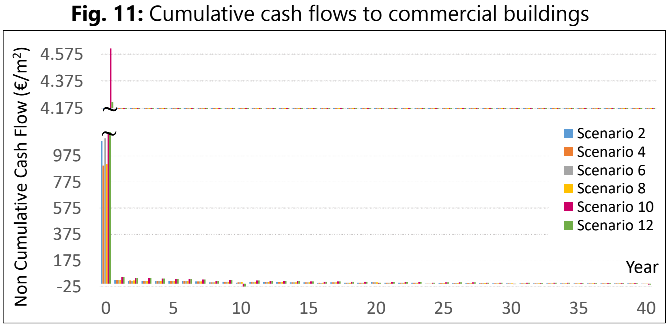


Fig. 12: Non-cumulative cash flows to residential buildings

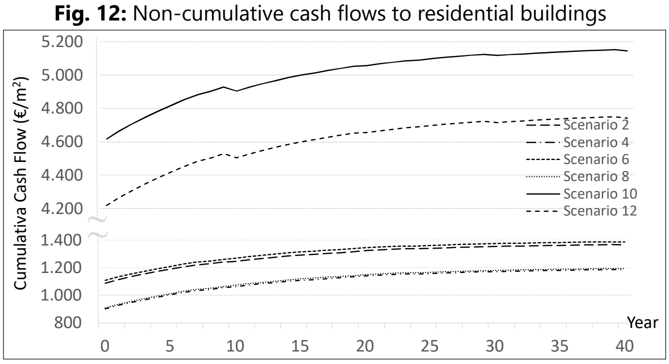


Fig. 13: Cumulative cash flows to residential buildings

Table 17: NPV of the socio-environmental analysis to commercial buildings

	Commercial buildings					
Scenario	1	3	5	7	9	11
NPV (€/m²)	977,15	853,13	999,89	862,49	4.175,05	3.919,66

Table 18: NPV of the socio-environmental analysis to residential buildings

	Residential buildings					
Scenario	2	4	6	8	10	12
NPV (€/m²)	1.364,43	1.183,86	1.386,65	1.193,22	5.143,45	4.742,25

5.3.4. Economic evaluation and application to Lisbon

From the financial, economic and socio-environmental analysis presented below, an economic evaluation was conducted at a building and urban level (**Table 19**). While at the building level was consider the typical roof area of a building in Lisbon, 147,39 m^2, at the urban level this area was multiplied by the number of buildings of each scenario (see 5.2.2).

This analysis concludes that, the greening of 10 375 roofs in Lisbon, corresponding to 1 549 947 m^2 (about 2% of Lisbon's surface area), over a 40 year period would lead to a social NPV of 3.430 $million$ €. In this way, green roofs provides obvious profits to the urban area of Lisbon, even though being expensive to the private sector. Observing the cumulative cash flows of the economic evaluation applied to the city of Lisbon (presented in **Fig. 14**), it can be distinguished long periods of profit with punctual losses (years 8, 10, 24 and 30). Those represent mainly maintenance and replacement costs.

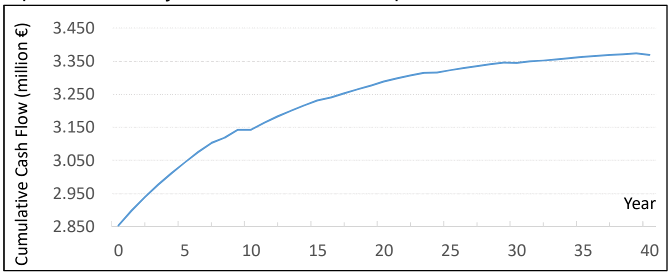


Fig. 14: Cumulative cash flows of the economic evaluation to Lisbon

The maintenance cost counted on the 20th year of the analysis is compensated by the benefit of longevity. The increased property's value (commercial, aesthetics and recreational), results in profits that overcome the high costs of installation, maintenance and replacement of green roofs. Thereby, applying green roofs deliver immediate cash incomes, yet only social and not directly to the investor. Since cash flows are always positive (economic and socio-environmental analysis) or always negative (financial analysis), it is not possible to calculate the IRR and payback period as initially proposed.

