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Benefit-Cost Analysis of an Extensive Green Roof Project in Izmir Katip Celebi University Cigli Campus

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Abstract
Green roofs are becoming more essential part of sustainable urban planning since they can enhance the quality of urban runoff, reduce building energy use, and provide aesthetic value to the surroundings. Despite the fact that they provide significant benefits to cities, they are not widely used. Initial expenses have been discussed as a barrier to implementation, but the long term benefits associated with green roofs have largely been ignored. An accurate assessment of the entire costs and benefits of green roofs to society, cities, and the environment will assist government officials to make decisions about whether or not to invest in green roof projects. However, detailed benefit-cost evaluations related to green roofs are still lacking. Therefore, by conducting a benefit-cost analysis (BCA) on the instance of extensive green roof installation in Izmir Katip Çelebi University Cigli Campus, this study attempts to evaluate the economic viability of green roof projects in Izmir. The analysis consists of estimating four cost items and four benefit items. Benefit items were investigated under two categories: public and private benefit. The results indicate that the net present value (NPV) of the green roof is positive, although some of the benefits were not quantified. It means that the green roof project in the context of this study is worth making. This paper can help both academic researchers and government officials in Izmir understand the relative benefit and costs of green roofs under specific conditions.
Keywords: green roofs; benefit-cost analysis; net present value; economic viability

1. INTRODUCTION

Recently, natural areas in cities have been decreased and replaced with impermeable surfaces as a result of rapid urbanization. Impervious surfaces that prevent water infiltration into the soil have led to environmental problems such as urban flooding, non-point pollution, and degraded water quality (Liu et al., 2013). In addition to urbanization, increased global temperatures also negatively affect the water cycle by leading large amount of evaporation (Cullis et al., 2015). With more evaporation, more rainfall events occur in some cities, which cause flooding. According to Izmir Green City Action Plan [GCAP, 2020], precipitation is likely to increase by 2mm in the period to 2050 but by 65mm by 2100. Climate change and increased urbanization, when combined, not only intensify environmental problems but also have an economic impact on communities. Local governments have taken measures to construct sustainable cities and enhance resilience in order to address these issues. Green infrastructure which is a nature-based solution for addressing sustainability and resilience goals helps reduce the negative effects of urban development and climate change. In the context of this, many communities have promoted green roofs as a green infrastructure strategy through initiative programs and regulations to promote their advantages (Carter & Jackson 2007). Green space in urban areas is more difficult to develop due to dense blocks and expensive land prices; a green roof is being investigated since it may be implemented on top of existing infrastructure (Bae&Lee., 2012).

Green roofs are becoming very popular due to several benefits such as decreasing the amount and volume of runoff, providing new habitats for wildlife and plants, as well as their aesthetics enhancement compared to traditional roofs (Collier et al., 2013). Moreover, many studies have shown that they are beneficial in a variety of ways, including energy savings, UHI effect mitigation, and increasing membrane lifetime. There are two main types of green roofs based on their function and qualities: (1) intensive green roofs, which have a soil thickness of at least 150 mm and are mostly accessible, (2) extensive green roofs, which have a soil thickness of less than 150 mm and are mostly inaccessible (Claus &Rousseau, 2012).

Although they provide lots of benefits to cities, their installation is not very common (Carter& Keeler, 2008). The added weight on the building structure, the possibility of membrane collapse, water leakage from green roof systems, the lack of technical stuff, and knowledge about green roofs have been discussed in the literature as potential difficulties to its implementation (Shin&Kim, 2019). However, the initial cost and the expenses of maintenance are listed as the most significant barriers to implementation. Because of that, green roofs should be assessed for their economic feasibility. A benefit-cost analysis is used to determine the economic viability of green roofs in North America, Europe, and Asia. Benefit-cost analysis (BCA) compares the predicted and estimated cost and benefits related to a project. If the predicted benefits outweigh the costs, it means that the project is worth making. On the other hand, if the costs outweigh the benefits, the project may need to be reconsidered. When conducting BCA on a project, more accurate results will be obtained by converting all future costs and benefits to their present values. The present net value (NPV) is calculated by subtracting the present values of all costs from the present values of all benefits. Benefit-cost analysis has become a critical step in government policy-making (Arrow et al., 1996). This tool provides an objective policy decision on suggested initiatives. Furthermore, defining costs and benefits in monetary terms allows for a clear comparison and presentation of the results.

However, only a small number of studies compare and quantify the costs and benefits of green roofs. Previous research on the economic viability of green roofs has been evaluated. The list of costs and benefits considered in previous research is summarized in Table 1. Each study focuses on different advantages and cost items based on the green roof types and the location of the study. The benefits of green roofs have been mostly discussed under two topics: individual benefits and public benefits. Individual benefits include energy use for heating and cooling, membrane durability, aesthetics benefits, and LEED certification bonus (Clark et al., 2008; Nurmi et al., 2013). Reduced stormwater runoff, improved air quality, moderation of the urban heat island effect, and increased urban biodiversity are some of the public advantages of green roofs (Brenneisen, 2006; Rosenzweig et al., 2006).

