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Authors
Krause, F.
Koomey, J.G.

Publication Date
1990-07-01

LBL-27311
UC-402

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UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE
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F. Krause and J. Koomey

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Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

LBL-27311

UNIT COSTS OF CARBON SAVINGS FROM URBAN TREES, RURAL TREES, AND ELECTRICITY CONSERVATION: A UTILITY COST PERSPECTIVE

Florentin Krause
Jonathan Koomey

Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

July 1990

The work described in this paper was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Utility Technologies of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

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ABSTRACT

This paper compares the cost of sequestered and conserved carbon from rural tree planting, urban tree planting, and efficiency improvements, from the perspective of an electric utility and its ratepayers. Of these three options, energy efficiency appears to be the most widely applicable and attractive carbon mitigation measure from the utility's perspective. The majority of the demand-side resources we consider would allow carbon savings at negative net cost, while rural trees almost always have positive net cost to the utility. Urban trees can in many cases be comparable in cost to conservation, but are subject to a larger number of constraints (particularly in siting). For example, conservation can work in almost every type of building, while urban trees are most likely to be successful for some fraction of residential and small commercial buildings. Rural tree planting, both in the US and abroad, is an important tool in combating global warming; however from the utility's perspective, this option appears to be less cost-effective than conservation or urban trees under a wide variety of different assumptions.

Keywords: carbon, carbon dioxide, energy conservation, cost/benefit analysis, energy efficiency, global warming, greenhouse effect, urban trees.

1. INTRODUCTION

Global warming has become of increasing concern both in the scientific community (Hansen 1988, Schneider 1989) and in the popular press (Begley et al. 1988, Lemonick 1989). Because the utility industry is responsible for a substantial fraction of carbon dioxide emissions in the U.S., this sector is likely to be an important focus of policies to mitigate these emissions. Recently, a variety of options, including energy efficiency and tree planting by utilities have been proposed to mitigate urban heat islands and to offset power plant carbon dioxide releases that contribute to global warming (Akbari et al. 1988, Akbari and Rosenfeld 1989, Dudek 1988).

This paper compares the costs of investing in energy efficiency to those of planting urban and rural trees from the utility perspective.[1] The main purpose of the analysis is to establish a consistent methodology for comparing the costs of carbon savings from these options, and to carry through the comparison using plausible assumptions. The methodology developed is more important than the actual numbers used, although we feel some broad conclusions can be drawn from the crude estimates of costs we present.

The second section (after this introduction) sets forth the methodology for calculating per unit costs of reducing carbon emissions through conservation and the costs of sequestering carbon through tree planting. The third section explores the factors affecting the unit cost of saved and sequestered carbon. The fourth section presents the results of our survey of data sources and our subsequent analysis. The fifth section explores the size of the surcharge on U.S. electricity production needed to finance tree planting to offset the carbon emissions from that production. Finally, the sixth section compares the potential impacts on electricity rates from planting trees or implementing conservation.

2. METHODOLOGY

Societal Versus Utility Least-Cost Perspectives

In any comparative assessment of utility-related investments, it is important to specify the cost-benefit perspective that is being used. Over the last few years, standardized definitions of these perspectives have become available in the context of new regulatory and utility planning approaches known collectively as Least-Cost Utility Planning (LCUP) (Krause et al. 1988). One defining feature of LCUP is the integrated treatment in utility resource plans of conventional supply resources and previously neglected demand-side resources (load management and conservation).

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[1] The comparison of these options from the societal perspective is more difficult, as described below.

Clarifying cost perspectives is always important, but it is especially crucial when costs and benefits of investments accrue to different members of society. Conservation and trees offer multiple, non-comparable benefits to utilities and to society at large. Conservation reduces energy consumption, avoids peak power, reduces carbon dioxide, NO_X, SO_X, and other emissions, creates more jobs per kWh than supply projects, and keeps more money in the state (or country) than supply projects. Urban trees reduce energy consumption, avoid peak power, reduce carbon dioxide, NOx, SO_X, and other emissions, supply yard shade, enhance property values, prevent erosion, control storm drain runoff, enhance groundwater recharge, provide wildlife habitat, supply wood and leaves, and sequester carbon (from tree growth). Rural trees reduce NO_X, SO_X, and other pollutants, create recreational opportunities, prevent erosion, protect watersheds, supply wood, leaves, fruits, animal habitat, and animal fodder, and sequester carbon (from tree growth).

From a societal perspective, all these and other benefits should be included in an analysis of the least-cost approach to reducing carbon emissions. From the perspective of a utility facing regulatory demands to reduce net carbon emissions, only a small subset of these benefits is relevant. In the case of rural trees, it is only the amount of sequestered carbon that is of interest.[2] The other benefits of rural trees accrue to the rest of society and are irrelevant to the utility's choice. However, urban shade trees planted in the utility's service territory save energy and peak demand, and both sequester carbon and reduce carbon emissions. Conservation saves energy and peak demand, and reduces carbon emissions.

The question of which investment *society* should choose is, of course, more complicated. For the purposes of this analysis, we assume that conservation and urban and rural tree planting offer societal benefits of comparable magnitude. We restrict our discussion to the utility's choice to plant trees or invest in efficiency.

Cost definitions

For energy efficiency investments, we use the concept of cost of conserved energy or CCE (Meier et al. 1983). Calculating CCE involves annualizing the capital cost of a conservation measure, and dividing by the number of kWh saved each year. This calculation yields a cost per kWh that is analogous and comparable to the delivered per unit cost of electricity from a power plant. However, this approach ignores the non-energy related benefits of conservation.

