# A Framework for Cost-Benefit Analysis of Green Roofs: Initial Estimates

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## Background

Environmental cost-benefit analysis is a decision support tool that provides a format for enumerating the range of benefits and costs surrounding a decision. In this study, cost-benefit analysis is used to determine the economic value of green roofs for both private decision makers (i.e., building owners) and public decision-makers (i.e., city and state policy makers) in New York City.

Environmental cost-benefit analysis involves determining which benefits and costs to consider, the means to measure them, and approaches for aggregating them, accounting for present and future cash flows associated with an investment related to the environment (such as a green roof). Many seemingly worthwhile environmental projects are never implemented. Such cost-benefit analysis can be used to choose among a range of alternatives, to compare seemingly different environmental projects, and to identify instances where specific groups are given advantages or disadvantages. Benefits and costs are converted into present values by discounting and summing future benefits and costs into present terms. These dollar-denominated present values allow decision-makers to compare the value of investments across potential uses of scarce financial resources.

Green roofs provide private and public property owners numerous potential benefits, but these benefits can be difficult to quantify and value. Benefits can take many forms including reductions in harmful environmental impacts and private cost savings associated with energy production. Green roofs may even provide aesthetic benefits and habitat ecosystem values. Quantifying the benefits from reducing environmental impacts can be difficult given the wide range of contexts in which green roofs might be developed. For example, a green roof installed on a Manhattan skyscraper will not have the same impact on energy use as one installed on a warehouse in Queens. Similarly, due to differences in the sewer and treatment system, green roofs installed in the Newtown Creek sewage-shed may not yield the same reduction in combined sewer overflow (CSO) as a similar sized system in the North River sewage-shed (see Tillinger et al., this report).

Moreover, even where environmental impacts can be reasonably quantified, it may still be difficult to derive the full economic value of the benefits. For example, sewer system complexities can compromise efforts to directly correlate reduced runoff volume (from green roofs) with reduced treatment costs. In addition, green roofs will have different levels of public benefits depending on the scale over which they are installed. We are therefore designing flexible computer models that will permit users to evaluate green roofs in a variety of ways.

Examples of cost-benefit analyses applied to green roof infrastructure in North America are rare. One example, a life-cycle cost (LCC) analysis of an individual building in Multnomah County, Oregon, shows that the project is a good investment for the county (Lee, 2004). This project however was partially paid for by outside funders and without this funding, the project would not have had a positive life-cycle cost (Lee, 2004). The LCC analysis included first cost (i.e., installation cost), replacement cost for the roof membrane, energy costs, stormwater costs, and the residual value of the roof at the end of the life-cycle period analyzed, with all cash flows converted to present value using a real discount rate of 3% per year (Lee, 2004). Energy impact was measured as the net effect on heating and cooling costs, and stormwater costs were based on a reduction in the City of Portland's stormwater fee. Although New York City has a building-level stormwater fee, green roofs have not yet been approved as stormwater infrastructure, so stormwater is not included in our building-level analysis for New York.

Another example is a 1999 study of buildings in Chicago, IL, conducted as part of the City's Urban Heat Island Initiative. The analysis estimates that greening all of the city's rooftops (30% of 224 square miles) would save $100 million in annual energy costs and would cut peak electricity demand by 720 megawatts (Roy F. Weston, Inc. 2000). This study projected cooling cost savings for a green roof on Chicago's City Hall to be about $3,600 annually (Roy F. Weston, Inc., 2000).

In addition, a cost-benefit analysis for a hypothetical medium-rise building in Singapore shows a positive life-cycle cost only when an extensive, inaccessible green roof is installed, and energy savings from year-round cooling requirements are included (Wong et al., 2003). The Singapore analysis includes assumptions on service life (i.e., the life of the waterproof membrane on a standard roof compared to that on a green roof), installation, operating and maintenance costs, and inflation and discount rates (Wong et al., 2003).