5.4. Sensibility analysis

There is some uncertainty related to the parameters involved in the economic evaluation, as they are controlled by the market and nature (like climatic conditions, as they control the green roof benefit's efficiency). Therefore, long-term results can be estimated, but always with some risk involved. The sensibility analysis has the purpose to determine which parameters the NPV outcomes depends the most.

The NPV of the economic evaluation to Lisbon was recalculated varying the parameters individually between ranges of $\pm 15\%$, while maintaining the remaining constant (**Fig. 15**).

It was concluded that the most important parameters are property, aesthetics and recreational value, and sound insulation, associated to the high building's price in Lisbon. In addition, this valorization refers to the entire building and not only the apartment placed under the roof (except for sound insulation benefit). The following main parameters are discount rate and air quality. Apart from job creation, costs of installation, maintenance and replacement, all the other parameters have little impact in the analysis. The most significant NPV variance is 5,49%, corresponding to 188 $million$ €. This proofs that NPV isn't indifferent to the parameters variability, as the feasibility of the investment can be compromised by future uncertainties impossible to predict.

Note that the discount rate, energy consumption, installation, maintenance, replacement and demolition costs, and maintenance inflation have a negative influence on NPV. That is because almost all of those represent costs, and consequently, if increased, reduce the NPV. Energy consumption is included because, despite being in general a benefit, it is not in scenario 2 (scenario with more weight in the analysis). Also included there is the demolition cost that, being a gain, it is not taken into account in the longevity benefit. A pessimistic, optimistic and most probable scenarios were analysed. The pessimistic scenario varies parameters to -15% and the optimistic to $+15\%$. Note that to parameters with a negative influence in the result, as said before, the variation has an opposite signal. The most probable scenario's parameters vary according to what is expected, as stated below:

- Discount rate $-7{,}5\%$, as in the future it could be considered a lower risk investment;
- Energy consumption $+15\%$, as the climate change tends to cause severe temperature fluctuations, and therefore, increase the heating and cooling needs;

Table 19: Economic evaluation at a building and urban area – application to the city of Lisbon

	Building NPV			Urban NPV		
Scenario	**Financial**	**Economic**	**Socio-environmental**	**Financial**	**Economic**	**Socio-environmental**
1	-6.207,88 €	100.621,18 €	145.978,48 €	-701.490,35 €	11.370.193,89 €	16.495.568,22 €
2	-10.186,24 €	158.477,87 €	203.835,16 €	-56.075.237,93 €	872.420.648,83 €	1.122.112.557,28 €
3	-5.883,76 €	82.093,47 €	127.450,76 €	-23.535,05 €	328.373,87 €	509.803,04 €
4	-7.289,29 €	131.502,29 €	176.859,59 €	-1.363.097,16 €	24.590.929,03 €	33.072.743,17 €
5	-2.809,66 €	104.019,40 €	149.376,70 €	-118.005,81 €	4.368.814,88 €	6.273.821,27 €
6	-6.735,23 €	161.797,41 €	207.154,70 €	-13.537.816,19 €	325.212.785,33 €	416.380.948,09 €
7	-4.485,15 €	83.492,08 €	128.849,38 €	-22.425,74 €	417.460,40 €	644.246,88 €
8	-5.890,68 €	132.900,91 €	178.258,20 €	-1.331.292,58 €	30.035.605,38 €	40.286.354,03 €
9	-15.475,77 €	543.810,81 €	623.721,27 €	-649.982,32 €	22.840.054,04 €	26.196.293,34 €
10	-15.389,17 €	688.482,44 €	768.392,90 €	-30.932.227,07 €	1.383.849.696,96 €	1.544.469.720,95 €
11	-15.924,90 €	505.656,52 €	585.566,98 €	-79.624,48 €	2.528.282,59 €	2.927.834,89 €
12	-15.838,29 €	628.551,20 €	708.456,96 €	-3.579.454,37€	142.052.571,86 €	160.111.271,94 €
			LISBON	**3.369.481.163,11 €**		