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[2] Some utilities may choose to plant trees on watershed lands that they own or control in connection with hydroelectric facilities. In this case, the benefits of such tree planting are relevant and can in some cases be quantified.

A modification of this concept can be applied to the carbon savings from efficiency investments. Previous analyses have calculated a cost of conserved carbon (CCC) by annualizing the total cost of the conservation investment, and dividing by the amount of carbon saved annually (Akbari et al. 1988). This approach is equivalent to a single-attribute analysis that neglects the non-carbon related benefits of conservation. In the analysis below, we present a two-attribute method for calculating the cost of conserved and sequestered carbon that integrates the energy and carbon benefits.

Calculating the Cost of Conserved and Sequestered Carbon

We use a simple two-attribute model to represent the utility's least-cost choices: utility avoided cost savings, and avoided carbon releases to the atmosphere. We first quantify the *value* of the energy and peak demand savings from conservation and urban trees, and subtract this value from the *cost* of installing efficiency or planting urban trees. This procedure yields a *net* cost of conserved energy, which can then be converted to a cost of conserved carbon. This cost of conserved carbon can then be directly compared to planting rural trees *from the utility's perspective.*[3]

The cost of conserved energy (CCE) is defined as the annualized cost[4] of the conservation investment divided by the annual energy savings. More formally, this definition is

$$\text{CCE (\$/kWh)} = \frac{\text{(Capital Cost)(CRF)}}{\text{(Energy Savings/yr)}} \tag{1}$$

where CRF is the capital recovery factor used to annualize the capital cost of the conservation measure.[5] A net CCE can be calculated using some estimate of benefits (i.e., utility costs avoided by the conservation measure). We have chosen levelized avoided costs of \$0.05/kWh, which includes avoided variable costs and avoided capital costs.[6]

$$\text{Net Cost} = \text{Costs} - \text{Benefits} \tag{2}$$

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[3] We assume in our analysis that the regulators have instituted some mechanism to remove the utility's short-run disincentive to conserve (due to revenue losses), such as California's Electricity Revenue Adjustment Mechanism (Krause et al. 1988)

[4] This cost may just be the capital cost, as shown here, or include program costs or the present value of additional operation and maintenance costs due to the conservation measure.

[5] The CRF is equal to $\frac{(r(1+r)^n)}{((1+r)^n-1)}$ where r is the discount rate and n is the lifetime of the investment.

[6] This estimate is meant to be plausible and conservative, not precise. We sidestep the task of calculating appropriate avoided costs, since the intricacies of these calculations are strongly dependent on the characteristics of conservation measures and the particular utility system under consideration (Krause et al. 1988, NERA 1977).

$$\text{Net CCE (\$/kWh)} = \text{CCE} - \text{Avoided Costs} = \text{CCE} - \$0.05/\text{kWh}$$

The net CCE is negative if conservation is economically attractive.

The cost of conserved carbon to the utility is defined as

$$\text{CCC (\$/t-C)} = \frac{(\text{Net CCE})(1{,}000{,}000)}{\text{CB}} \tag{3}$$

where CB is the carbon burden (i.e., the amount of carbon saved, in g-C/kWh) and 1,000,000 is the number of grams per metric ton Unlike conventional approaches, this equation explicitly accounts for the value of energy and peak demand savings from conservation when calculating CCC.

For a rural tree, the cost of sequestered carbon can be defined as

$$\text{CSC (\$/t-C)} = \frac{(\text{Capital Cost})(\text{CRF})}{(\text{C sequestered/yr})} \tag{4}$$

For an urban tree, the calculation is a little more complicated since carbon is both saved and sequestered. The cost of sequestered/saved carbon (CSSC) for urban trees can be defined as

$$\text{CSSC (\$/t-C)} = \frac{(\text{Net CCE})(1{,}000{,}000)}{(\frac{\text{SR}}{\text{ES}} + \text{CB})} \tag{5}$$

where SR is the sequestration rate of the tree (g/tree/year), and ES is the annual energy savings per tree (kWh/tree/year).[7]

Carbon Saving Benefits of Energy Efficiency

The carbon savings can be computed from energy savings using knowledge of which utility plants are likely to be curtailed in response to a change in load (i.e., the marginal units), the carbon burdens of each fuel, and the transmission and distribution losses. Typical direct carbon burdens for each fuel (based on lower heating values) are shown in Table 1, along with the

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[7] This formulation of CSSC for urban trees leads to an inversion of scale when the net CCE is negative, since adding the sequestration rate to the carbon burden leads to a less negative CSSC. This subtlety makes *exact* comparison between urban trees and conservation measures difficult within this framework whenever the net costs of conserved energy are negative. We ignore it because all negative cost investments are extremely attractive, and other benefits are liable to be important when considering the societal perspective. In addition, the sequestration rate is typically only 10% of the energy-related carbon savings per tree (Akbari et al. 1988), so the error introduced is small. The methodology is correct for positive net CCEs, when accurate comparisons are most important.

carbon burden associated with consumption of electricity generated by those fuels, calculated using a heat rate of 10,000 Btus/kWh[8] and a transmission and distribution (T&D) system loss factor of 6%. The direct carbon burden for each fuel is higher than that released in the burning of the fuel because it includes the carbon released from energy consumption when extracting and processing the fuel (Unnasch et al. 1989).

The marginal power plants are those that will curtail their output if conservation or urban trees reduce load below the expected level. The fraction of time that oil, gas, and coal-fired plants are on the margin is a crude measure of what fraction of the electricity savings is generated by each fuel,[9] and can be used to calculate a weighted average carbon burden for energy savings. These "marginal fractions" more accurately characterize the carbon *savings* per kWh than carbon burdens based on the fraction of *total* generation from each fuel.