Table 1. The list of costs and benefits considered in previous research

Variables	**Authors**								
	Wong et al. (2003)	Carter and Keeler (2008)	Clark et al. (2008)	Clause and Rousseau (2012)	Nurmi et al. (2013)	Peng and Jim (2014)	Feng and Hewage (2018)	Nordman (2018)	Shin and Kim (2018)
Cost									
Groundwork	x	x			x				x
Construction	x	x	x	x	x	x	x	x	x
Operational and Maintenance	x	x		x			x	x	x
Disposal							x		x
Planting	x	x							
Individual benefits									
Energy saving	x	x	x	x	x	x	x	x	x
Life span of the roof cover				x	x		x	x	x
Aesthetic value					x		x		x
Property value					x			x	

Noise muffling				x	x		x		
Public benefits									
Air pollution (NO2 uptake)		x	x	x	x	x	x	x	x
Mitigation of urban heat island						x			
Reduction in stormwater runoff		x	x	x	x		x		x
Water quality improvement				x					
CO2 reduction						x			x
Increment of biodiversity					x				

Clark et al. (2008) evaluated the net present value (NPV) of a green roof at the University of Michigan. The average green roofs and conventional roofs costs were calculated in this study. The research measured and included the advantages of green roofs, such as energy savings, pollutant reduction, and stormwater fee reduction. Green roof amenity values, as well as operating and maintenance expenses, were not taken into account. In the study, the NPV of the green roof was found to be 25-40 percent lower than that of the conventional roof. Finally, the long-term benefits of green infrastructure outweighed the higher initial construction expenses. Bianchini and Sewage (2012) also reported a positive NPV for green roofs. Other researchers have found negative NPVs for green roofs. For example, Carter and Keeler (2008) conducted a study of green roofs' NPV. They found that the present value cost of a green roof was 10-14 percent greater than that of a conventional roof. Previous research has shown a broad variety of results. This study will contribute to the ongoing scholarly debate about the economic viability yof green roofs by investigating an empirical extensive green roof implementation on an existing three-story building in Izmir Katip Celebi University Cigli Campus in Izmir, Turkey.

The overall purpose of this research is to look at the costs and advantages of a green roof at Izmir Katip Celebi University in order to determine the economic viability of such projects in Izmir, Turkey. The findings of this study will contribute to current literature as well as policymakers' understanding of the economic viability of installing a green roof. Furthermore, this study allows for a comparison of this investment to similar building-level investments.

2. METHODOLOGY

2.1. Study Area

Izmir is a fast-growing urban city because of immigrations. Rapid urbanization led to many environmental problems such as urban flooding, water pollution, etc., and also, have affected the quality of people's life. The city has recently taken concrete actions to address these negative consequences. The government requires buildings over 60 thousand square meters to implement green roof systems. The new regulation prepared in 2019 was approved by the Ministry of Environment and Urbanization and entered into force in June. Moreover, Izmir is one of three leading cities in the EU-funded Urban GREENUP project, which seeks to use nature-based solutions to reduce the effects of climate change, improve air quality and water management, and increase city sustainability (GCAP, 2020). Izmir Katip Celebi University is selected as a study area in Izmir. One of the reasons is that it is located in a highly urbanized area. This region is designated as a continuous urban fabric, which implies it is dominated by impervious surfaces, according to a map supplied by the European Environmental Agency in 2018. The second reason is that campuses in cities in terms of sustainability will be great examples to inspire other parts of cities to adopt green techniques. University campuses also provide great opportunities to increase awareness toward green roofs through a partnership with the government. A flat roof from the campus was chosen and investigated for benefit-cost analysis. The roof is located on the top of the central classroom 1 building (shown on the map with green color). The green-colored area is nearly 1,114 square meters (Figure 1).