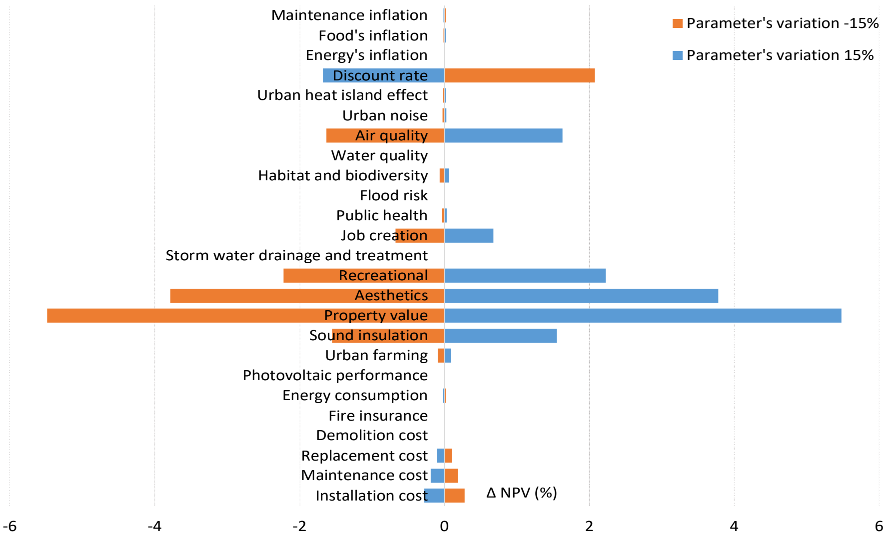


Fig. 15: Sensibility analysis to the parameters of the socio-environmental analysis to Lisbon

- Urban heat island effect +15% related to the previous;
- Storm water drainage and treatment +5%, as the climate change also results in intense rainfall events (variance restricted by the limited retention capacity of green roofs);
- Flood risk +10%, as global warming (GW) increases the sea level, important to Lisbon because the proximity of the river (variance restricted by the same reasons);
- Water and air quality +15%, associated to the current urbanization and development, and consequent increasing levels of pollution;
- Urban farming +15%, as GW increases the air temperature leading to several problems in agricultural production and therefore, to more expensive products;
- Installation, maintenance, replacement and demolition costs −7,5%, as green roofing becomes a more current solution (limited by the public's acceptance), note that demolition cost being a benefit has a +7,5%, variance;
- Public health +15%, as increasing pollution levels cause more health problems;
- Property, aesthetics and recreational value +7,5%, as the building's commercial value have been rising;
- Job creation +15%, as unemployment is a current issue and this benefit tends to be valorized;
- Inflation +15%, as CPI tend to rise;
- Others 0%, as it is difficult to estimate their future behaviour;

The results are exposed in **Fig. 16**.

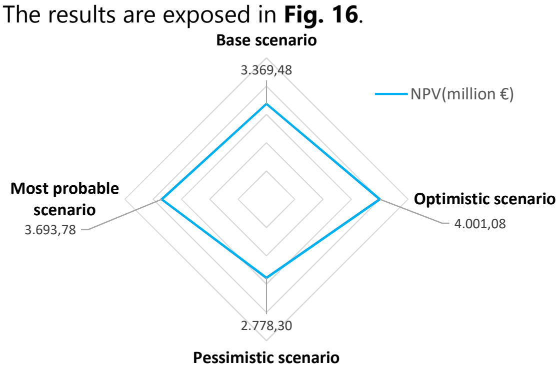


Fig. 16: Optimistic, pessimistic and most probable scenario's NPV

In the best of hypotheses, the NPV increases 19% and in the worst decreases 18%. The results showed that, given realistic assumptions, in the future, green roofs will be an attractive investment, with NPV 10% higher than the present scenario.

