Maximizing the Energy Benefits of Urban Forestation

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This paper examines key issues involved in evaluating benefits of tree planting programs from the perspective of electric utilities, as well as from a wider perspective of public and private entities that may benefit from such programs. The nation's largest shade tree program, sponsored by the Sacramento Municipal Utility District (SMUD) in collaboration with the Sacramento Tree Foundation (STF), is used as a case study. Results of a recent analysis of the energy benefits of SMUD's Shade Tree Program are presented, along with program modifications being implemented to improve program cost-effectiveness. A sensitivity analysis of the relative importance of major uncertainties surrounding the benefits of the Shade Tree Program is presented, and priorities for future research are discussed.

INTRODUCTION

In 1990, the Sacramento Municipal Utility District (SMUD), in conjunction with the Sacramento Tree Foundation, initiated the nation's largest organized shade tree program to reduce building cooling loads. The program's objective was to plant 500,000 shade trees by the year 2000. A secondary objective of the program was to create an urban forest that will help mitigate the *urban heat island* effect—or the increase in summer outdoor temperatures caused by urban development. An additional indirect energy benefit that might result from the Shade Tree Program was the effect of trees as wind breaks, which may reduce infiltration of unconditioned outside air into buildings. Potential non-energy benefits of the program included improving the region's air quality, enhancing esthetics and quality of life in the region, and improving property values of program participants.

The Shade Tree Program provides a comprehensive and long-term program in tree planting, management, education, and citizen participation. The program is implemented in collaboration with the Sacramento Tree Foundation (STF), a non-profit community organization whose goal is improving the quality of life in the Sacramento area by inspiring and motivating the community to plant and perpetuate a healthy urban forest.

Utility customers interested in participating in the Shade Tree Program contact SMUD, which schedules an appointment for a site visit by one of the STF's Community Foresters. During site visits, Community Foresters and customers mutually select appropriate tree species and locate specific sites for each tree planting. Program participants then attend a local tree planting demonstration conducted by Community Foresters to learn about proper planting and maintenance of the trees. After attending the tree planting demonstration, customers receive trees in five-gallon containers free-of-charge and are then responsible for planting and caring for the trees received.

Through 1995, over 200,000 trees have been planted through the program, representing over 40 percent of the goal of planting 500,000 trees in Sacramento. However, under SMUD's strategic plan for 1996–2000, the goal of the Shade Tree Program has shifted from planting a specified number of trees to focusing directly on the goal of shading homes to reduce summer cooling loads. From the perspective of electric utilities, tree-planting programs represent a type of demand-side management (DSM) program, having a tangible economic value to the utility. This value can be quantified based on avoided supply costs, or the decrease in supply costs to the utility due to reduced building electrical loads. In the case of the Shade Tree Program, avoided supply costs include reduced cooling energy costs and reduced capacity requirements needed to meet SMUD's peak summer demand for cooling. SMUD's total investment in the program since 1990 has been about 10 million dollars, or approximately two million dollars per year.

SHADE TREE PROGRAM IMPACTS

Since 1994, SMUD and the U.S. Department of Agriculture Forest Service's (USDAFS) Western Center for Urban Forest Research and Education have collaborated on a variety of different evaluation studies to develop more accurate methods for assessing the impacts and cost-effectiveness of SMUD's Shade Tree Program. The following sections describe how this method was developed and applied to the program to identify its impacts and cost-effectiveness.

Building Simulation Modeling

As part of a study of the technical potential for planting shade trees in Sacramento, the impacts of individual trees on utility electric loads (energy and peak capacity) were estimated for 72 different shading scenarios (Simpson & McPherson 1995; 1996). These scenarios represented mature trees of different sizes, orientation, and distances[1] from a typical post-1990 home in Sacramento. In another study, the load impacts of over 1,000 trees planted at 240 homes participating in the Shade Tree Program were analyzed using shade and building simulation models developed from data collected through on-site visits (McPherson & Simpson 1995).