We calculated the appropriate marginal fractions for the U.S using the methodology described in US DOE (1988c).[10] Table 1 shows these fractions, the resulting carbon burden for energy savings, and the carbon burden calculated using total generation and the 1987 fuel mix. The carbon burden for energy savings is higher than that based on the 1987 fuel mix because the marginal fuels are oil, natural gas, and coal, while 27.4% of net generation in 1987 is from carbon-free hydroelectric and nuclear power (US DOE 1988a), which are rarely used on the margin in most of the U.S.

Fuel prices to utilities in 1987 (US DOE 1988b) and the assumptions in Table 1 for marginal fractions, heat rates, and T&D losses, imply short run variable costs of $0.021/kWh. For comparison, the operating costs of existing

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[8] Conventional oil and gas power plants are typically less efficient than baseload coal plants, which may somewhat offset the lower direct carbon burden of these fuels. We ignore this effect here.

[9] This approach assumes that the energy savings is spread evenly over the year.

[10] Like all simplifications of complicated phenomena, these estimates of marginal fractions submerge important details. They are useful for order of magnitude estimates, but calculations for a particular utility should use estimates of marginal fuels and avoided costs appropriate in that context. These estimates can be derived from typical utility system simulation models (Marnay et al. 1989).

Table 1. Carbon burdens of fossil fuels and electricity

	Direct g-C/kWh fuel[a]	Electric Generation g-C/kWh elect.
Natural Gas	60.7	189
Oil	83.0	258
Coal	103.4	321
US AVERAGE		
Marginal (for Energy Savings[b])		265
Average (Based on 1987 Fuel Mix)		224

ASSUMPTIONS

T&D losses:	6%
Heat Rate:	10,000 Btus/kWh
Adjusted Heat Rate:	10,600 Btus/kWh
Marginal Oil Fraction:	15%
Marginal Gas Fraction:	35%
Marginal Coal Fraction:	50%

[a] Carbon burdens for fuels are from Unnasch et al. 1989, and are based on lower heating values. The direct carbon burden for each fuel is higher than that released in the burning of the fuel because it includes the carbon released from energy consumption when extracting and processing the fuel. g-C/kWh = grams of carbon per kWh (3412 Btus/kWh for fuel and 10,600 Btus/kWh for delivered electricity).

[b] Carbon burdens for energy savings calculated using marginal fractions from US DOE 1988c. The marginal carbon burden represents a crude estimate of the amount of carbon savings from each kWh of energy savings, based on information about which power plants will be curtailed in response to a demand reduction (i.e., which power plants are marginal).

power plants in Michigan is $0.03-$0.04/kwh (Krause et al. 1987). Combined with our assumption of $0.05/kWh total avoided costs, these assumptions imply an avoided capital cost of $0.029/kWh.

Carbon Sequestering Benefits of Tree Planting

In tree planting, carbon sequestering can be discussed at the level of the tree and at the level of a land area that is being reforested or afforested.[11] We discuss the dynamics from the perspective of reforestation of an area. Here, one must distinguish between the sequestering capacity of the forest growth (which is equivalent to the electricity production capacity of a power plant or capacity savings of an efficiency investment) and the cumulative carbon sequestered by the trees.

The sequestering capacity is a function of the annual biomass yield of the forest. For a natural forest, net sequestering occurs only during the growth period of the forest, i.e., during the movement of the forest area toward a steady state (when carbon released by decay is equal to carbon uptake by photosynthesis). The sequestering capacity varies over time, beginning at low values at the seedling stage, to the peak period of early growth, followed by a declining carbon intake as the forest matures.

The cumulative carbon sequestered by a reforested area is the average carbon held in the forest area over the cycle of growth and harvesting. If the reforested area is left in its natural state, the long-term, steady-state carbon storage is equal to the integral of carbon sequestered during all stages of growth and maturation. If the forest is periodically clear-cut and replanted or otherwise managed, the average carbon storage per hectare will be lower (see Figure 1, from Krause et al. (1989)), since the carbon fixed in the natural forest now cycles back and forth between the terrestrial biosphere and the atmosphere. But it is still higher than on unforested land. As a rule, managed temperate forests contain about 80 percent as much carbon in their vegetation as natural forests (Houghton 1987). In a short-rotation fuelwood plantation, the stored carbon fraction would be significantly lower.

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[11] In the context of reducing net fossil carbon releases, we refer to reforestation as an activity that improves the stocking of previously forested land over current, steady-state, non-forested conditions. It does not refer to the replanting of forests after harvest to maintain current yields. Afforestation means planting trees on non-forest land.