6. Conclusions

Green roofs installation instead of traditional roofs is a feasible investment at an economic social-environmental level, but not at a financial level. This been said, political and financial incentives could be an alternative method in order to make this solution attractive to the private investors. Financial gains don't exceed the high costs at the owners perspective, producing losses up to 68,18 and 106,60 $€/m^2$, for extensive and intensive roofs respectively. At a social perspective, the profit ranges between 1.193,22 and 5.143,45 $€/m^2$ as it is referred to an extensive or intensive roof. However, social benefits are only noticeable to a generalized application of green roofs.

Intensive roofs become more expensive, but return greater benefits. Although their potential, the structure's load capacity is a barrier to their installation, especially being Lisbon an old city. Extensive roofs on the other hand are less expensive but also less profitable. In order to consider the private and public perspective, a similar amount of extensive and intensive roofs should be installed, keeping in mind the intermediate solution of semi-intensive roofs, not approached in this analysis.

Applying green roofs in residential buildings is more advantageous than in commercial buildings, preferred in a rehabilitation context. This been said, and since a large part of Lisbon's buildings are old, if the present analysis only had taken into account the recent buildings, the NPV would represent just 8,7 % of the scenario base which is 3.369 $million$ €.

The property, aesthetics and recreational value and sound insulation benefits are the most relevant parameters for the NPV results. Through a sensibility analysis, it was obtained NPV variances between 1,5 and 5,5%, by individually varying the parameters at $\pm 15\%$.

The present study estimates that green roofs are feasible solutions to high urbanized areas, such as Lisbon. However, the cash-flows assumed were based on countless uncertainties, so more research data is needed to support the results. Therefore, it must bear in mind the assumptions made and that each situations is unique, leading possibly to different results.

Finally, this paper didn't approached buildings used only for commercial purposes in Lisbon. Those, representing usually large surfaces, would return higher gains since associated to lower installation costs.

REFERENCES

[1] Carter, T., Keeler, A., *Life-cycle cost–benefit analysis of extensive vegetated roof systems*, *Journal of Environmental Management*, vol. 87, n. 3, pp. 350–363, 2008.

[2] Berardi, U., GhaffarianHoseini, A., GhaffarianHoseini, A., *State-of-the-art analysis of the environmental benefits of green roofs*, *Applied Energy*, vol. 115, pp. 411–428, 2014.

[3] Refahi, A. H., Talkhabi, H., *Investigating the effective factors on the reduction of energy consumption in residential buildings with green roofs*, *Renewable Energy*, vol. 80, pp. 595–603, 2015.

[4] FLL, *Guidelines for the Planning , Construction and Maintenance of Green Roofing - Green Roofing Guideline*. 2008.

[5] Silva, C. M., Flores-Colen, I., Coelho, A., *Green roofs in Mediterranean areas – Survey and maintenance planning*, *Building and Environment*, vol. 94, pp. 131–143, 2015.

[6] Bianchini, F., Hewage, K., *Probabilistic social cost-benefit analysis for green roofs: A lifecycle approach*, *Building and Environment*, vol. 58, pp. 152–162, 2012.

[7] Sproul, J., Wan, M. P., Mandel, B. H., Rosenfeld, A. H., *Economic comparison of white, green, and black flat roofs in the United States*, *Energy and Buildings*, vol. 71, pp. 20–27, 2014.

[8] Coelho, A., *Green Roof Maintenance – Construction project support and rehabilitation* (in portuguese), Instituto Superior Técnico, 2014.

[9] Getter, K. L., Rowe, D. B., Andresen, J. A., Wichman, I. S., *Seasonal heat flux properties of an extensive green roof in a Midwestern U.S. climate*, *Energy and Buildings*, vol. 43, n. 12, pp. 3548–3557, 2011.

[10] Connelly, M., Hodgson, M., *Thermal and Acoustical Performance of Green Roofs: Sound Transmission Loss of Green Roofs*. 2008.

[11] Grant, G., Engleback, L., Nicholson, B., *Green Roofs: their existing status and potential for conserving biodiversity in urban areas*, n. 498. 2003.