Avoided Cost Benefits from Direct Shading of Buildings

The simulation model used for estimating electric load impacts from trees planted through the Shade Tree Program was calibrated to statistical estimates of average unit energy consumption (UECs) and demand load shapes for homes with central electric cooling. These statistical estimates were developed by SMUD for use in utility program planning and load forecasting. Additional adjustments were made based on the percentage of program participants that were estimated to have central air conditioning or other types of electric cooling equipment. Finally, energy and demand savings estimates for individual shading scenarios were reduced further to yield results that were consistent with site-by-site simulation results for the sample of homes modeled by Simpson and McPherson (1995; 1996).

The load impact estimates were also combined with data collected in on-site visits to estimate additional savings from shading of adjacent homes. Results of this analysis indicated that up to 23 percent of trees planted may provide some benefits from direct shading of adjacent buildings. Overall, it was estimated that the additional reduction in utility electric load resulting from shading of adjacent buildings equaled about 15 percent of that from shading participants' homes.

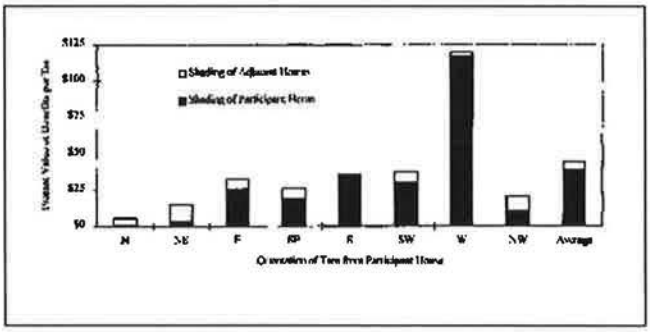
Finally, the estimated reduction in energy and capacity attributable to shade trees, weighted for the impact from shading both a participant's home and an adjacent home, was converted to a dollar value to the utility. Load impacts over the life of a shade tree may be given dollar value by using the utility's avoided cost of power supply in discounted present value. This will be referred to herein as "estimated program benefits."

Figure 2 summarizes estimates of the average per tree program benefits for trees planted during the 1991-1993 program period. Average estimated program benefits for each tree planted to the west of participants' homes ($120) were estimated to be nearly three times greater than the average benefits for all trees planted through the entire program ($39). In eastern and southern orientations (east, southeast, south, and southwest), average estimated program benefits from shading of participant homes ranged from about $19 to $35 per tree.

Trees to the north, northeast, and northwest of homes provided average estimated program benefits of less than $11. However, trees planted to the northwest and northeast of participants' homes were found to have the highest benefits from shading of adjacent buildings ($11 to $12 per tree). In each of these locations, average program benefits from shading of adjacent buildings were found to exceed average benefits from shading of participants' homes.

Figure 2 compares the percentage of total number of trees planted in each orientation during 1991-1993 to the percentage of total estimated program benefits attributable to trees planted in each of these locations. As Figure 2 shows, trees planted on the west accounted for only 18 percent of trees planted through the program, but provided nearly one-half (47 percent) of program benefits. Trees planted on the north, northeast, and northwest of participants' homes represented 21 percent of all trees planted, but contributed only about eight percent of total program benefits.

Figure 1. *Average Estimated Program Benefits per Tree by Tree Orientation*



Note: Based on estimated long-term tree mortality of 42.5 percent for trees planted through program in 1991–1993.