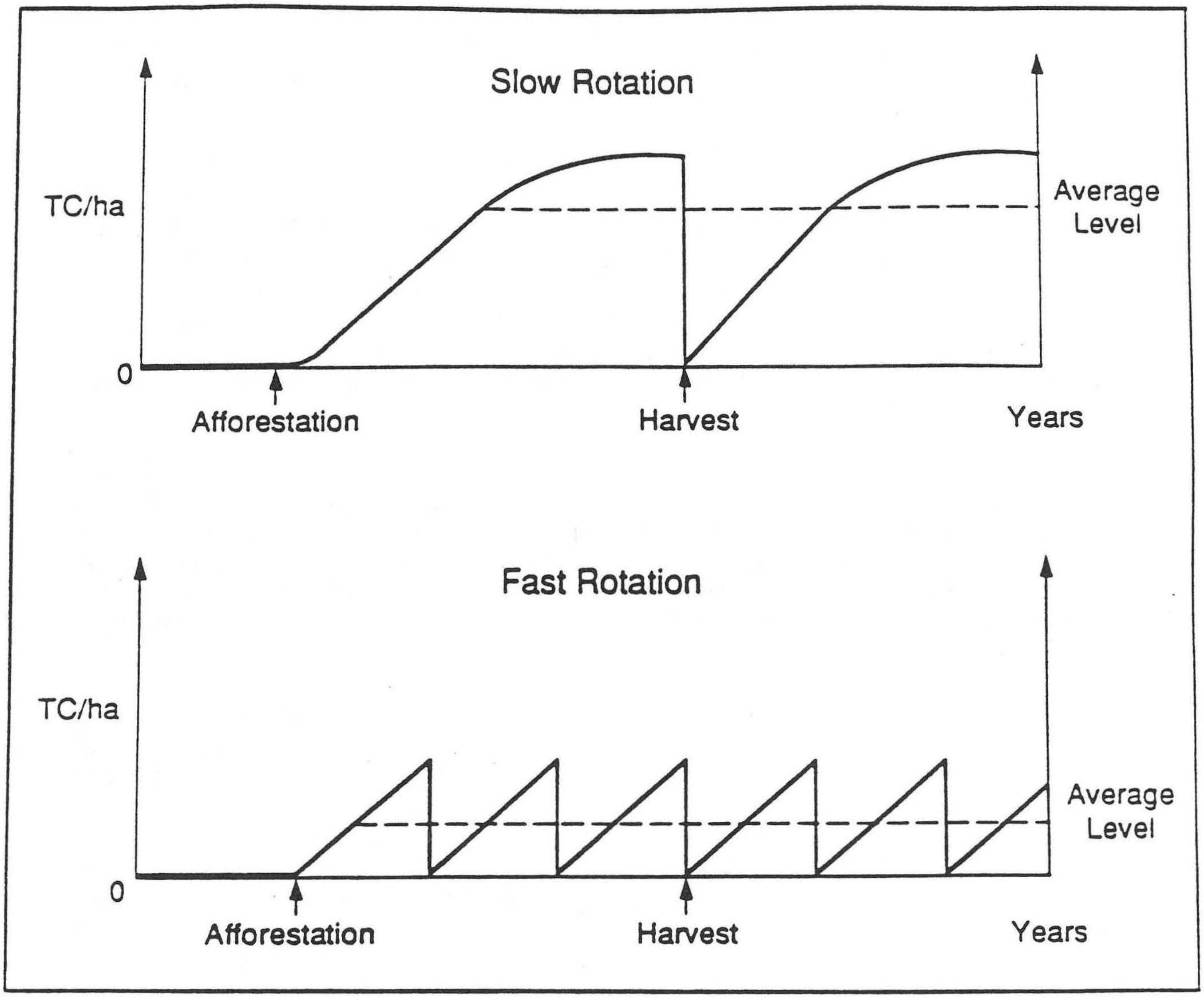

Figure 1. Simplified relationship between harvesting and carbon storage for sustainable yield forestry

The figure shows the level of carbon storage over time and the consequent average carbon storage in the forest for slow and fast rotations. If the forest is clear cut frequently, the time-averaged carbon storage level will be lower than if it is allowed to grow for many years.

The speed at which wood products are consumed or burned,[12] and the manner of harvest, shape the balance between sequestering and carbon releases over time.

The net sequestering rate of a reforested area is simply the average rate of carbon intake between the point of planting and the point at which the first planting reaches the carbon storage level that will be maintained over the planting and harvesting cycle in the long-term. The net sequestering rate is a function of the type of forest management and species selection. A managed forest or plantation maximizes growth rates at the expense of cumulative carbon storage. If a reforested area is left unmanaged, it will grow more slowly, but will eventually achieve a higher carbon storage per unit area, due to the efficiency of plant diversity and biological succession in utilizing sunlight and soil resources. Since forests provide economically valuable products, the maximum feasible carbon storage will usually not be reached in reforestation or afforestation schemes.

Simplified Treatment of Average Cumulative Storage and Yields

Data on forest growth are usually given in terms of harvestable annual biomass yields in tonnes/ha or m^3/ha. These values typically refer to the point in forest growth where harvesting yields the maximum economic benefit, i.e. before forest growth slows down due to maturation. For temperate forests, this point may be 30-50 years after replanting.

To calculate the average cumulative storage benefit of tree planting, one must distinguish between afforestation for commercial purposes and afforestation for the purpose of creating natural forests. We concentrate on the former case. To illustrate the overall method, we discuss the case of planting temperate forests. For these, we assume that trees are harvested after 40 years. We further assume that growth is reasonably linear, and that the cumulative carbon storage achieved in the first growth cycle is forty times the rate of carbon fixing based on annual forest biomass yield. Over several growth cycles, the average cumulative carbon storage is assumed to be half this value as shown in Figure 1. During the first growth cycle, this long-term average level is reached after twenty years.

This assumption allows a simplified treatment of reforestation in which the cumulative carbon sequestration benefit is equal to the annual benefit multiplied by half the harvest rotation period, or, in our example, twenty years. The structure of the tree planting benefit then becomes the same as that from

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[12] Some of these products include fuel that may be burned to displace fossil fuels or construction products that may be used in buildings that will last for decades. We have ignored the potential carbon savings or carbon storage from these uses of wood because of lack of data on how much harvested wood is used for various purposes. More research is needed to collect these data and include them when estimating net carbon sequestration rates from tree planting.

efficiency improvements, which save equal amounts of carbon each year over the life of the investment.