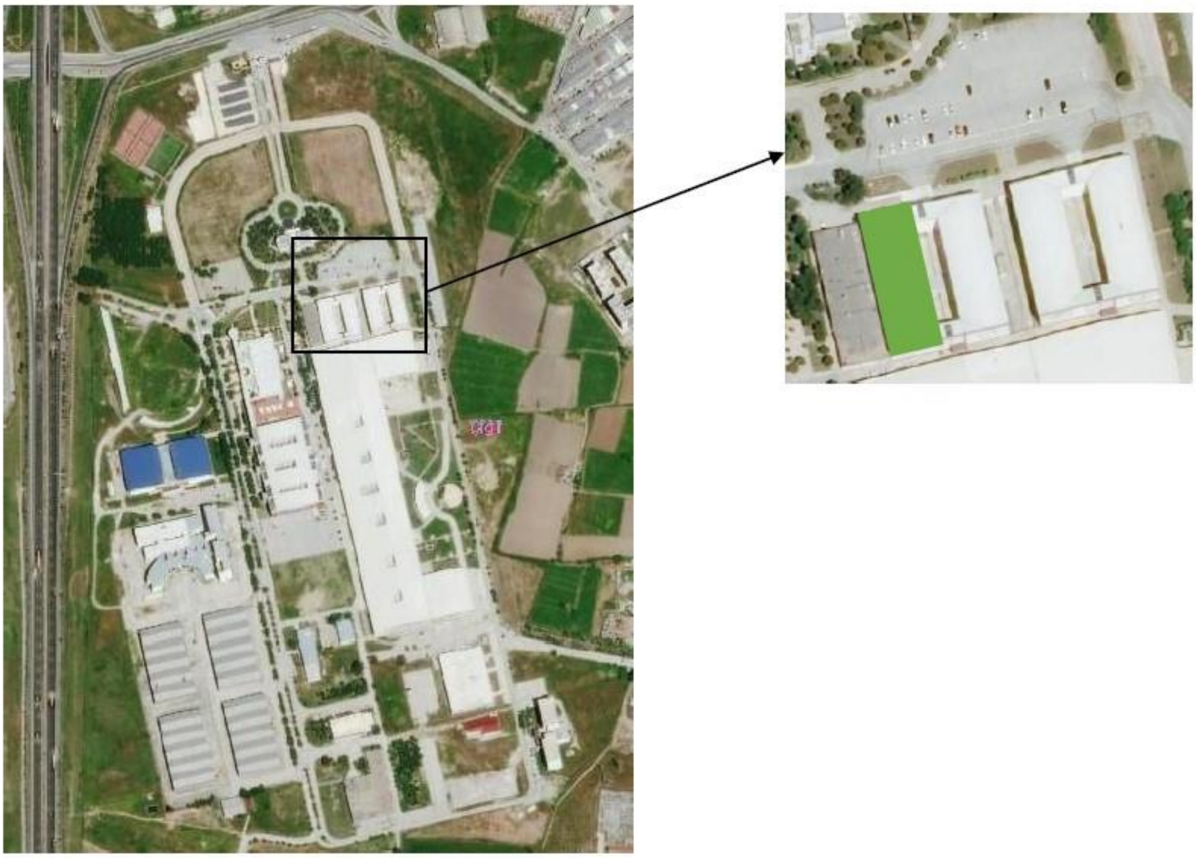

Figure 1. Location of the study area and green roof area

2.2. Green Roof Design

An extensive green roof design was chosen for this study since the selected roof was not suitable for intensive green roof design. The layers of extensive green roofs consist of waterproofing, root barrier, drainage/filtering, filter fabric, growing medium, and vegetation layer. Growth media should allow drainage, have sufficient water holding capacity, support plants' roots, and provide enough nutrients. For these reasons, a growth media consisting of minerals (70%) such as clay, sand, and broken brick, and organic compounds (30%) like compost and peat were planned to be used. The vegetation layer for the extensive green roof should consist of plants which have shallow-rooted since growth media is not very deep in extensive green roofs. Based on the climate conditions in Izmir *Sedum tectractinum* were chosen for the top layer of extensive green roofs. Figure 2 represents what the green roof design will look like and shows its layers of it. The layers of an extensive green roof which used in the study were obtained by a local firm in Izmir. Items (cost and benefits) in the analysis were calculated based on this roof. Figure 3. represents the appearance of a green roof with sedum species in this study.

