Evaluating the Cost Effectiveness of Shade Trees for Demand-Side Management

Proper planning and placement of trees as part of a utility DSM strategy offers a number of benefits to utilities and their customers in certain markets. When all of the benefits — including those not easily quantified — are counted, trees may be a resource and customer service tool your utility should consider.

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Electric utilities are placing greater emphasis on demand-side management programs to defer construction of new generating facilities. Shade trees that are wisely selected and located can conserve cooling energy by directly shading buildings, as well as by lowering summertime temperatures via evapotranspirational (ET) cooling.[1] Several utilities have found trees to be cost-effective energy conservation measures and have invested in shade tree programs for DSM. Also, urban trees are becoming part of electric utilities emission offset programs because of their ability to sequester carbon dioxide, intercept particulates, and absorb gaseous pollutants.

However, the environmental, economic, and social benefits trees provide can be offset by costs associated with planting, pruning, removal and replacement of dead trees, disposal of green waste, water use, and biogenic hydrocarbon emissions.[2] The cost effectiveness of trees for DSM is difficult to evaluate because few studies have documented avoided energy costs as trees mature, tree loss rates, current saturation, and potential penetration of new energy conserving plantings. This article presents information on these topics to assist electric utilities interested in evaluating shade trees as a DSM option.

I. Avoided Energy Costs

The magnitude of cooling energy savings from a tree depends on its placement (west shade is best), crown shape (a broad, spreading crown is best), crown density (75% or greater blockage of incoming sunlight is best), growth rate, and longevity. To account for reduced irradiance through tree crowns, we simulated energy savings from tree shade using the Shadow Pattern Simulator (SPS).[3] Micropas4, a commercially available building energy analysis program,[4] estimated hourly cooling loads using hourly shading coefficients from SPS and data regarding building and occupant characteristics of the two story, energy efficient base-case residence.

Simulated annual air-conditioning energy savings and peak savings are shown in **Figures 1** and **2** at five-year intervals from a single tree opposite the west wall of the energy efficient 1,761 sq ft residence.[5] The tree was assumed to grow at a modest average rate of 1.2 ft per year, starting as a 6-ft tall transplant (15 gal) and reaching 13 ft at year 5, 19 ft at year 10, and 24 ft at year 15. The deciduous tree was assumed to obstruct 85% of the incoming solar radiation during the in-leaf period and 25% during the leaf-off period.[6] Fifteen years after planting, air-conditioning energy and capacity savings were projected to range from 50 to 400 kWh and 0.3 to 0.65 kW per tree, respectively. Savings shown in Figures 1 and 2 are conservative, in that only shading effects are considered. Some studies have found ET cooling effects to be three to four times greater than savings from direct shade.[7]

Because ET cooling and wind speed reductions are the aggregate effects of neighborhood trees, Forest Service researchers are measuring relations between the extent of tree canopy cover and the magnitude of these indirect effects. Limited data suggest that a 5% increase in canopy cover could reduce summertime air temperatures and wind speeds by as