The present cost-benefit model considers the benefits and costs of individual green roofs as well as green roof infrastructure, with assumptions specific to New York City. It assumes uniform extensive green roofs planted with *sedums* and/or other related plants. The objective is to illustrate the methods employed in cost-benefit analysis and to provide preliminary estimates of benefit-cost ratios associated with green roofs. It is important to note that actual benefits and costs vary widely depending on building type and use, green roof location, green roof system selected, and the extent to which green roof infrastructure has already been adopted and/or supported at the municipal level.

## Methods

Development of the green roof cost-benefit model involved the delineation and valuation of the potential benefits and costs of green roofs. Costs and benefits were aggregated and discounted in a spreadsheet model. Benefit-cost ratios for private (single building) and fifty percent green roof infrastructure scenarios are presented.

### *Determining Benefits and Costs*

Potential benefits and costs of green roofs were determined based on a survey of prior research. Benefits and costs were then divided into private and public. Private costs are those paid for by a building owner or residents, for example green roof installation and maintenance costs. Private benefits include energy savings and cost-savings associated with the longer service life of a roof membrane. Public costs might include a subsidy or other government program paid for by taxpayers that is aimed at increasing adoption of green roof infrastructure. Public benefits are those experienced by a preponderance of city residents, regardless of whether the building they live in has a green roof, and include reduced stormwater runoff and urban heat island reduction.

Private and public benefits were further divided into two tiers. Tier I includes benefits and costs covered by the research areas covered in this report related to energy, hydrology, and the urban heat island and are listed in Table 1. In general, Tier I costs and benefits appear to be more significant and well-defined in the near-term. Tier II adds potential benefits such as improved air quality and public health, reduced greenhouse gas emissions, increased property values due to sound insulation, and the aesthetic enjoyment derived from viewing and being near plants.

### *Cost-benefit Model Calculations*

A cost-benefit model for green roofs was developed in Excel permitting the user to enter

Table 1. Baseline data for cost-benefit analysis.

| Fixed inputs | Value |
|---|---|
| **Private green roof scenario** | |
| Roof area for an average flat roof in New York City (sq. ft.) | 2,397 |
| Percent of roof area greened | 75% |
| Green roof area (square feet) | 1798 |
| Time period (number of years) | 55 |
| Private discount rate | 8.00% |
| Inflation rate | 3.00% |
| **50% Green roof infrastructure scenario** | |
| Flat roof area in New York City (acres) | 21,249 |
| Percent of New York City's flat roofs greened | 50% |
| Percent of each roof greened | 75% |
| Flat roof area greened (acres) | 7968 |
| Approximate number of roofs greened | 144,832 |
| Average size of each green roof (square feet) | 2,397 |
| Percent of land area in New York City with green roofs | 4.2% |
| Time period (number of years) | 55 |
| Social discount rate | 5.00% |
| Inflation rate | 3.00% |

numerous assumptions that in turn generate differing financial output. The model can explore several cost and benefit scenarios and scales of implementation. Two general model scenarios were chosen: 1) a private green roof scenario and 2) a 50% green roof infrastructure scenario. Flat roof area data from Hydroqual/Comcarto were used to generate roof areas associated with each scenario (Hydroqual/Comcarto, 2003). The private scenario assumes a single green roof of 1,798 square feet (167 square meters). The infrastructure scenario assumes 7,968 acres (32 km$^2$) of green roofs. This corresponds to about 144,832 roofs or 4% of New York City's total land surface area of 189,131 acres (765 km$^2$).

In the private analysis, we assume that the green roof is paid for by the building owner and benefits the owner and/or building residents. In the infrastructure analysis, the costs associated with administering a municipal-level support program for green roofs are added to installation costs, and public benefits such as stormwater runoff and heat island reduction are included.