Figure 2. *Percent of Total Trees Planted and Total Estimated Program Benefits by Tree Orientation*

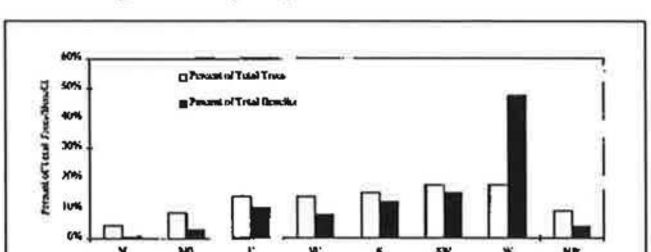


Figure 3. Present Value of Avoided Supply Cost Benefits per Tree

NORTHWEST

Size	Distance	PVB
LARGE	Adjacent	$44.41
MEDIUM	Adjacent	$12.08
LARGE	Near	$5.62
SMALL	Adjacent	$5.06
MEDIUM	Near	$3.37
LARGE	Far	$2.81
SMALL	Near	$1.69
MEDIUM	Far	$1.40
SMALL	Far	$1.12

NORTH

Size	Distance	PVB
LARGE	Adjacent	$3.65
MEDIUM	Adjacent	$2.25
LARGE	Near	$.84
LARGE	Far	$.00
MEDIUM	Far	$.00
MEDIUM	Near	$.00
SMALL	Adjacent	$.00
SMALL	Far	$.00
SMALL	Near	$.00

NORTHEAST

Size	Distance	PVB
LARGE	Adjacent	$30.23
SMALL	Adjacent	$.00
SMALL	Near	$.00
SMALL	Far	$.00
MEDIUM	Near	$.00
MEDIUM	Far	$.00
LARGE	Near	$.00
LARGE	Far	$.00
MEDIUM	Adjacent	$.00

WEST

LARGE	Near	$184.43
LARGE	Adjacent	$170.60
LARGE	Far	$154.69
MEDIUM	Adjacent	$134.33
MEDIUM	Near	$130.96
MEDIUM	Far	$88.69
SMALL	Adjacent	$65.90
SMALL	Near	$38.13
SMALL	Far	$22.89

EAST

LARGE	Adjacent	$69.26
LARGE	Near	$61.96
MEDIUM	Adjacent	$49.32
LARGE	Far	$32.58
SMALL	Adjacent	$14.32
MEDIUM	Near	$2.81
SMALL	Near	$2.81
MEDIUM	Far	$.28
SMALL	Far	$.28

SOUTHWEST

LARGE	Adjacent	$88.37
MEDIUM	Adjacent	$53.58
LARGE	Near	$47.50
LARGE	Far	$14.60
MEDIUM	Near	$13.76
SMALL	Adjacent	$6.46
MEDIUM	Far	$3.93
SMALL	Near	$1.40
SMALL	Far	$.28

SOUTH

LARGE	Adjacent	$105.78
MEDIUM	Adjacent	$74.92
LARGE	Near	$58.28
MEDIUM	Near	$11.51
SMALL	Adjacent	$7.58
LARGE	Far	$6.74
MEDIUM	Far	$.28
SMALL	Far	$.00
SMALL	Near	$.00