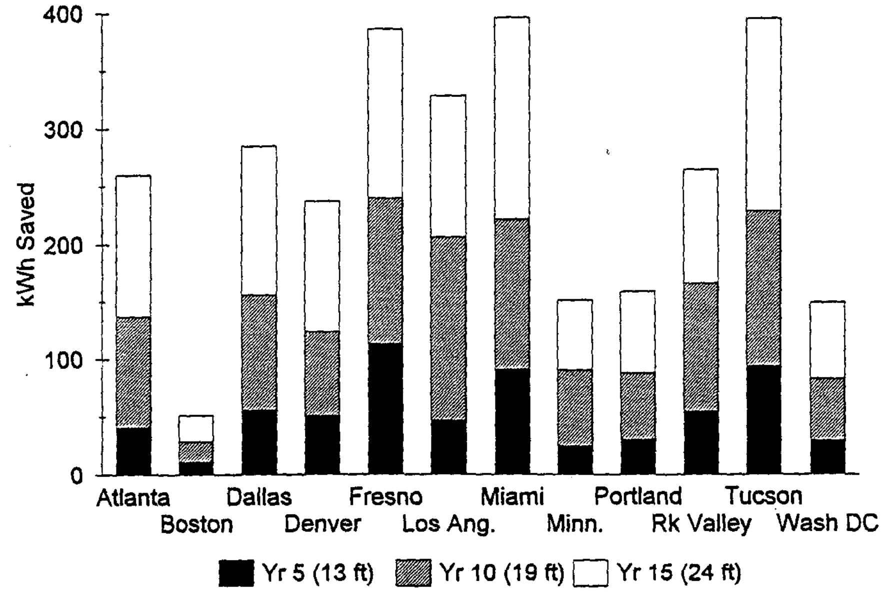

Figure 1. Simulated annual air-conditioning savings due to shade from one deciduous tree opposite the west wall of an energy efficient, two story home at year 5 (13 ft tall), year 10 (19 ft), and year 15 (24 ft).

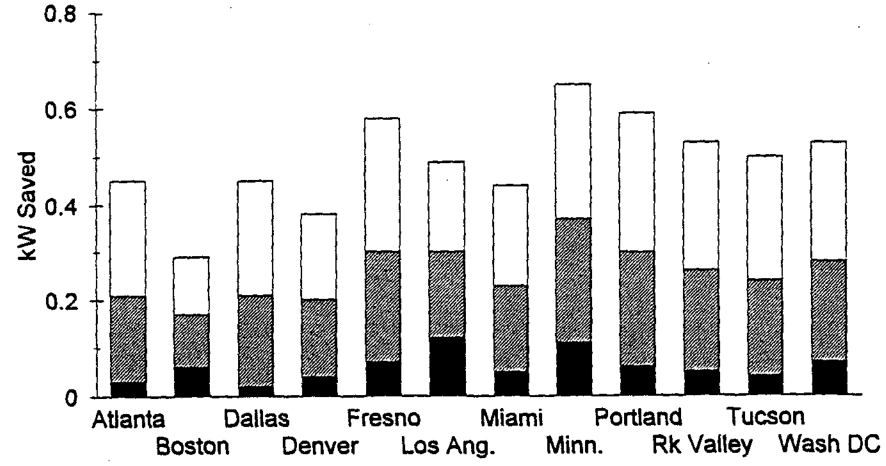

Figure 2. Simulated peak demand savings for air-conditioning savings due to shade from one deciduous tree opposite the west wall of an energy efficient, two story home at year 5 (13 ft tall), year 10 (19 ft), and year 15 (24 ft).

much as 2-4°F (1-2°C) and 10%, respectively.[8] Using these assumptions, annual heating and cooling savings from three 25-ft tall trees (two on the west and one on the east) were simulated for the energy efficient two story structure. On an average per tree basis, total annual heating and cooling energy savings ranged from 2 to 9% ($7-50), with the greatest dollar savings in the warmest climates (**Figure 3**).

Projected annual and peak air conditioning savings varied across climate regions. Correct tree placement is most important in hot arid and cold climates. In the former, shade is the predominant factor contributing to cooling savings. In the latter case, even shade from bare branches during winter can substantially increase heating costs. The role of ET cooling appears to be relatively greater in temperate and hot humid climate regions with greater amounts of summertime cloud cover. As expected, reduced wind speeds from increased tree cover resulted in greatest heating savings in cool climate cities. For instance, in Boston and Minneapolis heating savings attributed to reduced wind speeds accounted for over 50% of the total annual energy savings. However, shade from deciduous trees located to shade east walls increased heating costs more than it reduced cooling costs in Boston, Minneapolis, and Portland.[9] Therefore, the potential energy costs of trees improperly located near buildings are greatest in cool climates, while their potential energy savings are greatest in warm climates. Other findings from computer simulations[10] are:

- Greatest cooling savings come from a tree on the west in all cities.
- For the buildings studied, the best location for a second tree was also west of the residence, except in Miami, where afternoon summer thunderstorms make east shade more valuable.
- Even deciduous trees to the south of buildings may increase heating demand more than they reduce cooling loads. South shade has the potential to obstruct solar access to roof-mounted hot water collectors and photovoltaic systems.
- When shading and indirect effects were modeled, annual air-conditioning savings from the 25-ft deciduous tree (about 15 years after planting) were projected to range from 100 to 400 kWh (10-15%), and peak demand savings ranged from 0.3 to 0.6 kW (8-10%) in most cities.