Model inputs include baseline data for each scenario and variable assumptions reflecting high, medium, and low green roof performance. The medium performance scenario represents our current best guess for all parameters. The low and high scenarios are used to illustrate the range of benefits and costs associated with extensive green roofs. However, because all the high-performance parameters (i.e., high stormwater retention, large heat island reduction, low costs, etc.) are grouped into a single scenario, this scenario is likely unrealistically high. Conversely, the low performance scenario results are aggregated in the other direction. All data were converted into common units in the model and the time period for the analysis is 55 years.

## *Tier I Private Benefits and Costs*

***Installation costs*** The installation costs represent the private investment in a green roof project. The estimated cost of installing a standard (non-green) roof is $9 per square foot (W.P. Hickman Systems, Inc., 2003; verified with Marshall and Swift Manual, 1998). Industry estimates from green roof manufacturers range from about $10 per square foot to $25 per square foot or more for an extensive green roof. In general, the cost of installing an extensive green roof (including new waterproof membrane, drainage layer, growing medium, and vegetation) is about twice as expensive as installing a new waterproof membrane on a standard roof. Therefore a cost of $18 per square foot was used for the green roof installation cost in the medium scenario. In the high-performance scenario, the cost was reduced to $12 per square foot and in the low scenario it was increased to $24 per square foot.

***Architecture and engineering costs*** Architecture and engineering costs associated with green roof installation was assumed to be 0.20% of installation costs.

***Service life*** On a standard roof, the waterproof membrane is generally replaced every 20 years due to damage from ultraviolet radiation. Because the green roof protects the membrane from sunlight damage and large-amplitude diurnal temperature cycles, its service life is expected to double. Following Wong et al. (2003) and Lee (2004), this analysis assumes a standard roof service life of 20 years and a green roof service life of 40 years. In other words, although a green roof is approximately twice as expensive to install, its service life is doubled. The low scenario assumes that there was no improvement in service life and the high scenario assumes a 60-year service life.

***Maintenance costs*** For standard roofs, maintenance costs of $0.10 per square foot were estimated based on data from the Institute for Real Estate Management (IREM) (IREM, 2003). On extensive green roofs, minimal maintenance is needed; estimates range from $0.06 to $1.25 per square foot per year (Giesel, 2003; Peck and Kuhn, 2003). In this analysis, a median value of $0.60 per square foot per year is used for the medium-performance scenario. The high-performance scenario assumes that the maintenance costs for a green roof will be no higher than the maintenance costs for a standard roof, and the low-performance scenario assumes the costs will be $1.10 per square foot per year.

***Energy used for cooling*** Green roof impact on energy used for cooling is the most difficult input parameter to estimate because it will not be the same for any two buildings. Cooling demand depends on building specifications, location, and use, among other factors. An average cost of cooling a building with a standard roof in New York City was estimated at $0.16 per square foot through five independent calculations. Sources for the calculations include the Energy Information Administration in the U.S. Department of Energy (EIA, 2004), the New York State Energy Research and Development Authority (NYSERDA, 2004), the Building Owner and Manager's Association 2003 Experience and Exchange Report (BOMA, 2003), Efficient Windows (EW, 2004), and the EPA Energy Star Roofing Comparison Calculator (EPA, 2004). The medium scenario assumed that a green roof could reduce energy demand for cooling by 15%. This is higher than preliminary results from an experiment at the Pennsylvania State University Center for Green Roofs Research, which show a reduction of approximately 10% (Berghage, 2004). However, it is substantially lower than the 75% reduction in cooling demand during the summer months found for a small experimental building in Ottawa (Liu and Baskaran, 2003). In a Manhattan skyscraper, the reduction may be less than 1% and for a single-story office building in Queens, the reduction could be more than 20%.

## Tier I Public Benefits and Costs

Green roof infrastructure would result in the following additional public benefits and costs.