SOUTHEAST

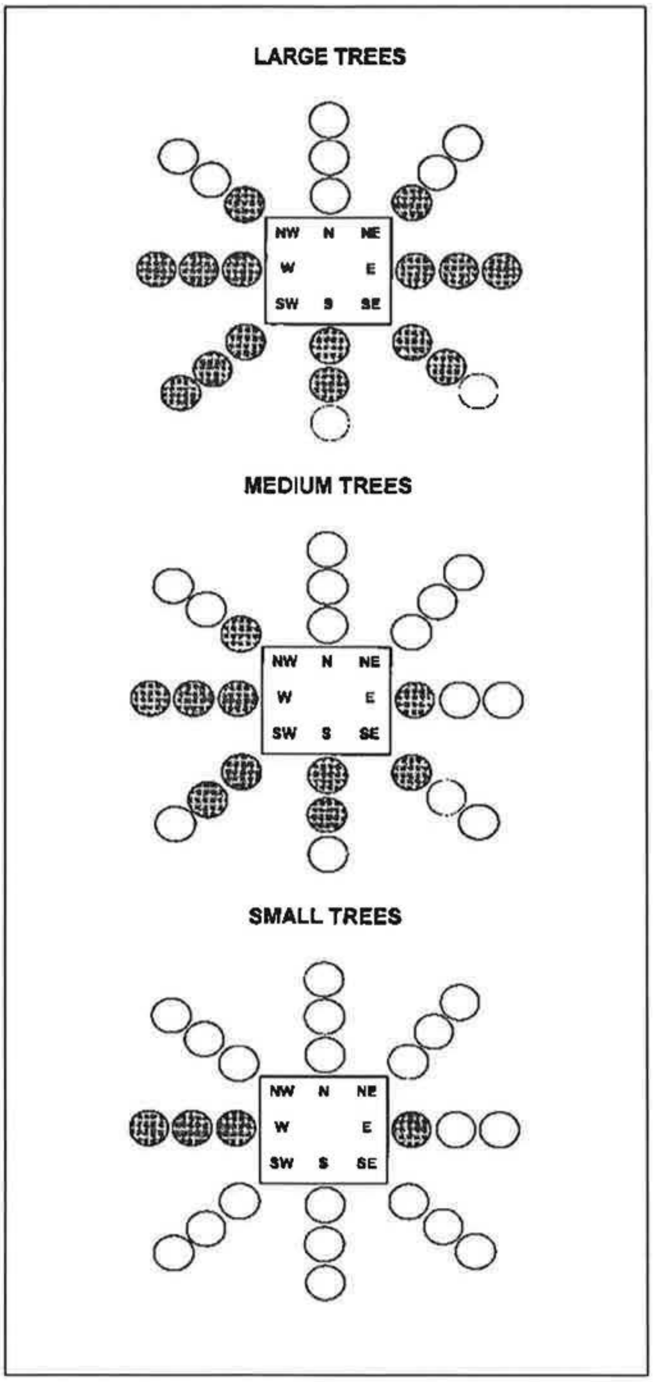
LARGE	Adjacent	$80.82
MEDIUM	Adjacent	$31.35
LARGE	Near	$20.50
MEDIUM	Near	$6.46
LARGE	Far	$6.18
SMALL	Adjacent	$2.81
MEDIUM	Far	$.84
SMALL	Near	$.28
SMALL	Far	$.00

Source: SMUD (1995).

Notes: Shaded scenarios indicate trees with benefits over $11. Distance of tree from building based on the following categories: adjacent (15–30 ft), near (30–50 ft), and far (50 ft). Avoided cost benefits based on low growth rate shown in Table 4 and high survival rate shown in Table 5. Assumes that indirect impacts of shading on heating loads are offset by indirect impacts of reduced wind speeds in winter months.

developed to represent a range of 30-year survival rates that may occur for program trees. USDAFS staff estimated that potential long-term survival rates for additional trees planted through the program are likely to range from 58 to 60 percent (see Figure 7). In view of the lower-than-expected survival of trees planted through the program from 1991–1993, a long-term survival rate of 58 percent was selected as *the most likely* future scenario for trees already planted. However, a long-term survival rate of 70 percent was selected to represent a scenario of greater survivability that could be achieved for trees currently being planted under improved tree stewardship by program participants. To improve survival rates for trees planted through the Shade Tree Program, increased emphasis is now being placed on tree stewardship and monitoring of survival rates.

Figure 4. *Cost-Effective Planting Sites by Tree Size and Orientation*



Note: Shaded sites are incrementally cost-effective at $11 per tree.