3. FACTORS AFFECTING THE UNIT COST OF SAVED CARBON

Many factors influence the cost of efficiency improvements, including the capital and installation costs, site suitability, the intensity of utilization of a particular device (hours per year, load factors), possible additional maintenance costs (not only to operate, but to ensure persistence of savings), the program overhead costs of utility or state conservation programs (administration, marketing, enforcement, etc.), the measure lifetimes, and the choice of discount rate. Here, too, local factors such as climate are important, as are non-carbon benefits (e.g. reduction in life cycle costs, savings in air pollution other than carbon dioxide, etc.).

A similar catalog of factors exists for sequestered carbon from tree planting. The main ones are seedling price, planting cost, maintenance cost (protection from animals, cars, etc. watering and fertilization), survival rate, land quality and climate (determining range of usable species and growth rates), the type of species planted, location (urban versus rural), the harvest rotation (average cumulative carbon storage over several harvest cycles), type of organization doing the reforestation (labor costs and overhead), land cost (rent, incentive requirements to compensate for lost opportunity costs), economic benefits other than carbon savings (soil conservation, energy conservation, etc.), and the discount rate used in calculating unit costs.

For urban trees, the factors affecting the cost of carbon sequestration are the same as for rural trees, but include other factors affecting energy savings, such as site suitability, air conditioner efficiency, leaf disposal costs, and water costs.

This list of factors underscores the point that an adequate determination of per unit costs requires detailed specifications and the investigation of specific circumstances. Only where a sufficient number of detailed analyses are available and typical or average applications can be reasonably well defined can more aggregate comparisons be made.

While the cost of conserved energy (and therefore, carbon) in the US electricity sector has been reasonably well established (Geller 1986, Hunn et al. 1986, Krause et al. 1987, Meier et al. 1983, SERI 1981), the cost of sequestered carbon from tree planting has been less well researched. This is due, in part, to the different focus of commercial forestry research and climate stabilization research. Also, from a climatic perspective, tree planting anywhere in the world is relevant, including in Third World countries with widely varying climatic and economic conditions.

In view of these limitations, we restrict ourselves to a preliminary analysis that establishes order of magnitude estimates for the cost of avoided carbon from tree planting, without attempting to systematize and bring into full consistency the various data. We have constructed carbon sequestration costs per ton using estimates from various sources on carbon uptake rates per tree, survival rates, costs per tree, and planting density. Instead of deriving one estimate, we have combined reasonable estimates of these parameters in a way that yields upper and lower bounds for tree planting costs. There are large uncertainties in any such estimates.

Data sources

Data on the cost of conserved energy were taken from analyses covering a large number of end-uses for entire utility service territories in Michigan (Krause et al. 1987) and in Texas (Hunn et al. 1986). We summarized these data by cost of conserved energy: we grouped them as low (from $0-0.03/kWh saved), medium (from $0.03-0.05/kWh saved), and high (from $0.05-0.085/kWh saved). To make the residential estimates from the Michigan Electricity Options Study (MEOS) and the commercial estimates from the Texas study comparable, we express the quantity of energy savings 20 years from the forecast's base year as a fraction of *total utility system* electricity sales in that year. We also express carbon savings as a fraction of total utility system carbon emissions in the same year (using the U.S. average and marginal carbon burdens for simplicity). We adjusted the costs in the Texas study, which assumed a 10% real discount rate, to reflect a 7% real discount rate. Table 2 summarizes the data on the cost of conservation, and Figures 2 and 3 show the aggregated supply curves of conserved energy and conserved carbon. The figures summarize the CCEs, net CCEs, and costs of conserved or sequestered carbon.

Table 2. Summary of Typical Conservation Supply Curves for Residential and Commercial Sectors

	Weighted Average CCE $/kWh	Net CCE $/kWh	CCC $/tonne-C	Energy Savings as % of Total Sales	Carbon Savings as % of Total C Emissions
MICHIGAN ELECTRICITY OPTIONS STUDY (RESIDENTIAL MEOS)					
Low	0.013	-0.037	-138	3.1	3.6
Medium	0.044	-0.006	-23	0.6	0.7
High	0.080	0.030	113	0.2	0.2
All	0.022	-0.028	-106	3.9	4.6
TEXAS STUDY (COMMERCIAL)					
Low	0.010	-0.040	-149	3.1	3.6
Medium	0.039	-0.011	-43	0.7	0.8
High	0.053	0.003	11	0.5	0.6
All	0.020	-0.030	-113	4.3	5.1

MEOS Total Electricity Sales 20 Years from Base Year (TWh)	81
MEOS Total Carbon Emissions 20 Years from Base Year (Megatonnes)	18
Texas Total Electricity Sales 20 Years from Base Year (TWh)	289
Texas Total Carbon Emissions 20 Years from Base Year (Megatonnes)	65

	Range of Cost of Conserved Energy (CCE)
Low	< $0.03/kWh
Medium	$0.03-0.0499/kWh
High	$0.05-0.085/kWh