***Urban heat island*** The urban heat island effect refers to an increase in urban temperatures as compared to surrounding suburban and rural temperatures (see Solecki et al. in this report). Green roof infrastructure could reduce outside urban air temperatures, and this could result in lower demand for cooling throughout New York City in the summer. Results from the research in this report show that 50% green roof infrastructure could reduce surface temperatures by 0.1 to 1.4°F. We assume a linear relationship between surface temperature and air temperature and use the average value of 0.8°F for the medium-performance scenario. 0.1°F is used in the low-performance scenario and 1.5°F is used in the high-performance scenario. We assume that air conditioning is turned on when the temperature rises above 65°F; this is used in heating-degree-day calculations. We estimate average summertime temperatures in New York City at 80°F based upon temperatures registered in recent years. The percentage reduction in this 15°F gap with green roofs was calculated. With a 0.8°F reduction, the gap was reduced by 5% (from 15°F to 14.2°F), resulting in a 5% reduction in energy demand for cooling with a total cost savings of $213 million. In the low-performance scenario, demand was reduced by 0.7% and in the high-performance scenario demand was reduced by 10%.

***Stormwater runoff capital expenditures and operating costs*** The ability of green roof infrastructure to capture rainfall during storms could reduce the amount of stormwater that enters the sewer system and is then directed to wastewater treatment plants. This could have the effect of reducing capital expenditures and operating costs for wastewater treatment. In this analysis, we assume a linear relationship between the amount of water that enters a treatment plant and the capital expenditures. Current annual capital costs are ~$180 million based on data published in the New York City Budget and Mayor's Management Report (NYC IBO, 2003), and the Independent Budget Office of the City Council (2004). In the medium scenario, we assume that green roofs can retain 50% of the rainwater that falls on them (see Tillinger et al. in this report). This high scenario assumes 80% capture, and the low scenario assumes 20% capture. Rainfall capture is multiplied by land-area greened (4% of New York City's land area with a 50% green roof infrastructure scenario) and percent combined sewage from rainwater (an estimated 65% for New York City) to obtain the percent reduction in combined sewage that enters the sewer system. This figure is then multiplied by a scale factor of 90% because it is unlikely that a 10% fall in CSO will reduce expenditures by 10%. With the medium scenario, capital expenditures were reduced by 1.9%. With the low scenario they were reduced by 0.6% and with the high scenario by 3.4%. We further assume that green roofs would cut operating costs by 10% of capital expenditures or $18 million.

***Scale factor for installation and maintenance costs*** In the private scenario, installation costs for a green roof were estimated at $18 per square foot. The infrastructure scenario involves greening over 144,000 rooftops. If adopted, economies of scale would almost certainly bring down the costs. One study suggests that for each doubling in production volume of several selected environmental technologies, the amount by which costs decline is in the range of 0.7 to 0.9 (Papathanasiou and Anderson, 2001; see also IEA, 2000). Scaling up from a single green roof to over 144,000 green roofs involves approximately 18 doublings, which would reduce costs to 0.02 * $18 per square foot or $3.6 square foot. However, given the base cost of $9 per square foot for a standard roof, a reduction of this magnitude is unlikely. Instead, we assume that scaling would reduce installation costs to $15 per square foot for the medium scenario. In the high-performance scenario, cost is reduced to $10 per square foot, just above the cost of a standard roof. The low-performance scenario assumes that cost remains at $18 per square foot.

***Program costs*** A green roof infrastructure program would likely require some degree of administrative support at the municipal level. Initial program administration and setup costs are estimated at 0.1% - 0.3% of investment (installation) costs or just over $30 million for the medium scenario.

### *Tier II Private Benefits*

***Sound reduction*** According to research done by Zinco, a green roof company in Germany, green roofs provide sound insulation of approximately 3 decibels (Zinco, 2003). This figure is used to estimate the change in property value for buildings with green roofs in New York City.

***Food production*** Several green roofs have been used to grow food crops, including the Fairmont Hotel in Vancouver. Food production value is estimated at $0.10 per square foot for the medium scenario based on the Fairmont Hotel's production (GRHCa, 2003).

***Private aesthetic benefits*** Aesthetic benefits are based on the value of enjoying a green roof as a building amenity. For the medium-performance scenario, it was assumed that the green roof would benefit 6 people: two of whom would be willing to pay $50, two $25, and two $10. For the high-performance scenario, this figure was doubled and for the low scenario, it was cut in half.