Impacts of Tree Shading on Heating Loads

Even during winter months, bare trunks and limbs of the type of deciduous trees planted through the Shade Tree Program block at least 30% of the sunlight that would otherwise reach building surfaces (Huang, Y.J., et al. 1992; Simpson & McPherson 1995). This reduction in solar heat gain

Figure 5. *Potential Tree Plantings and Marginal Benefits and Costs*

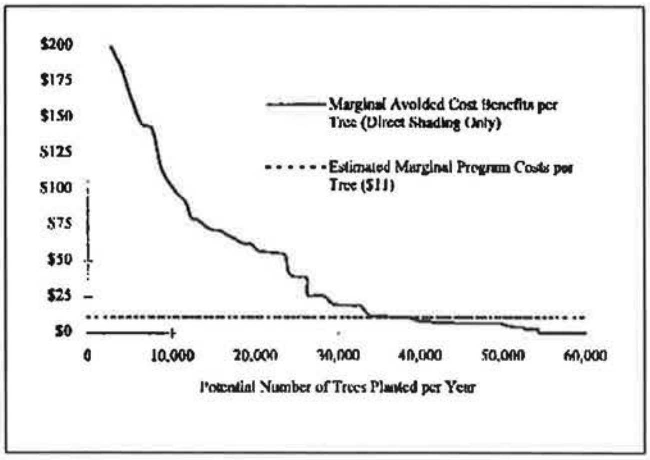


Figure 6. *Tree Growth Rates*

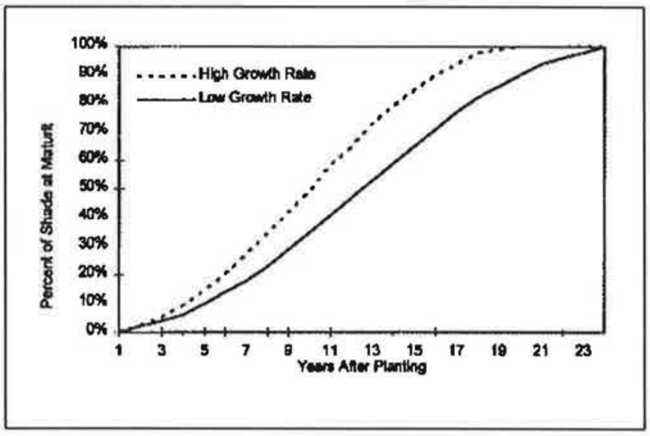
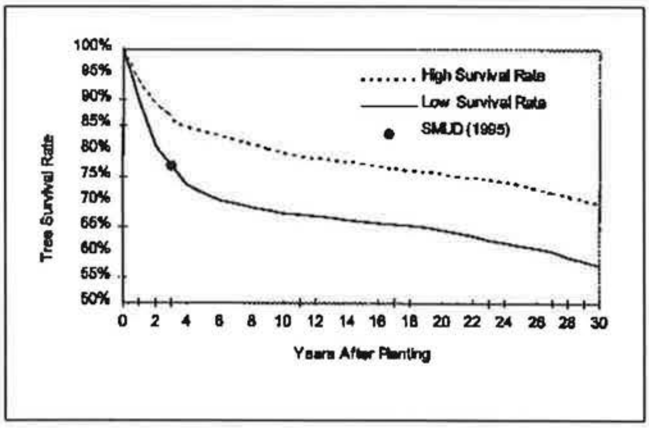


Figure 7. *Long-Term Tree Survival Rates*



results in an *increase* in heating loads during winter months. In a typical electrically-heated home in Sacramento that has participated in the Shade Tree Program from 1991 to 1993, building simulation results indicated that shading during winter months from each tree planted will increase heating energy requirements by 83 kWh per year, or 87 percent of the average cooling savings per tree (95 kWh). The relatively high level of this increase in average heating loads can be attributed to the fact that over 45 percent of trees planted through the program during this time period have been sited to the south, southeast, or southwest of buildings.