Avoided Costs ($/kWh)	0.05
Real Discount Rate	7%

Net CCE = CCE - Avoided Costs
$/tonne-C = $/metric tonne carbon

REFERENCES:
Krause et al. 1987
Hunn et al. 1986

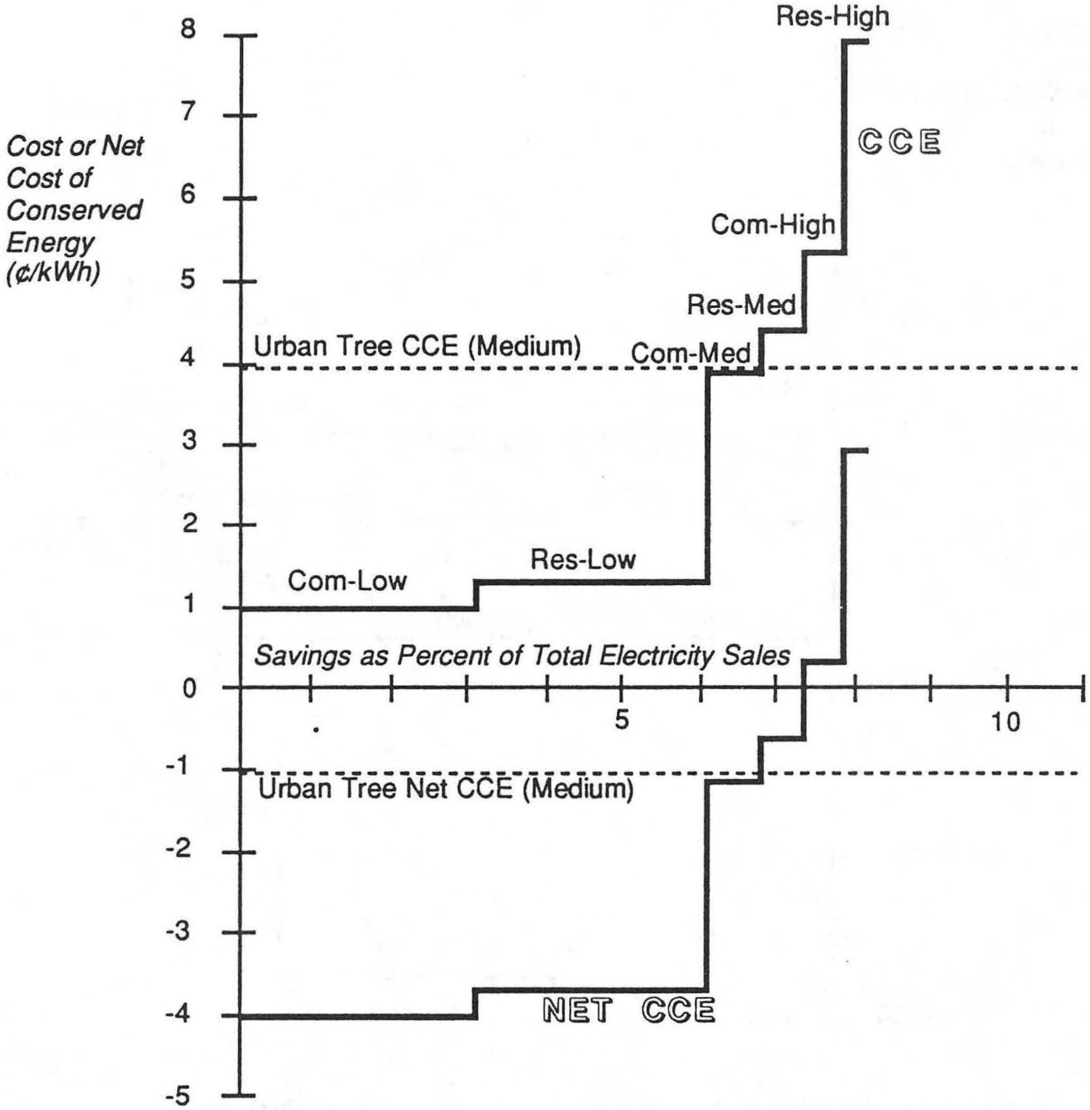

Figure 2. Aggregate supply curve of conserved energy

This graph shows typical values for the CCE and net CCE of energy efficiency and urban trees. Energy savings are expressed in terms of percent of total system electricity sales twenty years from the forecast's base year. The discount rate is 7% real. CCE is from Table 2. Net CCE = CCE - 5¢/kWh (avoided costs).