### *Tier II Public Benefits*

***Greenhouse gases*** A study in Toronto estimated that greening all rooftops could cut greenhouse gas emissions by 2.4 megatons annually (GRHCb, 2003). To obtain a crude estimate of the potential impact in New York, we multiplied this figure by the population of New York relative to the population of Toronto. Savings for the medium-performance scenario were $0.18 per square foot (see Parry, 2003; Tol, 2003; CEA, 1998).

***Air pollution*** The same study indicates that 10.8 square feet (1 meter) of grass roof can remove 0.44 pounds of airborne particles per year (GRHCb). Thus, airborne particulates should be reduced by 0.04 pounds per square foot of green roof. The U.S. Forest Service estimates a benefit of $2.2 per pound or $1.43 per square foot (Nowak et al., 2002). Reductions in nitrogen oxides, ozone, sulfur dioxide, and carbon monoxide were assumed to be 10% – 30% of the reduction in airborne particulates. The average value of 20% was used in the medium-performance scenario. Dollar values associated with the reductions varied by pollutant and were estimated based on the Forest Service model.

***Health*** Health savings were estimated based on mean willingness to pay for a longer and/or healthier life based on EPA numbers.

***Public aesthetic benefits*** The private analysis assumed the green roof would have aesthetic value for a small number of building residents. In the public analysis, we assume in the medium scenario that each of the 144,000+ green roofs will be enjoyed by approximately 12 people so that about 1.7 million of the city's residents would benefit from 50% green roof infrastructure. In the low-performance scenario, this number is cut in half; in the high-performance scenario, this number is doubled.

### *Model Output*

The model generates a benefit-cost ratio for each scenario. The benefit-cost ratio is defined as the aggregate discounted benefits over a specified time period divided by the aggregate discounted costs over the same time period.

Benefits, costs, and economic parameters such as discount and inflation rates were input into the model. Present-value calculations were used to convert expected future monetary flows into a single present value based on the premise that a dollar today is worth more than a dollar tomorrow due to risk and uncertainty. A higher discount rate reduces the present value of future cash flows. Future cash flows are converted into present value using the formula:

$$\text{Present Value} = \frac{\underline{\text{Future Value}}}{(1+r)^t}$$

Where r = discount rate; and
t = time period (in this case measured as years from the present)

Industry surveys can help to estimate appropriate discount rates. With respect to real estate values, surveys by Korpacz and the Real Estate Research Corporation are used (PricewaterhouseCoopers, 2003). Discount rates for an office building range from 8.5% for a prime Class A building in Midtown Manhattan to 12.0% for an old Class B building in a less desirable location (PricewaterhouseCoopers, 2003). Rates for hotels and nursing homes with uncertain income streams rise to between 13% and 25% (PricewaterhouseCoopers, 2003). Real discount rates (i.e., discount rates adjusted to reflect purchasing power) typically applied to environmental issues range from 2% to 6%. Based upon a survey of 2,160 economists in 48 countries, Weitzman concluded that the discount rate for expected benefits and costs of projects proposed to mitigate the possible effects of global climate change should be 4% for the immediate future (years 1-5), 3% for years 6 to 25, 2% for years 26 to 75, 1% for years 76 to 300, and 0% for benefits and costs occurring more than 300 years hence. A survey of 50 economists produced similar means and standard deviations. For a single estimate, Weitzman suggests the use of 2% (Weitzman, 2001). A California study more analogous to this analysis entitled "The Costs and Financial Benefits of Green Buildings" used a discount rate of 5% (Kats et al., 2003).

In this analysis, a private discount rate of 8% and a social discount rate of 5% are used. In addition, the model currently assumes that technological change and economies of scale will reduce the cost differential over time. However, potential technical changes must be studied more thoroughly.