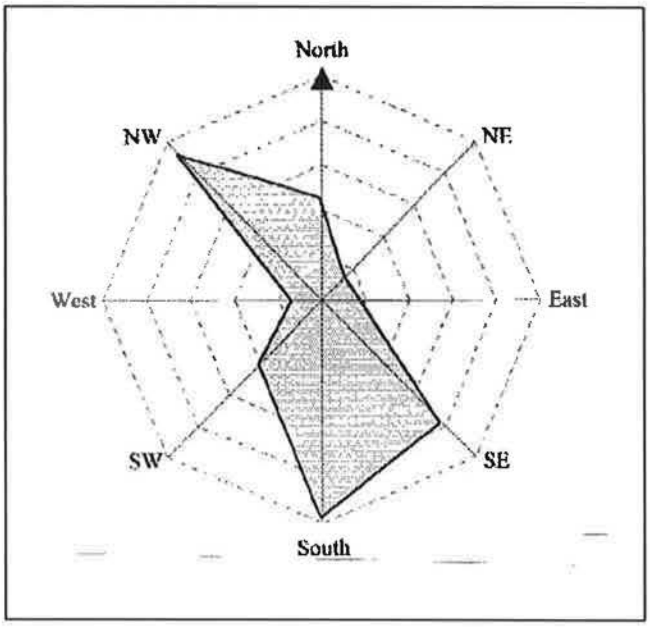
However, trees can also serve as *wind breaks* which reduce wind speeds, thereby reducing infiltration of outside air into buildings and conductive heat loss from exterior building surfaces. Several researchers have suggested that savings from the wind-shielding effects of shade trees are likely to equal or exceed the increased heating loads due to decreased solar gain in winter months (Huang, Akbari & Taha 1991; Huang, Y.J., et al. 1992; Simpson & McPherson 1995).

To compare the potential wind effects of trees with the winter heating impacts of increased shading from trees planted in different orientations, hourly weather data for a typical meteorological year in Sacramento were analyzed in several ways. First, total annual heating degree hours (using a base temperature of 65° F) were calculated for each hour during which winds occur from each direction. In addition, another measure of potential effects of wind on heating loads was developed by multiplying heating degree hours (at 65° F) by the wind speed (meters per second). By taking both temperature and wind speed into account, this measure may provide the best indication of the relative effects of wind from each direction on annual heating loads.

Results of this analysis, depicted in Figure 8, indicate that winter savings from the wind-shielding effects would be greatest for trees planted in southern orientations in Sacramento. Figure 9 compares the relative *decrease* in heating loads due to reductions of wind speeds for trees planted in different orientations to the relative *increase* in heating loads due to direct shading of buildings. As shown Figure 9, analysis of local weather data indicated that there is likely to be a high direct correlation between heating savings from wind-shielding effects and increased heating loads from decreased solar gain. As a result, in assessing the benefits of SMUD's Shade Tree Program, it has been assumed that the increase in building energy loads due to direct shading from trees planted through the program would be approximately offset by a decrease in heating loads due to the effect of trees as *wind breaks* during winter months.

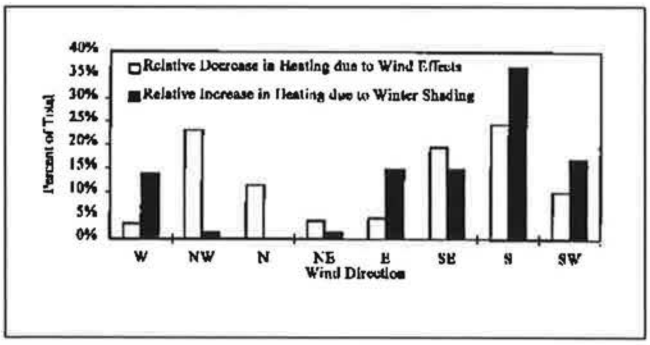
An important consequence of this assumption is that new tree siting guidelines implemented by SMUD continue to allow planting of some trees on southwestern, southern and southeastern orientations from homes. In these locations, building simulation results indicate that most of the cooling savings from trees could be offset by increased heating leads from shading during winter months. However, since it was assumed that the trees would have no net effect on heating loads due to the effect of trees as wind breaks, trees on southern locations still met cost-effectiveness criteria used by SMUD in revising tree siting guidelines. As illustrated in the following section of this paper, the net effect of trees on heating loads represents one of the major sources of uncertainty which may be addressed in future research on urban forestry.