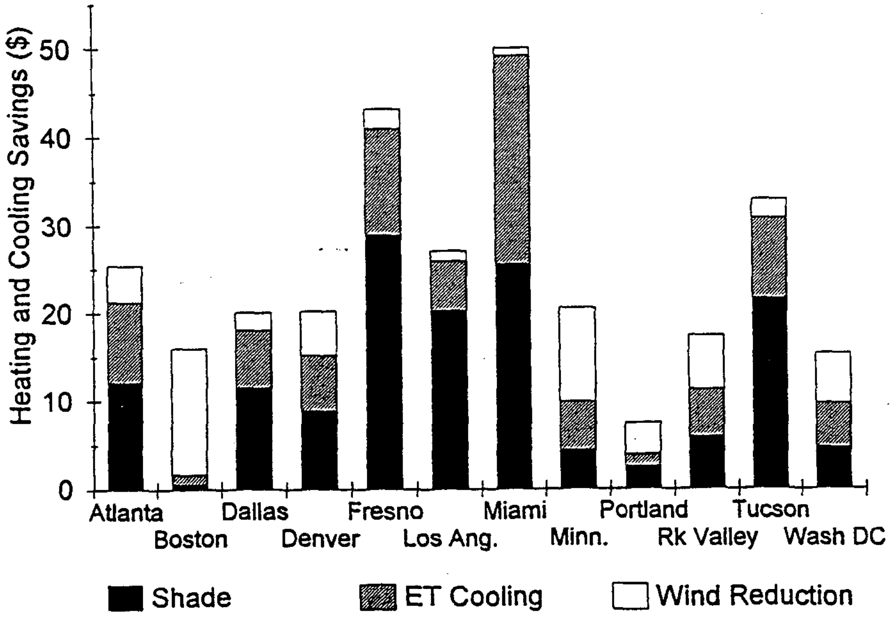

Figure 3. Simulated total annual heating and cooling savings from one 25-ft deciduous tree (calculated as the average of 2 trees on the west and 1 tree on the east).

Relatively few studies have monitored effects of trees on electric air-conditioning consumption of individual buildings,[11] but data to test the accuracy of modeled savings are forthcoming as more utilities begin evaluating trees as a DSM option. Actual savings are likely to be less than described above because of less-than-optimal tree location and growth. In fact, the availability of space for energy conserving tree plantings varies widely depending on land use characteristics.

II. Technical Potential, Saturation, and Natural Adoption Rates

If measured and simulated energy savings suggest that a shade tree program could provide significant energy savings, more detailed analysis first requires defining and identifying the technical potential for shade trees. Energy conserving planting sites, including sites occupied by existing trees, can be defined as having technical potential. Once the technical potential is known, current saturation is determined as the percentage of technical potential occupied by trees. Low technical potential and high saturations indicate low potential for energy conserving tree plantings.

Natural adoption refers to the rate that residents will adopt a DSM option in the absence of DSM incentives. The natural adoption rate (NAR) for shade trees is the rate that energy conserving planting space is filled due to new plantings or the growth of existing trees in the absence of a shade tree program. Because urban landscapes are heterogeneous and trees are dynamic, continuously growing, dying, and being planted, evaluating these rates for energy conserving tree planting can be more difficult than it is for other DSM measures.

A. Technical Potential

In regions with large cooling loads, technical potential could include planting sites to the west, east, and south of buildings. We have interpreted aerial photographs of 18 California cities using this definition to estimate the amount of space available for energy conserving tree plantings around single-family residential buildings. Initial analysis indicates that the technical potential averaged 21% of total residential land area for all cities, with values ranging from 16 to 30%. Hence, in this sample about one-fifth of all residential land area could contain trees located to provide beneficial building shade.