Finally, the model assumes that expenditures related to green roofs may be multiplied throughout the economy creating additional income and jobs. At present, the model uses a simple multiplier for income generation and job creation. Successful projects also generate tax revenues for governments. By multiplying income generated and expected property value increase by tax rates, the present value of fiscal impacts are estimated.

## Results

The results show a positive benefit-cost ratio for the medium (best-guess) performance scenario only when Tier II benefits are included (See Tables 2 – 4). This indicates that although individual green roofs may not be cost-effective,

Table 2. Benefit-cost ratios for all scenarios.

| **Tier I & Tier II results** | **Performance scenario** | | |
|---|---|---|---|
| **Tier I** | **Low** | **Medium** | **High** |
| Benefit-Cost Ratio Tier I, Private | 0.34 | 0.46 | 1.31 |
| Benefit-Cost Ratio Tier I, Public | 0.53 | 0.65 | 1.57 |
| **Tier II** | **Low** | **Medium** | **High** |
| Benefit-Cost Ratio Tier I & II, Private | 0.38 | 0.54 | 1.85 |
| Benefit-Cost Ratio Tier I & II, Public | 0.66 | 1.02 | 3.87 |

Table 3. Preliminary cost-benefit analysis results for Tier I and Tier II private scenario.

| **Average New York City Building Tier I & Tier II** | **Low** | **Medium** | **High** |
|---|---|---|---|
| Private benefits – Tier I | | | |
| Service life | | | |
| Standard roof installation costs foregone | $28,369 | 28,369 | 28,369 |
| Standard roof maintenance costs foregone | 3,822 | 3,822 | 3,822 |
| Cooling | 1,271 | 2,848 | 7,459 |
| Total private benefits – Tier I | 33,462 | 35,039 | 39,650 |
| Private costs – Tier I | | | |
| Installation cost of green roofs | (57,705) | (54,821) | (26,629) |
| Architecture and engineering | (115) | (110) | (53) |
| Maintenance costs of green roofs | (39,223) | (21,394) | (3,566) |
| Total private costs – Tier I | (97,043) | (76,325) | (30,247) |
| Net private benefits – Tier I | (63,581) | (41,286) | 9,403 |
| **Benefit/Cost Ratio Tier I Private** | **0.34** | **0.46** | **1.31** |
| Initial expenditures green roofs | (57,518) | (43,138) | (28,759) |
| Initial expenditures on standard roofs foregone | (21,569) | (21,569) | (21,569) |
| Difference in initial cxpenditure | (35,949) | (21,569) | (7,190) |
| Income generated | 42,202 | 46,217 | 56,126 |
| Jobs (construction) | 0 | 0 | 0 |
| Jobs (permanent) | (1) | (1) | 0 |
| Fiscal impacts (change in tax revenues) | (4,891) | (2,339) | 3,420 |
| Private benefits – Tier II | | | |
| Agricultural | 8 | 80 | 120 |
| Aesthetics/recreation | 787 | 3,149 | 12,597 |
| Sound | 2,225 | 3,067 | 3,741 |
| Total private benefits Tier II | 3,020 | 6,296 | 16,458 |
| Total private benefits – Tier I & Tier II | 36,482 | 41,335 | 56,108 |
| Net benefits – Tier I & Tier II | (60,561) | (34,990) | 25,861 |
| **Benefit/Cost Ratio Tier I & Tier II Private** | **0.38** | **0.54** | **1.85** |

green roof infrastructure is cost-effective when the full range of benefits is considered. Furthermore, the high-performance scenarios, which may become feasible as green roof technology is improved and the market for green roof infrastructure expands, show a positive benefit-cost ratio at both the private and public level. The results are particularly sensitive to the green roof installation cost. Here we assume that an individual green roof costs twice as much as an individual standard roof; however, as more green roofs are built, the costs are likely to be reduced. Therefore, in the public analysis, we assume that the cost is reduced somewhat to $15 per square foot. This reduction alone is not enough for a positive benefit-cost ratio within Tier I, but when additional benefits are added and a wider population is assumed to obtain the aesthetic benefits of green roofs, the benefit cost ratio becomes positive.