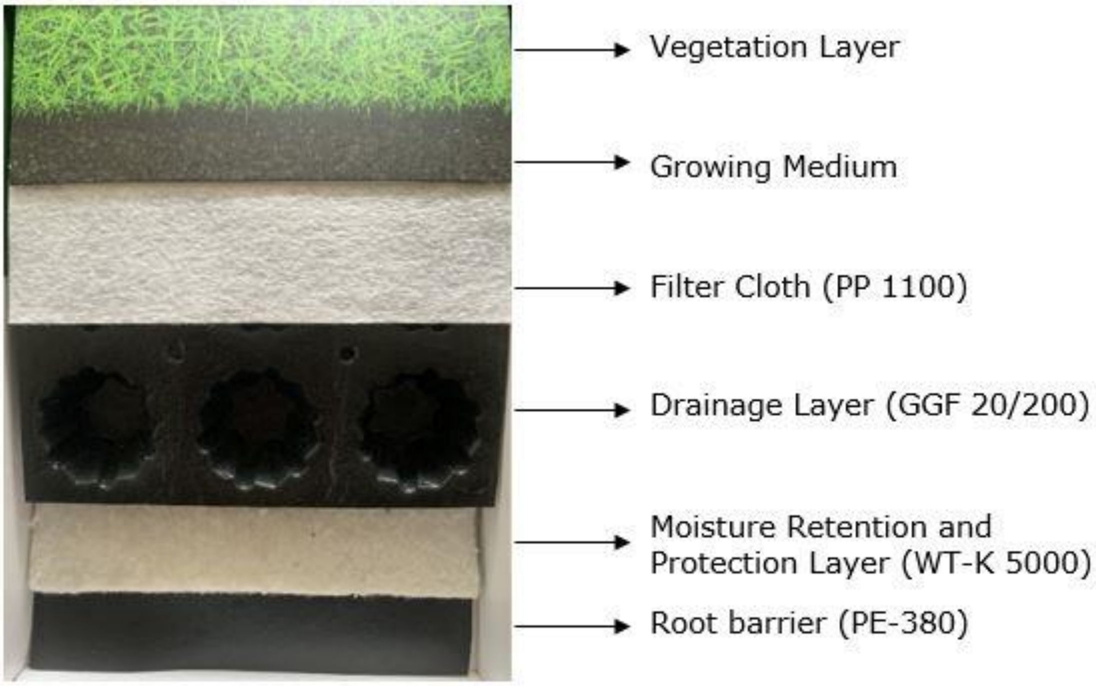

Figure 2. The layers of extensive green roof in the study

Figure 3. Example of an extensive green roof covered with sedum species (https://www.rubberroofingdirect.co.uk/roof-gardens)

2.3. **Methodology Used in the CBA of a Green Roof Project in İzmir Katip Çelebi University**

The first step to conducting a cost-benefit analysis (CBA) is to identify negative impacts (costs) and positive impacts (benefits) associated with the extensive green roof planned to install in Izmir Katip Çelebi University Cigli Campus. Benefits were divided into two groups based on prior research: public and individual. Other non-quantifiable benefits were noted as well. Physical units were used to quantify each benefit and expense. Previous research, government legislation, and corporations were evaluated to estimate cost and benefit items connected to the effects of green roofs. The present values of benefit and cost items were then calculated. The estimation involved calculation processes provided by the regulations, quotes from related businesses, and equations and values used in previous studies. Where necessary, cost and benefit values from the literature were adjusted to the City of Izmir data. Following this, after identifying the discount rate and the project's duration, the net present value (NPV) was computed. Finally, the NPV data were used to make a decision. These steps are shown in the diagram below (Figure 4):

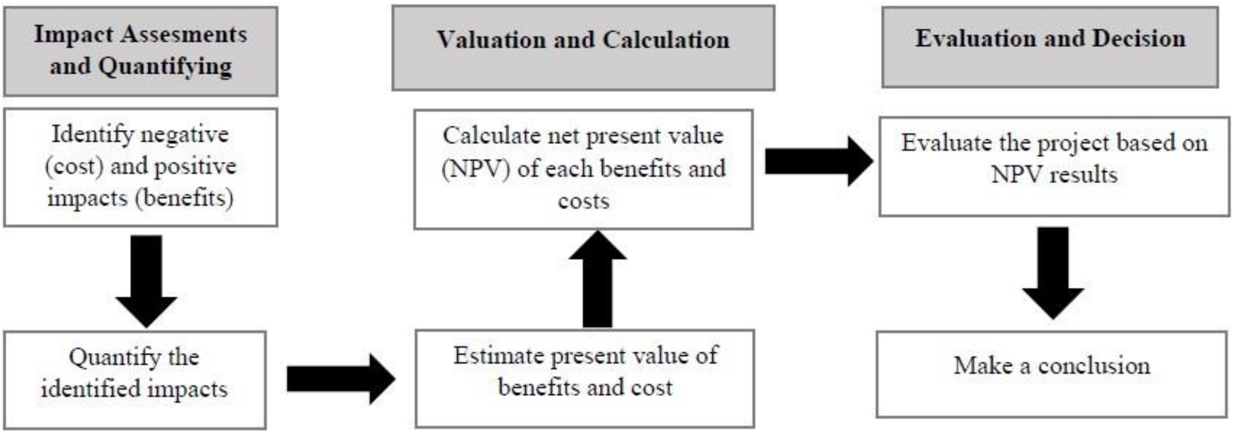

Figure 4. Steps in Benefit-Cost Analysis in this study

2.3.1. Impact Assessment and Quantifying
Estimation of Costs
Installation Cost
The whole cost of the extensive green roof installation from the foundation to the cost of planting was included in the building cost. The cost was determined based on quotations from local roofing companies and prior research in other parts of the world with similar climate conditions. The construction cost in this analysis includes the upfront cost associated with installing a green roof, such as waterproofing, structures, planting, and labor. In Turkey, the building cost per square meter is $10.5. The overall construction cost was calculated by multiplying the construction cost per unit by the entire area of the green roof installation. The entire area where an extensive green roof will be installed is approximately 1,144 square meters. In this scenario, the total installation cost is:

Total installation cost= the construction cost per square meter x the entire area in square meters

$11,697= 10.5 x 1,114

Operational and Maintenance Cost
Although green roofs are natural systems, they still require ongoing maintenance. On average, two to four annual maintenance appointments are required for a large green roof. Maintenance sessions for an extensive green roof in this study include weeding, checking the loss of growth medium, plants, and other potential problems such as leakage, insufficient drainage, etc. Sedum-covered roofs like in this study are easier to take care of and can survive without water for a long time so two maintenance sessions were assumed in this investigation. The same landscape design firms provided the total cost of maintenance. The average per square meter is .2 cents. The cost of operation and maintenance was calculated using the formula below:

Operational and maintenance cost= the cost of maintenance per square meter x the entire area in square meters x number of maintenance sessions in a year

$445.6 = 0.2 x 1,114 x 2

Disposal
Removal and disposal costs were included in this study because green roofs are expected to be removed after the 50-year operation term. Since there is currently no information

about green roof deconstruction in Turkey, the cost of removal was calculated using prior research. Green roofs can be disposed of in a variety of ways, including landfill, reuse, and recycling. Since recycling requires certain facilities, which most cities do not have, the calculation was based on landfilled option. Bianchini and Hewage (2012) estimated that the cost of disposing of green roof materials is between .3 cents and .2 cents per square meter. The disposal cost was estimated at .115 cents per square meter for this investigation. Disposal cost was calculated using this equation below:

Disposal cost = the entire area in square meters x the cost of disposal per square meter

$128.11= 1,114 x 0.115

Estimation of benefits

Public benefits

Reduction of Stormwater Runoff

Stormwater management is a problem in the City of Izmir. The city of Izmir and the Landscape Research Society has published a guideline named 'Resilient Cities to Climate Change: Green Revision Guidebook' to make the city more resilient to climate change. One of the recommendations of this guide was related to stormwater management such as increasing pervious surfaces in urban areas, the capacity of water infiltration, and reducing the number of impervious surfaces. Wastewater and stormwater are collected in the same pipe in Izmir and transferred to Çiğli and Southwest Wastewater Treatment Plants (GCOP, 2020). Reducing the amount of runoff that goes to the combined pipe systems will reduce the burden on the drainage network of Izmir.

Green roofs can prevent flood risk in cities by slowing and reducing the amount of stormwater runoff (Getter&Rowe, 2006). Compared to traditional roofs, green roofs can hold water and increase buildings' stormwater retention capacity. In addition to reducing stormwater volumes, green roofs reduce water pollution by improving surface water quality. This will decrease the amount of money spent annually on purification by municipal governments (Tomalty& Komorowski, 2010). In literature, while some authors quantify all the benefits related to stormwater management (groundwater replenishment, decreased water pollution, etc.), others can quantify some of them. For this study, we were able to quantify the reduced amount of stormwater through green roof installation in the current scenario. The term "reduced" refers to the reduction in stormwater entering the storm drain systems. The reduction in the amount of stormwater or treatment on-site will reduce emissions associated with the energy required to run wastewater treatment plants (GCAP, 2020).

The most reachable resource on the benefits and costs of green roofs is the Green Values Stormwater Toolbox calculator. The calculator employs a simple interface that allows users to enter lot-specific information and calculate stormwater runoff volume and reduction. Many authors have used this method to evaluate the value of green infrastructure options to traditional stormwater management strategies (Nordman et al., 2008; Beauchamp&Adamowski, 2012). The calculator allows you to customize your site. All of the required information to calculate the amount of rainwater absorbed by the green roof was updated based on the city of İzmir. Under the current circumstances, the extensive green roof in this project can hold 2,204.3 cubic feet (62.43 cubic meters) of rainwater. This implies that 62.43 cubic meters of stormwater runoff will not be treated since it will be absorbed by the green roof, saving the government money otherwise spent on treatment. However, no information was obtained related to stormwater treatment costs in Turkey. After that, prior research was investigated. In the literature, the authors used different amounts to estimate the cost. For instance, the purification costs of wastewater in Flanders were at .7580 euro/ft^3 (Claus & Rousseau, 2012). Hao et al. (2010) considered an operational cost of 2.205 euro/m^3. Since there are no up-to-date studies related to the treatment of the stormwater runoff, this study used the estimate of the CNT calculator, which is 26.57$ (reduced treatment benefits for 62.42 cubic meters).