Technical potential was defined differently in a Forest Service study conducted in cooperation with San Diego Gas & Electric Co. Results of initial tree shading simulations using weather data for several climate zones in the SDG&E service area indicated that adding more than one tree to the west of homes was marginally cost effective.[12] Therefore, technical potential was more narrowly defined as the number of single-family detached residences with planting space for at least one tree no closer than 12 feet and no further than 40 feet from the west-facing wall.

From aerial photographs of four largely residential census tracts we noted if there was potential for new tree planting (**Table 1**). For buildings without tree-planting potential, we determined if restrictions were due to presence of other trees, buildings, or paving/fences. Of the 6,610 single-family buildings surveyed, 61% were air-conditioned and 56% had technical potential for shade trees.

B. Saturation

Current saturation ranged from 8 to 44%, increasing with the median age of buildings in each tract. Trees are usually planted soon after homes are constructed, so it is not surprising that more growing space is occupied by trees in older neighborhoods than in newer neighborhoods. This relationship between saturation and building age blurs in neighborhoods over 30 years old, where one generation of trees may be gradually replaced. Urban forest stands in older neighborhoods are often characterized by their diverse age structure due to the intermittent replacement of trees planted 30 or more years ago.

C. Natural Adoption Rate

The NAR of trees opposite the west side of homes with technical potential was estimated to be 2 to 3% per year, regardless of neighborhood age. This calculation assumes a linear annual penetration rate, and largely reflects the increasing size of existing trees. In neighborhoods older than the oldest one in this study (20 years),

Table 1: Technical Potential for Energy Conserving Tree Planting on the West Side of Single-Family Residences in Four San Diego Census Tracts

Census Tract No.	No. S.F. Residences	Median Age (yrs)	% AC Saturation	% w/ Tech. Potential	% Current Saturation	% Annual Penetration
170.06	821	20	65	68	44	2
83.2	1393	18	67	34	34	2
170.26	2014	6	59	53	19	3
170.97	2382	5	59	67	8	2
Totals	6610	10	61	56	20	2

rates of tree removal and replacement planting could drastically alter past annual penetration rates, as well as future saturation. Studies are underway to investigate how the age structure, mature sizes, and growth rates of tree species occupying energy conserving sites influence annual penetration and future saturation.

This shade tree market analysis suggested that there was ample opportunity for a DSM shade tree program to conserve cooling energy via tree planting around these types of San Diego residences. There was space for planting trees opposite the west walls of more than half of the 6,610 houses surveyed. On average, only one in five of the residences with technical potential has trees that occupy the targeted planting space. Thus, over 40% of all houses surveyed have space available for a shade tree opposite their west wall. Because the NAR is only 2 to 3% each year, a DSM program could substantially increase the amount of tree shade on west walls.

III. Cost Effectiveness

Shade trees require large initial investments for planting, while energy benefits are relatively small until the tree crowns have grown large and dense. Other DSM options usually provide immediate energy savings upon implementation, and those benefits usually diminish as equipment ages. Cost/benefit analyses used to compare DSM options usually discount future benefits and costs to determine net present values. Shade trees could be expected to perform poorly in these analyses because the present values of large up-front planting and establishment costs are relatively great while the present values of future energy savings become relatively small. Despite this disadvantage, shade trees have been found to be cost effective.

In a cost/benefit analysis of six conservation treatments conducted by Arizona Corporation Commission staff,[13] small shade trees were second to increased attic insulation in cost effectiveness.

The present value in 1993 of three small shade trees was $50 for the target home cooled by air conditioner or heat pump only, and $200 for the same home assuming dual cooling. The analysis assumed planting costs of $45 per tree and annual maintenance costs of $6.67 during the first 5 years, increasing to $10 during each of the remaining 25 years. Expected annual cooling savings were assumed to be negligible during the first five years, then 0.48 kW and 717 kWh for the home with air conditioning or heat pump and 0.24 kW and 1,600 kWh for the home with dual cooling. A real discount rate of 7% was assumed. Installation of large shade trees ($382 to plant each) was not cost effective due to greater initial costs than for smaller trees.