Table 4. Preliminary cost-benefit analysis results for Tier I and Tier II public scenario.

| **50% Green Roof Infrastructure** | **Low** | **Medium** | **High** | **Annualized Medium** |
|---|---|---|---|---|
| Private benefits – Tier I | | | | |
| Service life | | (lowers relative costs below) | | |
| Standard roof installation costs foregone | $4,108,700,000 | 4,108,700,000 | 4,108,700,000 | 333,535,896 |
| Standard roof maintenance costs foregone | 553,600,000 | 553,600,000 | 553,600,000 | 44,940,120 |
| Cooling | 184,100,000 | 412,500,000 | 1,080,300,000 | 33,485,910 |
| Total private benefits – Tier I | 4,846,400,000 | 5,074,800,000 | 5,742,600,000 | 411,961,926 |
| Social/public benefits – Tier I | | | | |
| Water runoff capital expenditures | 21,800,000 | 54,400,000 | 87,100,000 | 4,416,081 |
| Water runoff operating cxpenditures | 2,200,000 | 5,400,000 | 8,700,000 | 438,361 |
| Energy/heat island cooling | 21,600,000 | 212,600,000 | 622,800,000 | 17,258,435 |
| Greenhouse gases (carbon dioxide) | 1,900,000 | 7,800,000 | 31,200,000 | 633,188 |
| Total social/public benefits – Tier I | 47,500,000 | 280,200,000 | 749,800,000 | 22,746,065 |
| Total private & social/public benefits – Tier I | 4,893,900,000 | 5,355,000,000 | 6,492,400,000 | 434,707,991 |
| Private costs – Tier I | | | | |
| Installation cost of green roofs | (6,268,100,000) | (6,616,500,000) | (3,856,700,000) | (537,113,991) |
| Architecture amd engineering | (12,500,000) | (13,200,000) | (7,700,000) | (1,071,549) |
| Maintenance costs of green roofs | (2,840,400,000) | (1,549,300,000) | (258,200,000) | (125,769,018) |
| Total private costs – Tier I | (9,121,000,000) | (8,179,000,000) | (4,122,600,000) | (663,954,558) |
| Social/public costs – Tier I | | | | |
| Program administration and setup | (17,400,000) | (9,600,000) | (3,900,000) | (779,308) |
| Program maintenance | (34,100,000) | (20,000,000) | (10,400,000) | (1,623,559) |
| Total social/public costs – Tier I | (51,500,000) | (29,600,000) | (14,300,000) | (2,402,868) |
| Total private & social/public costs – Tier I | (9,172,500,000) | (8,208,600,000) | (4,136,900,000) | (666,357,426) |
| Net benefits total – Tier I | (4,278,600,000) | (4,278,600,000) | (2,853,600,000) | 2,355,500,000 |
| **Benefit/Cost Ratio Social/Public – Tier I** | **0.53** | **0.65** | **0.53** | **0.65** |
| Initial expenditures green roofs | (6,247,800,000) | (5,206,500,000) | (4,165,200,000) | (422,653,064) |
| Initial expenditures on standard roofs foregone | (3,123,900,000) | (3,123,900,000) | (3,123,900,000) | (253,591,838) |
| Difference in initial expenditure | (3,123,900,000) | (2,082,600,000) | (1,041,300,000) | (169,061,225) |
| Income generated | 6,117,375,000 | 6,693,750,000 | 8,115,500,000 | 543,384,989 |
| Jobs (construction) | 33,222 | 33,437 | (3,360) | 2,714 |
| Jobs (permanent) | (65,825) | (38,048) | 27,712 | (3,089) |
| Fiscal impacts (change in tax revenues) | (213,751,875) | (51,078,750) | 519,592,500 | (4,146,469) |
| Private benefits – Tier II | | | | |
| Agricultural | 1,200,000 | 11,600,000 | 17,400,000 | 941,664 |
| Aesthetics/recreation | 228,100,000 | 912,200,000 | 3,648,900,000 | 74,050,538 |
| Sound | 322,200,000 | 444,200,000 | 541,800,000 | 36,059,251 |
| Total private benefits – Tier II | 551,500,000 | 1,368,000,000 | 4,208,100,000 | 111,051,453 |
| Total private benefits – Tier I & Tier II | 5,397,900,000 | 6,442,800,000 | 9,950,700,000 | 523,013,379 |