Figure 8. *Potential Heating Effects from Wind-Reduction by Tree Orientation*



Note: Relative annual wind effect = heating degree hours (base 65° F) × wind speed (meters/second).

Figure 9. *Comparison of Potential Effects on Heating Loads from Reduced Wind Speeds and Increased Shading of Buildings*



SENSITIVITY ANALYSIS OF KEY UNCERTAINTIES

To prioritize future research efforts, sensitivity analysis of program cost-effectiveness was performed for a variety of scenarios representing key major uncertainties surrounding program benefits and costs. Scenarios used in this analysis are described below:

- *Building simulation results.* A range of uncertainty of ±25 percent was used to assess the accuracy of load impact estimates. This was based on the uncertainty surrounding estimates of the load impacts of trees at maturity derived from building simulation modeling, and on the uncertainty of estimated savings from shading of adjacent homes.

- *Tree growth and survival rates.* Sensitivity analysis was performed using high and low rates of tree growth and survival shown in Figures 6 and 7.

- *Additional cost of maintenance and removal.* The total cost of planting shade trees used in analyzing the cost-effectiveness of the Shade Tree Program was limited to total program costs incurred by the utility. The analysis did not assign any economic cost for maintaining and removing trees by either program participants or local governments or utilities, which could incur additional tree trimming and leaf removal costs as a result of large-scale tree planting programs. In effect, it was assumed that these costs were offset by other benefits of tree planting, such as increased quality-of-life, aesthetics, or property values. However, to assess the sensitivity of program cost-effectiveness to these assumptions, a scenario was examined in which an additional cost of about $8 per tree was included to represent the present value of tree maintenance costs over the 30-year life of a tree, based on analysis by McPherson, Simpson & Scott (1996).

- *Free ridership.* Program participants who would plant trees using appropriate planting techniques, even without STF's assistance and free trees offered through the Shade Tree Program, represent *free riders.* The direct costs of trees provided to these participants and the resulting benefits were not included in the analysis of program cost-effectiveness under the total resource cost test used to assess most utility DSM programs. However, a large portion of the costs of the program are fixed administrative costs, which are not reduced when free ridership is incorporated into benefit/cost analysis. As a result, overall program cost-effectiveness is decreased by free ridership. To examine the importance of free ridership, a scenario was examined which assumed a free ridership rate of 30 percent.

- *Effects of deciduous trees on heating loads.* As described above, shade tree planting guidelines developed by SMUD are based on the assumption that that any increase in heating loads from tree shading is offset by heating savings from reduced wind speeds during winter months. The potential value of additional research on the wind-shielding effects of trees was assessed by examining program cost-effectiveness without this assumption.

- *Indirect cooling benefits.* The potential benefits from the indirect cooling effects of increased tree cover in urban microclimates were assessed based on the assumption that these indirect benefits were approximately equal to the benefits from direct shading of buildings (McPherson and Simpson 1995).

- *Effects on local air quality.* Urban trees may improve local air quality through direct absorption of ozone and other pollutants. At the same time, biogenic hydrocarbon emission from trees may play a role in ozone formation. Thus, researchers are currently uncertain whether urban tree planting may result in a net improvement or degradation of local air quality. Researchers at the USDA Forest Service have recently used cost analysis based on Best Available Control Technology (BACT) to quantify the monetary value of the effect of trees on local air quality. Based on this analysis, McPherson, Scott and Simpson (1996) have estimated that the net effect of tree planting on local air quality may range from an increase in the cost of pollution control of about $8 per tree to a decrease in air pollution control costs of almost $17 per tree.