Improvement of Air quality

Industrial firms in Izmir have produced major air and soil pollution issues. As a result, pollution reduction is crucial for Izmir to protect human health and the environment. There are 23 air-quality monitoring stations in Izmir. Data on PM10, SO2, CO, NO, NO2, and NOX was gathered from stations to see if the findings met national limit levels. According to Turkey National Air Quality Monitoring Network, levels of NO2, SO2, and PM in Çiğli, where the university is located, are high.

Green roofs can reduce air pollution by absorbing pollutants mentioned above through vegetation (Norman et al., 2018). Many cities with green roof installations have shown a significant decrease in air pollution. According to Berardi (2014), Singapore achieved to diminish air pollution by 37%. Clark et al. (2008) found that green roofs can lower energy demands and NO2 emissions in on-campus buildings with green roofs in another research. Yang et al. (2008) also measured the pollutants O3, NO2, and PM10 and found that green roof installation reduced them by 52 percent, 27 percent, and 14 percent, respectively.Unfortunately, the amount of data available on SO2, O3, and PM absorption by green roofs is inadequate to quantify, hence this study focused on NO2 reduction. There are different studies in the literature to quantify green roofs' air pollution benefits. One of them is Clark et al. (2008)'s study in Detroit and Chicago. This study found that sedum species absorb 0.01 pound NOx per ft2 and NO2 reduction was valued at $3,375 per US ton in 2004. Because sedum species were used on the green roof in this study, this estimate may be applied to ours.

Moreover, this estimation by Clark et al.(2008) is also most accepted and used in literature (Clause& Rousseau, 2012; Norman et al.2018, Feng, 2018). According to this estimation, sedum species can absorb 0.01 pound/ per ft2 (0.04 kg/m2). Since we have a 1,114 square meters green roof covered with sedum species, our green roof can absorb 44.56 kg NO2 (1,114 x 0.04) After this, we can quantify the benefits. Because there is no data available in Turkey to assess the cost of removing air pollution, the study relied on an estimation rate from previous research. According to Clark et al. (2008), the government spent $1.69 per pound ($3.73 per kilogram) to remove NO2. Our green roof will save $166.20 per year in our current scenario ($3.73 x 44.56 kg = $166.2).

Private Benefits

Energy saving

A green roof can decrease the energy consumption of a building by increasing the insulation function (Carter &Keeler, 2007). The energy-saving depends on the size of the building, the climate zone, and the type of green roof (Oberndorfer et al., 2007). The urban heat island effect will increase the demand for air conditioning so energy saving will gain more importance (GCOP, 2020). According to studies related to green roofs' energy savings, the savings can range from 2% and 48% depending on the environmental conditions (Berardi, 2014; Niachou et al., 2001). Coma et al. (2006) conducted an experimental study in Mediterranean conditions, similar to the city of Izmir's weather. In the study, during summer, the energy consumption of an extensive green roof was between 15% and 17%, and it was observed 10%-12% during winter sessions (Coma et al., 2006). Based on this, 16 percent of savings for summer and 11 percent of savings for winter were employed in the calculations for this study.

The city of Izmir, located in the Aegean Region of Turkey, has warm winters and hot, sunny summers. The electrical energy unit price was taken as 0.16/kWh, which is representative of electricity costs in Turkey's Aegean area. Because the rooms beneath the green roof at Izmir Katip Celebi University are being used as office space in this project, the yearly computation was based on the energy usage of office users. In Izmir, the air conditioner (AC) is used for over 8 months of the year.

On a hot summer day or a cold winter day, it was assumed that the office users used the AC for the duration of 9 h/ day. The AC with 9000 BTU consumes 0.8kw energy for one hour, and if we assume that it works 9 hours a day, its daily electric cost will be approximately $1.15/day for each office. There are almost 30 offices under the green roof. In this calculation, the daily energy consumption for 30 offices is $34.56/day. It equals $1,036 monthly. For summer times (almost 4 months), the cost will be $4,144, and 16% of it will be saved ($663.04). For winter times, the cost will be 4,144$ as well, but 11% (which equals $455.84) of it will be saved at this time. The total energy saved as a result of the green roof installation was anticipated to be $1,118.88.

Roof membrane

In traditional roofs, roof membranes should be replaced after twenty-five years (Mann, 2002). Vegetation cover on green roofs, on the other hand, may absorb UV and IR radiation, potentially doubling the life of the roof membrane (Getter et al., 2009). Oberndorfer et al. (2007) also stated that green roofs can increase the life span of roof membrane additional 20 years. Moreover, green roofs protect the roof membrane from storm events, temperature fluctuations, and weather circumstances (Doshi and Peck, 2013). Based on the studies related to the roof membrane and quotes from companies in Turkey, the expected savings from roof replacement is approximately $107.64/m2. This was calculated by multiplying this amount with the green roof's size in this project, which equals $119.910 (1,114 x 107.64).