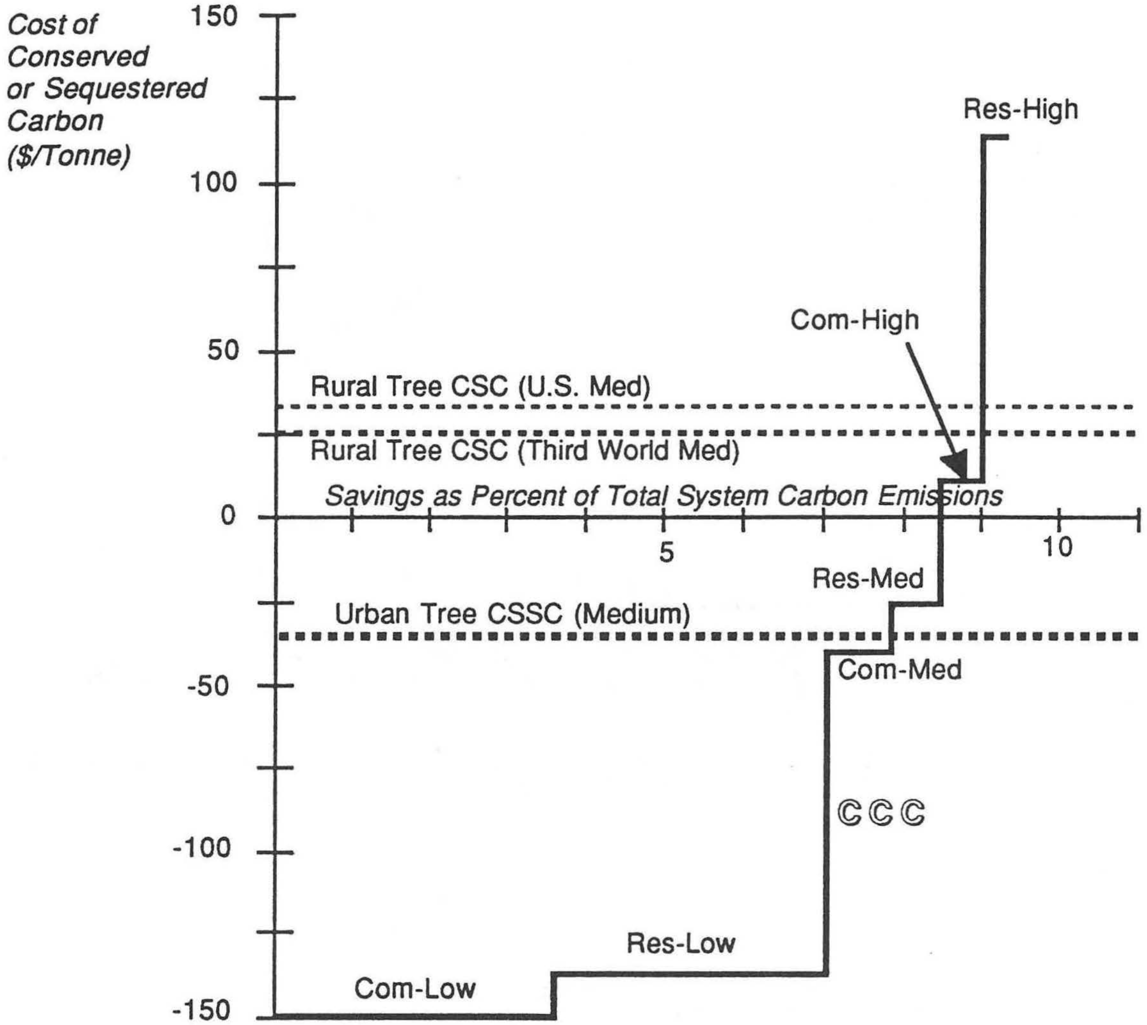

Figure 3. Aggregate supply curve of conserved carbon

This graph shows typical values for the CCC, CSC, and CSSC of energy efficiency, rural trees, and urban trees (respectively). Carbon savings are expressed in terms of percent of total utility system carbon emissions twenty years from the forecast's base year. Discount rate is 7% real. The CCC steps are the Net CCE steps of Figure 2, converted from kWh to tonnes of C; similarly for urban trees. Source: Tables 2-4.

Table 3 shows a plausible range of estimates for the carbon yields and costs of rural tree planting and reforestation. The carbon yields are from a wide variety of sources in the literature (Dudek 1988, Dyson et al. 1979, Harte 1985, Marland 1988, Postel et al. 1988, Ranney et al. 1987, Steinbeck et al. 1976, USFS 1982, Woodwell 1987). The cost data we reviewed show a wide range, since they often reflect personal estimates of individuals working for the US Forest Service, non-government organizations in the US involved in tree planting, commercial US nurseries, local governments, official development assistance and United Nations agencies, private development assistance organizations, and tree planting movements in Third World countries (Dudek 1988, Fortune 1975, Leach et al. 1988, Pilarski 1988).

In all cases, we used a 7% real discount rate and estimates of the *establishment cost* of the tree, including seedling cost, watering cost, and the cost of protecting the seedlings from animals and other hazards. Under schemes that would reward tree planting with subsidies from carbon taxes on energy use, some categories of land that could support trees could become economically valuable, changing the leasing or purchase price of such land. We have sidestepped this issue by calculating only the establishment cost as a lower bound to the cost of tree planting. We used 20 years as the investment life of rural trees, which is a conservative estimate given the many uncertainties. We assumed that urban trees would live for 30 years.

Table 4 shows the costs and energy savings benefits from urban tree planting from Akbari et al. (1988). We use establishment costs from $5-25/tree and relatively high survival rates of 0.85-0.95. We also assume that urban trees do not yield energy savings for ten years, and escalate the cost of the tree at the discount rate before annualizing the investment over 20 years. Akbari et al. calculated average energy savings to be 18.6% of cooling energy in 7 U.S. climates. We use 12% savings to be conservative. We assume cooling energy consumption of 2000 kWh, multiply this number by 0.12, and divide by 3 trees per house to get the energy savings per tree (80 kWh/year).[13]

4. DISCUSSION OF COST ASSUMPTIONS

The cost reports for tree planting differ enormously for different settings. For example, planting and protecting a young street tree in Los Angeles is estimated to cost $100, while planting a tree in a rural community fuelwood lot in India can cost as little as 25 cents. We have attempted to supply reasonable numbers for a few key parameters, such as sequestration rates, establishment costs, and survival fractions, and used these estimates to derive costs of sequestered carbon from the bottom up.

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[13] The calculation assumes that these energy savings accrue due to shading of the house. It ignores heat island mitigation, which occurs if enough trees are planted throughout a city to reduce overall average temperatures.

Table 3. Cost of Rural Trees

	Cost to Establish $/tree	Survival Fraction	Surviving Trees/ha	Cost to Establish $/ha
THIRD WORLD				
Low	0.25	0.8	1000	313
Medium	0.8	0.6	1000	1333
High	8	0.5	1000	16000
UNITED STATES				
Low	0.5	0.9	1000	556
Medium	1	0.75	1000	1333
High	9	0.6	1000	15000

	Sequestration Rate kG-C/tree/yr	Sequestration Rate tonne-C/ha/yr	Annualized Cost $/ha/yr	CSC $/tonne-C
THIRD WORLD				
Low	7.50	7.50	29	*3.93*
Medium	5.00	5.00	126	*25.17*
High	3.00	3.00	1510	*503.43*
UNITED STATES				
Low	6.50	6.50	52	*8.07*
Medium	4.00	4.00	126	*31.46*
High	1.35	1.35	1416	*1048.81*

ASSUMPTIONS

Real Discount Rate	7%
Investment Life (Years)	20
Capital Recovery Factor	9.4%

REFERENCES:

Carbon yield assumptions adapted from:
Dyson et al. 1979, Harte 1985, Marland 1988, Postel et al. 1988, Ranney et al 1987, Steinbeck et al. 1976, USFS 1982, and Woodwell 1987.