[12] Lagström, J., *Do Extensive Green Roofs Reduce Noise?*, *Igri*, n. 10, p. 40, 2004.

[13] Kuhn, M. E., Peck, S. W., *Design guidelines for green roofs*, *City*, p. 22, 2003.

[14] Breuning, J., *Fire & wind on extensive green roofs*, *In Proceedings of the Sixth Annual Greening Rooftops for Sustainable Communities Conference Awards and Trade Show 2008 Conference Proceedings*, pp. 1–6, 2008.

[15] Lamnatou, C., Chemisana, D., *Evaluation of Photovoltaic-green and other roofing systems by means of ReCiPe and multiple life cycle–based environmental indicators*, *Building and Environment*, vol. 93, pp. 376–384, 2015.

[16] Hashemi, S. S. G., Mahmud, H. Bin, Ashraf, M. A., *Performance of green roofs with respect to water quality and reduction of energy consumption in tropics: A review*, *Renewable and Sustainable Energy Reviews*, vol. 52, pp. 669–679, 2015.

[17] Vijayaraghavan, K., Joshi, U. M., *Can green roof act as a sink for contaminants? A methodological study to evaluate runoff quality from green roofs*, *Environmental Pollution*, vol. 194, pp. 121–129, 2014.

[18] Rowe, D. B., *Green roofs as a means of pollution abatement*, *Environmental Pollution*, vol. 159, n. 8–9, pp. 2100–2110, 2011.

[19] Connelly, M., Hodgson, M., *Experimental investigation of the sound absorption characteristics of vegetated roofs*, *Building and Environment*, vol. 92, pp. 335–346, 2015.

[20] Van Renterghem, T., Botteldooren, D., *Numerical evaluation of sound propagating over green roofs*, *Journal of Sound and Vibration*, vol. 317, n. 3–5, pp. 781–799, 2008.

[21] Vijayaraghavan, K., *Green roofs: A critical review on the role of components, benefits, limitations and trends*, *Renewable and Sustainable Energy Reviews*, vol. 57, pp. 740–752, 2016.

[22] Yang, J., Yu, Q., Gong, P., *Quantifying air pollution removal by green roofs in Chicago*, *Atmospheric Environment*, vol. 42, n. 31, pp. 7266–7273, 2008.

[23] Santamouris, M., *Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments*, *Solar Energy*, vol. 103, pp. 682–703, 2014.

[24] Bianchini, F., Hewage, K., *How "green" are the green roofs? Lifecycle analysis of green roof materials*, *Building and Environment*, vol. 48, pp. 57–65, 2012.

[25] Doshi, H., Peck, S., *Methods for Estimating Economic Public Benefits from Regional Implementation of Green Roof Technology*, pp. 1–21, 2013.

[26] Ascione, F., Bianco, N., de' Rossi, F., Turni, G., Vanoli, G. P., *Green roofs in European climates. Are effective solutions for the energy savings in air-conditioning?*, *Applied Energy*, vol. 104, pp. 845–859, 2013.

[27] Claus, K., Rousseau, S., *Public versus private incentives to invest in green roofs: A cost benefit analysis for Flanders*, *Urban Forestry & Urban Greening*, vol. 11, n. 4, pp. 417–425, 2012.

[28] Connelly, M., Hodgson, M., *Experimental investigation of the sound transmission of vegetated roofs*, *Applied Acoustics*, vol. 74, n. 10, pp. 1136–1143, 2013.

[29] Nurmi, V., Votsis, A., Perrels, A., Lehvävirta, S., *Cost-benefit analysis of green roofs in urban areas : case study in Helsinki*, pp. 1–71, 2013.

[30] Mentens, J., Raes, D., Hermy, M., *Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century?*, *Landscape and Urban Planning*, vol. 77, n. 3, pp. 217–226, 2006.

[31] Fioretti, R., Palla, A., Lanza, L. G., Principi, P., *Green roof energy and water related performance in the Mediterranean climate*, *Building and Environment*, vol. 45, n. 8, pp. 1890–1904, 2010.