Other Benefits Which Could Not Quantified

Increment of Biodiversity

Green roofs can help to promote local biodiversity by providing habitat for a range of animal species, including birds and insects. Many major cities have published a manual to encourage biodiversity on green roofs such as Toronto, London, etc. (Torrenca et al, 2013). Quantifying the increase in biodiversity, however, is challenging when compared to other quantifiable benefits. Furthermore, in the framework of this study, the extensive roof will be implemented, which has less biodiversity compared to intensive green roofs.

LEED Certification

Green roofs are also commonly built to obtain LEED certification. According to studies, LEED-certified office buildings rent for 4-7 percent more than comparable non-certified buildings (Fuerst&McAllister, 2011). Building developments must satisfy specific requirements to receive LEED certification. Because the current project did not match these criteria, the benefits of earning LEED certification were not quantified.

Noise Muffling

Green roofs have a good impact on a building's acoustic qualities. By providing weight to the roof structure, layers like substrate and drainage, as well as plants and growth media, may help minimize noise. Van Renterghem and Botteldooren's (2009) study demonstrated that green roofs can prevent traffic noise. Noise absorption greatly depends on the bulk of the structure. However, there is no traffic noise around the study area hence this benefit was not quantified.

Aesthetic impact

Green spaces have a positive impact on people's moods because they enhance mental and physical health, as well as social well-being (Abraham et al., 2010). Studies have demonstrated that a direct view onto a green roof will increase the price by 6% (Bianchini and Hewage, 2012). Furthermore, because no passers-by would see green roofs, evaluating their aesthetic impact in the context of this study will be impossible.

2.3.2. Calculation-Net Present Value Analysis

After assessing all relevant costs and benefits associated with an extensive green roof project in Izmir Katip Celebi University, net present value (NPV) was calculated using a discount rate. A discount rate is very critical in determining NPV in a project. The discount rate can be defined as an interest rate applied to the cost and benefits that are predicted to occur in the future. A 3 percent discount rate is appropriate for environmental projects with a lifespan of 30-75 years (Almansa and Martínez-Paz, 2011; Gollier and Weitzman (2010). The lifespan of a green roof has been estimated as about 40 years minimum and 55 years maximum (Mahdiyar et al., 2016). In this analysis, 50 years is used to conduct the assessment since many studies implied that green roofs can double the life span of a roof (which is twenty-five years) (Porsche and Köhler, 2003; Saiz et al., 2006). Companies related to roof construction in Izmir also confirmed that the roofs can be replaced after twenty-five years. Based on the benefits and costs of green roofs introduced above, the NPV equation below was used to analyze the cost and benefits (Figure 5):

$$NPV = \sum_{i=0}^{n}\left(\frac{B_i}{(1+r)^i} - \frac{C_i}{(1+r)^i}\right)$$

Figure 5. NPV Equation

Bi and Ci are the values of the benefits and costs that accumulate over a year i. The discount rate is r, and the project's net benefits are added up over time (n year). This formula was used to calculate all expenses and benefits. Table 2 detailed all of the economic inputs and outputs for the analysis.

3. RESULTS

Based on the results shown in Table 2, we can compare the private and public benefits of extensive green roofs. The total NPV of individual benefits in 50 years is $28,815 and the total NPV of public benefits in 50 years is $4,959. It is obvious that the individual benefits are over six times greater than the public benefits in the current scenario. Overall, total benefits (both public and individual benefits) are $33,775.01. The total NPV of lifecycle costs for green roofs in 50 years is calculated as $23,191.24. Based on these findings, this project's NPV is positive (-$23,191.24 + $33,773.01= $10,583.77). Positive NPV means that this project is worth making. In this scenario, even if we estimate only individual benefits, this project still has a positive NPV.

Table 2. Economic inputs and NPV results

		Value	Time-frame	NPV
Economic factor	Life-span	-	50	
	Discount rate	%3		
Costs	Initial cost	$11,697.00	One time	$11,697.00
	Operational and Maintenance cost	$445.6	Annual	$11,465.00
	Disposal	$128.11	At year 50	$29.24
Total cost				**$23,191.24**
Benefits				
Public benefits	The reduction of amount of stormwater	$26.57	Annual	$683.64
	Improvement in air quality (NO2 emission)	$166.20	Annual	$4,276.00
Total public benefits				**$4,959.64**
Private benefits	Energy savings	$1,118.88	Annual	$28,788.00
	Roof membrane	$119.90	At year 25	$27.37
Total private benefits				**$28,815.37**
Total benefits				**$33,775.01**