SDG&E has proposed a pilot shade tree program for 1993 aimed at doubling the NAR by planting about 5,000 trees (15 gallon) in neighborhoods where most households have air conditioning and tree saturation is low. A total budget of $237,800 is projected (about $48 per tree), with participants contributing an additional $10 per tree. The program is estimated to reduce demand at least 0.07 MW within the first six years and nearly 1 MW over a 20-year period. An average annual cooling savings of about 80 kWh per tree is anticipated. Annual avoided capacity and energy benefits are projected to average $62 and $53 per tree, respectively. The overall cost-benefit ratio for the 1993 pilot is 1.54.

The program is likely to be a joint effort between SDG&E and a local non-profit tree planting group. Similar arrangements have proven successful in Sacramento, where the Sacramento Municipal Utility District and the Sacramento Tree Foundation are planting 1,000 trees per week, as well as in Iowa, where utilities are supporting planting of trees for energy conservation in over 200 communities under the direction of Trees Forever.

Our cost/benefit study of proposed yard tree plantings in 12 U.S. cities assumed a 10% cost of capital and 30-year planning period. The following traits were characteristic of the most cost-effective programs:[14]

- ***Low unit planting and establishment costs that cut up-front investment:*** Use of trained volunteers, smaller tree sizes, and follow-up care to insure high survival rates are successful strategies.

- ***Regular maintenance of maturing trees:*** The loss of maturing trees is costly in terms of benefits foregone. The costs of regular tree care during the later years of a project are small compared to benefits received.

- ***Plantings targeted to markets where high levels of net benefits will be sustained:*** Investment in shade trees as a DSM measure should match costs with benefits by considering factors such as local climate, air-conditioning saturation, potential impact of trees on energy, environment, and human health, need for trees, and willingness of participants to maintain trees.

IV. Achieving Expected Performance

To provide the expected return on investment, shade trees should be: (1) properly planted and strategically located to achieve expected performance, (2) carefully selected to grow vigorously, cast dense shade, and maintain foliage throughout the cooling season, and (3) maintained in a healthy state. Judicious tree selection, location, and planting can be achieved through workshops and training sessions that provide hands-on education to all participants. Information on request, as is provided through the SMUD/Sacramento Tree Foundation shade tree hot line, improves the likelihood that participants will make informed tree care decisions.

Once planted, tree maintenance usually becomes the customer's responsibility. High loss rates and unhealthy trees will reduce technical performance and expected return on investment. Although yard tree mortality rates have not been studied systematically, our interviews with landscape contractors and arborists suggest that about 15 to 30% of the trees may die during the first five years and 0.2 to 2% will die each year thereafter.[15] Once established, the life span of healthy yard trees generally exceeds 30 years. Loss rates may be reduced if there is follow-up during the first years of establishment. Follow-up may consist of a mailed questionnaire used to track tree survival and health, invitations to tree care workshops, or site visits.

The economics of utility investment in follow-up after planting and long-term tree care needs further investigation. For instance, street tree data suggest that about one-third to one-half of all tree losses occur during the first two years after planting.[16] The price of guaranteeing two years' survival after planting may be less than benefits forgone due to establishment-related mortality.

V. Externalities and Other Benefits and Costs

The Energy Policy Act of 1992 calls for integrated resource planning, and utilities are increasingly incorporating environmental externalities into their planning process. Cost-Benefit Analysis of Trees (C-BAT) is a computer model that complements cost-effectiveness analysis by providing a broader accounting of social benefits and costs. C-BAT calculates the annual present value of benefits and costs over 30 years associated with tree planting. The model uses input regarding the numbers, locations, and species of trees to be planted, as well as expected costs for planting, pruning, removal, irrigation, pest/disease control, green waste disposal, litigation/liability, inspection, administration, and infrastructure repair. Growth and mortality rates are assigned, then tree population numbers and size are simulated. Benefits are projected using a variety of submodels for energy and carbon savings, air pollution interception/absorption, stormwater runoff reduction, salvage value, property value increases and other aesthetic, social, and ecological benefits. C-BAT was applied in 12 U.S. cities to project 30-year net present values and benefit-cost ratios associated with proposed tree plantings in parks/schools, yards, streets, and unimproved lands. Discounted benefit-cost ratios for yard tree plantings were among the highest found. An example is provided here for yard tree plantings associated with Pacific Gas and Electric's Shade Tree Program in Fresno.