[32] Köhler, M., Schmidt, M., Grimme, F. W., Laar, M., Paiva, V. L. D. A., Tavares, S., *Green roofs in temperate climates and in the hot-humid tropics – far beyond the aesthetics*, *Environmental Management and Health*, vol. 13, n. 4, pp. 382–391, 2002.

[33] Steusloff, S., *Input and output of airborne aggressive substances on green roofs in Karlsruhe*, *Urban Ecology*, pp. 144–148, 1998.

[34] Van Renterghem, T., Botteldooren, D., *In-situ measurements of sound propagating over extensive green roofs*, *Building and Environment*, vol. 46, n. 3, pp. 729–738, 2011.

[35] Currie, B. A., Bass, B., *Estimates of air pollution mitigation with green plants and green roofs using the UFORE model*, *Urban Ecosystems*, vol. 11, n. 4, pp. 409–422, 2008.

[36] Getter, K. L., Rowe, D. B., Robertson, G. P., Cregg, B. M., Andresen, J. A., *Carbon Sequestration Potential of Extensive Green Roofs*, *Environmental Science & Technology*, vol. 43, n. 19, pp. 7564–7570, 2009.

[37] Luo, H., Liu, X., Anderson, B. C., Zhang, K., Li, X., Huang, B., Li, M., Mo, Y., Fan, L., Shen, Q., Chen, F., Jiang, M., *Carbon sequestration potential of green roofs using mixed-sewage-sludge substrate in Chengdu World Modern Garden City*, *Ecological Indicators*, vol. 49, pp. 247–259, 2015.

[38] Saiz, S., Kennedy, C., Bass, B., Pressnail, K., *Comparative Life Cycle Assessment of Standard and Green Roofs*, vol. 40, n. 13, pp. 4312–4316, 2006.

[39] Wong, N. H., Tay, S. F., Wong, R., Ong, C. L., Sia, A., *Life cycle cost analysis of rooftop gardens in Singapore*, *Building and Environment*, vol. 38, n. 3, pp. 499–509, 2003.

[40] Tomalty, R., Komorowski, B., Doiron, D., *The Monetary Value of the Soft Benefits of Green Roofs. Final Report Prepared for: Canada Mortgage and Housing Corporation (CMHC)*, 2010.

[41] Peck, S., *The green roof infrastructure monitor*, *Green Roofs for Healthy Cities*, vol. 5, n. 1, pp. 1–13, 2003.

[42] GSA (General Services Administration), *A Report of the United States General Services Administration The Benefits and Challenges of Green Roofs on Public and Commercial Buildings*, n. May. 2011.

[43] Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, A., Mihalakakou, G., *Analysis of the green roof thermal properties and investigation of its energy performance*, *Energy and Buildings*, vol. 33, n. 7, pp. 719–729, 2001.

[44] Jaffal, I., Ouldboukhitine, S.-E., Belarbi, R., *A comprehensive study of the impact of green roofs on building energy performance*, *Renewable Energy*, vol. 43, pp. 157–164, 2012.

[45] Zinzi, M., Agnoli, S., *Cool and green roofs. An energy and comfort comparison between passive cooling and mitigation urban heat island techniques for residential buildings in the Mediterranean region*, *Energy and Buildings*, vol. 55, pp. 66–76, 2012.

[46] Silva, C. M., Gomes, M. G., Silva, M., *Green Roofs Energy Performance in Mediterranean Climate*, *Energy and Buildings*, vol. 116, pp. 318–320, 2016.

[47] Kolokotsa, D., Santamouris, M., *Review of the indoor environmental quality and energy consumption studies for low income households in Europe*, *Science of the Total Environment*, vol. 536, pp. 316–330, 2015.

[48] Blackhurst, M., Hendrickson, C., Asce, D. M., Matthews, H. S., Asce, A. M., *Cost-Effectiveness of Green Roofs*, n. December, 2010.