Figure 10 depicts results of a comparative analysis of the different uncertainties described above in terms of the potential change in program cost-effectiveness relative to a base case scenario with an expected program benefit/cost ratio of 1.35:1. Table 1 presents results of this analysis in terms of the potential effect on the number of trees that would be planted each year through the Shade Tree Program under each of these scenarios, assuming that all trees providing benefits of over $11 (the marginal cost of each additional tree) was planted at each home participating in the program.

CONCLUSIONS

From the standpoint of energy efficiency, this research found that the planting of trees to directly shade buildings was a cost-effective strategy for SMUD. Additionally, the sensitivity analyses identified the most important priorities for addi-

Figure 10. Sensitivity Analysis of Effect of Major Uncertainties on Program Cost-Effectiveness

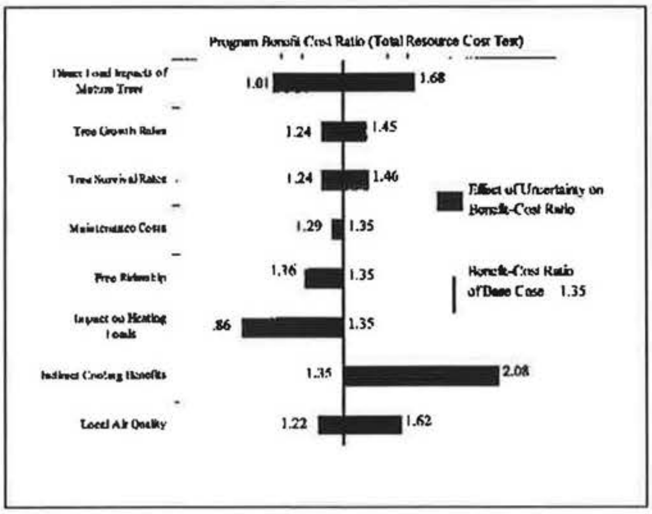


Table 1. Improved Information on Program Benefits

Source of Uncertainty	Relative Range of Uncertainty[a]	Maximum Change in Trees Planted[b]
Savings from Mature Trees	± 25%	− 17%
Tree Growth Rate	± 8%	± 3%
Tree Survival Rates	± 9%	± 3%
Free Riders	− 36%	
Maintenance & Removal Costs	− 4%	− 13%
Effects on Heating Loads	− 33%	− 33%
Indirect Cooling Benefits	+ 55%	+ 62%
Impact on Local Air Quality	−9% to +20%	+ 62%

[a] Maximum range of total annual potential program benefits (in dollars) as a percentage of benefits under base case scenario ($2,891,895).

[b] Maximum change in number of trees planted per year relative to base case scenario (34,479), assuming that the number of trees planted is *decreased* or *increased* based on change in estimated benefits of each tree planted, with all trees having benefits of at least $11 being planted. Assumes a maximum of 55,000 trees could be planted at the 10,000 to 15,000 sites visited each year by community foresters.

tional research on the impacts of urban tree planting programs. These priorities are improving estimates of potential benefits from reduced air pollution and from a reduction in the urban heat island effect. Among these two factors, quantifying the potential benefits from reduced air pollution may have a greater effect on the viability of urban tree planting programs.

To-date, electric utilities have been the primary sponsors of the largest-scale urban tree planting programs. However, as utilities seek to reduce operating costs and rates in anticipation of increased competition, significant reductions are likely to continue in expenditures for utility-sponsored energy efficiency programs. In order to maintain or expand expenditures for urban tree planting programs, new partnerships may be necessary between utilities and other groups that may benefit from urban forestation: local governments, citizens, and businesses. Developing improved estimates of the potential effects of tree planting programs on local air quality may provide an important framework for developing new partnerships and sources of funding for urban forestation.

ENDNOTES

1. Three sizes were small, medium, and large; eight orientations were north, northeast, east, southeast, south, southwest, west, and northwest; and three distances were adjacent (15 ft.), near (30 ft.), and far (50 ft.).

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