4. DISCUSSION

Findings and Implications

In literature, various benefit-cost analyses were conducted under different scenarios. Each author has investigated different types of green roofs or benefits and cost items associated with green roofs. In the context of this study, the cost and benefit items were determined and quantified for an extensive green roof project in Izmir Katip Çelebi University. The estimation was mostly based on existing literature and quotes from roof companies in Izmir. The results in the Table 1 indicated that the construction of an extensive green roof in Izmir Katip Çelebi University was desirable. Although other benefits associated with extensive green roofs could not be expressed in monetary terms, the NPV result was still positive. These unqualified benefits were listed as LEED certification, aesthetic improvement, etc. Including these benefits may increase the desirability of green roofs. The most significant benefits associated with extensive green roof in Izmir is the increase in roof life, improved air quality, and energy savings. Compared to these benefits, the avoidance of stormwater costs is less. According to Carter and Keeler (2007), one of the benefits of green roofs is that it increases the life of the roof membrane, and green roofs would be more expensive than traditional roofs without this benefit. However, this benefit was not significant compared to other benefits such as energy savings and improved air quality in the current study. The reason might be that replacing a roof costs differently in different regions. The life span of green roofs, counted as 50 years in this study, is crucial in benefit-cost analysis. The results of Arcadis's (2008) study in Rotterdam were strongly influenced by a longer life span of green roofs.

These results support some studies (Clart et al., 2008; Bianchini and Hewage, 2012), which reported positive NPV results. In Clark et al. (2008)'s study, the amenity benefits and operational and maintenance costs of green roofs were not included. Including different benefits and costs might change the results of the study. On the other hand, some authors found negative NPV results (Carter& Keeley et al., 2007; Sproul et al., 2014). The difference between the current study and other studies with negative NPV may be because different green roof types were used. Investigating different types of green roofs means that benefits and costs associated with these roofs might also change. For instance, an intensive green roof can provide more value like biodiversity enhancement, community space provision, etc. than an extensive green roof. Even if a similar type of green roof was employed or the same benefits or costs were estimated, the results still might be different. The reason might be that the economic feasibility of green roofs is mostly region-specific. For example, when calculating the reduced amount of stormwater runoff, we use rainfall data and weather conditions of the study area. Moreover, when estimating installation costs, each city has different amounts. Green roofs are widespread in Europe and America compared to Turkey because the government provides financial incentives or makes it mandatory to install green roofs in most cities. As a result, installation cost might be low compared to Turkey. The installation and maintenance cost is more likely to decrease when the market of green roofs expand.

Overall, the difference in results related to benefit-cost analysis studies might be because of (1) the location of the study area or (2) the type of green roof or (3) different cost and benefit items, or (4) different installation cost and benefit values. Therefore, more region-specific studies are needed to compare the benefits and costs of green roofs. However, studies in different regions are also great resources since continuing research might apply the techniques to different climate conditions and cases.

Limitations and Significance

There are two limitations to this study. First, some benefit items could not be included in this study. A few benefit items, such as noise cancellation and property value, were not considered, as they are not applicable in the context of this study. Furthermore, due to data availability, air pollutant removal estimation and cost of stormwater treatment relied upon data obtained from international studies. Further research is required to obtain more data for the conditions of Izmir. Another limitation is that only direct factors were included in the analysis. For example, the reduced cost of stormwater treatment was investigated, but other indirect factors related to the reduction of stormwater such as a decrease in water pollution, groundwater replenishment, etc. were not investigated.

The significance of this study is that it might be a pioneer since there are no other studies related to the BCA of green roofs in Izmir. This research might provide data for researchers who will study green roofs in Izmir. The benefit-cost analysis described here might also have applications beyond Izmir Kâtip Çelebi University. With some adjustments, the values calculated here might be more broadly applied. Future research can build on this investigation and provide value to both literature and city officials in the City of Izmir.

5. CONCLUSION

The city of Izmir needs green spaces, and keeping adequate green areas in such a densely populated city has been difficult. Green roofs are an excellent choice for converting impermeable areas to green spaces. Greening cities with green roofs will gain more importance in the future because of their environmental and economic advantages. Green roofs may help alleviate the effects of urbanization and the consequences of climate change such as increased precipitation and extreme weather events. This paper focused on evaluating the economic feasibility of green roof projects in Izmir by corporating four benefits and four cost items. This analysis resulted that installing an extensive green roof on campus is suitable. It means that the benefits of the green roof outweigh its increased costs. Although applying green roofs to every rooftop in Izmir might not be possible for all buildings, this paper demonstrated the effectiveness of an extensive green roof in a campus environment with Mediterranean climate conditions.

As cities continue to become more highly urbanized, providing a balance between natural and built environments will gain more importance. Governmental actions are required to spread the installation of green roofs. If green roofs increase, the cost of installation will decrease. It means that economic feasibility will increase as well. This research can inform policymakers about the economic feasibility of green roofs and can be used as a guideline to calculate benefits and costs for future green roof projects. Financial incentives are very critial to encourage their use. City officials in Turkey may think about providing incentives when a green roof project has a positive NPV result. Moreover, this paper also contributes to ongoing research about the BCA of green roofs and provides an example from a Mediterranean climate.

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