[49] Niu, H., Clark, C., Zhou, J., Adriaens, P., *Scaling of Economic Benefits from Green Roof Implementation in Washington, DC*, *Environmental science & technology*, vol. 44, n. 11, pp. 4302–4308, 2010.

[50] Akbary, H., *Energy Saving Potentials and Air Quality Benefits of Urban Heat Island Mitigation*, *Solar Energy*, pp. 1–19, 2005.

[W1] ZinCo. (2016). Available at http://www.zinco.pt/, accessed 20, April.

[W2] CityFarmer. (2016). Available at http://www.cityfarmer.org/greenpotential.html, accessed 16, August.

[W3] Green Roof Technology. (2016). Available at http://www.greenrooftechnology.com/ , accessed 20, April.

[W4] Vegetal i.D: (2016). Available at http://www.vegetalid.us, accessed 16, April.

[W5] The green roof centre. (2016). Available at http://www.thegreenroofcentre.co.uk/green_roofs/, accessed 4, May.

[W6] Optigreen. (2016). Available at http://www.optigreen.co.uk/system-solutions/, accessed 20, April.

[W7] SIG. (2016). Available at http://www.singleply.co.uk/how-much-will-a-green-roof-weigh-2015/, accessed 20, April.

[W8] - Neoturf. (2016). Available at http://www.neoturf.pt, accessed 20, April.

[W9] Jornal de Negócios. (2016). Available at http://www.jornaldenegocios.pt/opiniao/economistas/detalhe/os_verdadeiros_custos_da_poluicao_do_ar.html, acedido a 15 de September.

[W10] PORTDATA. (2016). Available at http://www.pordata.pt/, accessed August.

[W11] e-konomista. (2016). Available at http://www.e-konomista.pt/artigo/o-que-e-o-premio-de-risco-e-como-o-calcular/, acedido accessed 23, September.

[W12] INE. (2016). Available at https://www.ine.pt/, accessed August.

[W13] Gerador de Preços (2016). Available at http://www.geradordeprecos.info/obra_nova/Coberturas/Planas/Nao_acessiveis__nao_ventiladas/QAD050_Cobertura_verde__sistema_Urbanscape.html, accessed 12, July.

[W14] OkTeleseguros. (2016). Available at https://www.okteleseguros.pt/, accessed 8, August.

[W15] CML. (2016). Available at http://www.cm-lisboa.pt/, accessed 16, August.

[W16] ERSE. (2016). Available at https://www.portaldocidadao.pt/web/entidade-reguladora-dos-servicos-energeticos/entidade-reguladora-dos-servicos-energeticos, accessed 8, August.

[W17] Idealista. (2016). Available at https://www.idealista.pt/comprar-casas/, accessed 8, August.

[W18] ProDeR. (2016). Available at https://www.google.pt/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwj-nOXAjJjPAhVGGhQKHYw9CFQQFggdMAA&url=http%3A%2F%2Fwww.proder.pt%2FResourcesUser%2FDocumentos_Diversos%2F221%2FProdutividades_minimas_fisica_de_refer%25C3%25AAncia_17_Jan_2011.pdf&usg=AFQjCNHBZop6RjZPc68oyblZGKj5RFYGSQ, accessed 16, August.

[W19] Continente. (2016). Available at https://www.continente.pt/pt-pt/public/Pages/homepage.aspx, accessed 17, September.

[W20] AdVT. (2016). Available at http://adlvt.pt/, accessed 25, August.

[W21] Investing. (2016). Available at http://br.investing.com/commodities/carbon-emissions-historical-data, accessed 8, August.

[W22] GHG Protocol. (2016). Available at https://www.google.pt/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwifs8OC6JzPAhUOsBQKHV2rACQQFggbMAA&url=http%3A%2F%2Fwww.ghgprotocol.org%2Ffiles%2Fghgp%2Ftools%2FGlobal-Warming-Potential-Values.pdf&usg=AFQjCNEOWKLvAiftnlv_GiE4M1vSRs9jqg&bvm=bv.133178914,d.d24&cad=rja, accessed 8, August