Table continued on next page.

| 50% Green Roof Infrastructure | Low | Medium | High | Annualized Medium |
|---|---|---|---|---|
| Public benefits – Tier II | | | | |
| Particulates removed | 80,500,000 | 321,800,000 | 965,400,000 | 26,123,068 |
| NOX removed | 12,200,000 | 97,400,000 | 289,600,000 | 7,906,734 |
| Ozone removed | 12,200,000 | 97,400,000 | 438,500,000 | 7,906,734 |
| SO2 removed | 2,900,000 | 23,100,000 | 104,100,000 | 1,875,211 |
| Carbon monoxide removed | 1,800,000 | 14,400,000 | 64,800,000 | 1,168,963 |
| Total social/public Benefits -- Tier II | 109,600,000 | 554,100,000 | 1,862,400,000 | 44,980,709 |
| Total social/public benefits – Tier I & Tier II | 157,100,000 | 834,300,000 | 2,612,200,000 | 67,726,774 |
| Total private and public benefits – Tier II | 661,100,000 | 1,922,100,000 | 6,070,500,000 | 156,032,162 |
| Total private and social/public benefits – Tier 1 & Tier II | 6,059,000,000 | 8,364,900,000 | 16,021,200,000 | 679,045,542 |
| Net benefits total – Tier I & Tier II | (3,113,500,000) | 156,300,000 | 11,884,300,000 | 12,688,116 |
| **Benefit/Cost Ratio Social/Public – Tier I & Tier II** | **0.66** | **1.02** | **3.87** | **1.02** |

In general, it is important to include both the benefits that are more easily quantifiable and those that are not, in environmental cost-benefit analysis. The exclusion of benefits that are not easily measured may return a negative benefit-cost ratio for environmental projects that are actually cost-effective.

### *Caveats*

These results should be considered as preliminary estimates. To the extent possible, model assumptions were based on empirical studies. The number of studies is limited at the present time forcing us to utilize data with limited applicability to conditions in New York City. Given these limitations, no building specifications beyond square footage were used in the model.

### Conclusion

Green roof infrastructure could be a cost-effective way to help solve some of New York City's environmental and human health problems, when multiple private and public benefits are considered together.

### Further Research

The cost-benefit analysis could be improved with additional empirical research on each of the potential benefits and economic impacts of green roofs in New York City. Additional research into capital and operating expenditures for stormwater through examination of publications and interviews of knowledgeable individuals is a priority. Customizing the estimates for the New York City Region by conducting surveys to measure potential aesthetic and recreational benefits is also important.

The flexibility of the spreadsheet permits us to look at several different valid paths to obtaining estimates of costs and benefits. Further disaggregation of calculations would allow greater customization for the New York City Region. Tie-in to other models including the EPA DOE2 model to measure energy used by buildings, the NY Externalities Model, and Input/Output models such as REMI and IMPLAN could also improve the analysis.

Sensitivity tests, further scenario analysis, and a consideration of a variety of spatial scales such as: 1) square foot, 2) building, 3) Census tract, 4) zip code, 5) regulator basin, 6) sewage-shed, 7) city, 8) state, and/or 9) region could help provide insights on the necessary scale of adoption for certain benefits to be realized.

Comparison of costs and benefits of green roof infrastructure, and other strategies, approaches and technologies such as reflective roofing and stormwater retention Best

Management Practices (BMPs) could help policy makers determine whether green roof infrastructure is a good choice for New York City.

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