PG&E began a Shade Tree Program in Fresno during 1991 and has developed a program for new customers who purchase energy efficient houses. The current program is delivered through a local non-profit tree planting group, Tree Fresno. A $10 rebate coupon is offered to customers who plant approved trees where they will shade residential buildings.

The C-BAT simulations assumed planting of 3,300 (5 gal and 3 ft tall) trees annually from 1991 to 1995 at an average cost of $15 per tree. Chinese pistache, a deciduous tree which grows rapidly to 50 ft tall, was selected as the representative species. Of the 16,500 trees planted, 3,399 (21%) were projected to die during the 30-year period. Mature tree pruning and removal costs were assumed to be $196 and $644, respectively. Dead trees were assumed to be removed but not replaced. Program administration costs were assumed to be $6.50 per mature tree. A 10% cost of capital was assumed and a consumer price index was applied to account for projected effects of inflation on prices.

The 30-year net present value of PG&E-sponsored yard tree plantings in Fresno was estimated to be $22.3 million and the overall benefit-cost ratio was 19.3 (**Table 2**). Most dollars were projected to be spent for pruning, planting, program administration, and dead tree removal. Largest benefits were projected from property value enhancement, energy savings, and avoided stormwater run-off. The 30-year present values of all benefits and costs per planted tree were $1,426 and $74, respectively.[17]

About 70% of the single-family homes in Fresno are air conditioned. Also, assuming that less than optimal tree selection and location cuts cooling energy savings to about half of the maximum, a healthy, 40-ft tall yard tree (about 25 years old) was projected to save 347 kWh per year. This energy savings translated into about 208 gallons of water saved at the power plant, since approximately six-tenths of a gallon is used for each kilowatt-hour of electricity produced.

Table 2: Projected Present Value of Benefits and Costs for Yard Tree Plantings in Fresno (16,500 trees planted, 21% mortality for 30 years, 10% cost of capital)

Benefit Category	Present Value (in $1,000s)	Cost Category	Present Value (in $1,000s)
Energy:		Planting:	226
Shade	3,949	Pruning:	383
ET Cooling	1,484	Removal:	
Wind Reduction	303	Tree	175
Subtotal	5,736	Stump	0
Air Quality:		*Subtotal*	175
PM10	167	Irrigation:	94
Ozone	26	Landfill:	0
Nitrogen Dioxide	174	Inspection:	0
Sulfur Dioxide	17	Pest/Disease:	5
Carbon Monoxide	13	Infrastructure Repair:	
Subtotal	397	Water/Sewer	56
Carbon Dioxide:		Sidewalk/Curb	43
Sequestered	151	*Subtotal*	99
Avoided	267	Liability:	38
Subtotal	418	Administration:	201
Hydrologic:		**Total Costs:**	**1,222**
Runoff Avoided	614		
Saved at Power Plant	11		
Subtotal	625		
Property/Other:	16,351	**Net Present Value:**	**22,305**
Total Benefits:	**23,527**	**Benefit/Cost Ratio:**	**19.3**

Avoided power plant emissions can result from energy savings provided by shade trees. Also, because trees intercept particulates and absorb gaseous pollutants they can offset power plant emissions. Uptake rates were estimated assuming average deposition velocities to vegetation from limited literature on this subject and monthly pollution concentrations from monitoring stations in Fresno.[18] Power plant emission rates were linked to fuel mix (primarily natural gas) and implied valuation was used to estimate the societal value of reducing air pollutants through tree planting. Assumptions regarding air pollution control costs, emission factors, and deposition velocities are listed in **Table 3**.

The 40-ft tree was projected to remove atmospheric carbon by sequestering 103 lb in tree biomass and reducing power plant emissions by 153 lb during one year (Table 3). The impled value of carbon removal was projected to be $2.81. With the exception of carbon dioxide, implied values for the pollution uptake by trees were several times greater than values for emissions avoided. The value of avoided emissions will be relatively greater in areas where coal is a primary fuel and uptake rates are lower due to cleaner air. In this example, total implied values were largest for nitrogen dioxide ($1.45) and particulates ($1.33). The Environmental Protection Agency is considering the concept of using trees as biomass pollution sheds to generate emission reduction credits.

Urbanization increases the land area that is paved or covered with roofs and other impermeable surfaces, which can increase the incidence and severity of flooding. One means for controlling storm run-off is to construct basins that detain run-off and thus reduce stream flows and flooding potential. Many jurisdictions require construction of onsite detention basins for new development to insure that off-site flow does not exceed pre-development rates. To purchase land, construct, and landscape a basin costs approximately $0.02 per gallon of capacity. The crown of the mature yard tree in Fresno was estimated to intercept 182 gallons of rainfall per year, which ultimately evaporates. The annual implied value of this run-off storage was projected to be $3.64.

Table 3: Projected Annual Air Pollution Uptake and Avoided Power Plant Emission Rates From A Healthy 40 ft Deciduous Yard Tree in Fresno

Air Pollutant	Depostion Velocity (cm/sec)	Emission Factor (lb/MWh)	Control Cost ($/ton)	Annual Uptake (lb/tree)	Annual Avoided (lb/tree)	Implied Value ($/tree/yr)
PM10	0.6	0.09	1,307	2.02	0.03	1.33
Ozone (VOC)	0.45	0.03	490	0.84	0.01	0.21
NO_2	0.4	0.45	4,412	0.50	0.16	1.45
SO_2	0.66	0.02	1,634	0.16	0.01	0.14
CO	0.001	0.68	920	0.03	0.23	0.12
CO_2	NA	0.0004	22	102.82	153.13	2.81

VI. Summary and Conclusions

Cost-effectiveness studies conducted by several utilities suggest that shade tree programs can be viable energy conservation measures in certain markets. When direct and indirect effects are considered, annual air-conditioning savings from a 25-ft tall deciduous tree (about 15 years after planting) were projected to range from 100 to 400 kilowatt-hours (10-15%), and peak cooling demand savings ranged from 0.3 to 0.6 kilowatts (8-10%) in most cities. In a study of over 6,000 single-family residences in San Diego, over 40% were found to have space available for tree planting to shade west-facing walls. The natural adoption rate of trees for energy conservation was 2 to 3% per year for neighborhoods ranging from 5 to 20 years old. SDG&E is implementing a pilot shade tree program targeted to markets characterized by low NARs and tree cover, but relatively high air-conditioning saturation.

Results from the computer model Cost-Benefit Analysis of Trees suggest that benefits from energy savings, air pollution mitigation, avoided run-off, and increased property values associated with yard trees can outweigh planting and maintenance costs. Although the resident can obtain substantial cooling energy savings from direct building shade, benefits accrue to the community as well, due to the aggregate effect of trees on urban climate. Shade tree programs can promote revitalization of our cities by creating new jobs, healthier environments, and positive community interactions.[19]

Finally, the ability of urban trees to remove atmospheric carbon dioxide is far from irrelevant. Carbon emissions avoided due to energy conservation from shade trees usually exceed the amount of carbon sequestered and stored in tree biomass.[20] This suggests that, despite the expense of planting and maintaining trees in urban areas, such a program may be a very cost-effective component of U.S electric utilities' carbon offset programs. ■

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Endnotes:

1. In a process similar to sweating, trees use heat to evaporate water from their leaves before it can heat the air, thus cooling the air immediately around the leaves. The cumulative effect of many leaves and trees can cool the air in a large area.

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15. *Id*.

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