Cost assumptions adapted from:
Dudek 1988, Fortune 1975, Leach et al. 1988, and Pilarski 1988

Table 4. Cost of Urban Trees

COST	Cost to Establish $/tree	Survival Fraction	Cost per Surviving Tree $/tree	Cost after Ten yrs @ 7% $/tree	Sequestration Rate kG-C/tree/yr
Low	5	0.95	5.26	10.35	6.5
Medium	15	0.9	16.67	32.79	4
High	25	0.85	29.41	57.86	1.35

COST	C Saved + C Sequestered kG-C/tree/yr	Annualized Cost $/tree/yr	CCE $/kWh	Net CCE $/kWh	CSSC $/tonne-C
Low	27.7	0.98	*0.012*	*-0.038*	*-109*
Medium	25.2	3.09	*0.039*	*-0.011*	*-36*
High	22.6	5.46	*0.068*	*0.018*	*65*

Assumptions

Cooling Energy Usage (kWh/house)	2000
Cooling Savings	12.0%
Trees/house	3
Energy Savings (kWh/yr/tree)	80
Real Discount Rate	7%
Capital Recovery Factor	9.4%
Lifetime (years)	30
Growth Period (years)	10
Avoided costs ($/kWh)	0.05
Carbon Burden for Savings (g/kWh elect)	265
REFERENCE:	Akbari et al. 1988

Range for Rural Trees

The range of costs of sequestered carbon (CSC) spans more than two orders of magnitude, ranging from a low estimate for third world rural trees of about $4/t-C, to a high estimate of more than $1000/t-C for high cost rural trees in the U.S. This large range is due to the wide range of reported establishment costs (up to one and a half orders of magnitude) and a smaller range of sequestration rates (a factor of 2-5). The range of survival fractions chosen adds almost another factor of two.

Rural Tree Planting in the US and the Third World: Comparison

Our estimates of the utility's CSC for rural tree planting in the U.S. range from about $8/t-C to more than $1000/t-C, while the range for CSC of rural tree planting in the third world is from $4/t-C to about $500/t-C. For U.S trees, we have assumed slightly higher establishment costs and survival rates than those for third world trees, while the sequestration rates are lower to reflect the slower growth of temperate forests compared to tropical forests. Figure 3 shows lines representing our medium estimates of the CSC of rural trees in the Third World and in the U.S.

Range for Urban Trees

Table 4 shows that planting urban trees is comparable in cost to efficiency resources, and can be far cheaper than planting rural trees for sequestration alone. Because of the energy savings provided by urban trees, the CSSCs for low and medium cost assumptions are negative. They range from -$109 for the low cost assumptions to $65/t-C for the high cost assumptions. Figure 2 shows lines representing the cost (and net cost) of conserved energy for urban trees based on the medium cost assumptions ($15/tree, 90% survival rate, 4.0 kg/yr sequestration rate). Figure 3 shows the CSSC for the same assumptions.

Range of US Electricity Efficiency

The net CCE is actually negative for the low and medium cost conservation, since the cost of conserved energy in these two cases is less than the assumed avoided costs. The lowest CCC is -$149/t-C, while the highest is +$113/t-C. Under our assumption about avoided cost, in the Michigan and Texas cases more than 90% of the potential energy and carbon savings in the residential and commercial sectors *can be captured at negative net cost to the utility and its ratepayers*. By contrast, carbon savings from planting rural trees will always have a positive net cost to the utility.

5. SIZE OF ELECTRICITY SURCHARGE TO FINANCE TREE PLANTING

The utility's choice of carbon-saving techniques depends on the unit cost of saved carbon and on the size of carbon savings that can be obtained from each resource in the aggregate. For example, utilities that are trying to fulfill a certain carbon-reduction target may need to plant rural trees in addition to investing in urban trees and low-cost conservation. While the latter options often have negative net costs to the utility, rural trees have positive costs. How much would it cost the utility to pursue rural tree planting, if such tree planting is to be financed by a per kWh surcharge?

The average carbon burden of US electricity production (based on the 1987 fuel mix) is 224 g/kWh delivered. Based on the data in Table 3, the surcharge needed per kWh to offset these carbon emissions with rural tree planting in the U.S. ranges from $0.002/kwh to $0.23/kWh, with the middle estimate at about $0.007/kWh. For third world rural trees, the range is from $0.0009/kWh to $0.11/kWh, with the medium estimate at $0.006/kWh.

6. IMPACTS ON RATES

Utility-financed rural tree planting will increase electricity rates. Depending on the cost estimate used, this impact could be as little as about $0.001/kWh for the cheapest rural trees in the third world to as much as $0.23/kWh for expensive rural trees in the U.S. Assuming a medium value of $0.006/kWh, the rate impact would be of the order of ten percent or less of current electricity prices.

The impact of demand-side resources and urban tree planting on rates depends on the marginal cost structure of the utility. Where utilities face rising marginal costs, energy savings will reduce rates. Where short-run marginal costs are lower than average rates, energy savings will cause rates to increase (to offset lost sales and cover fixed costs). The impact of demand-side programs on rates is typically on the order of a few percent of the electricity price (Krause et al. 1988).

With the appropriate caveats regarding the uncertainty of costs for tree planting, these figures suggest that rate impacts from either option will be comparable in magnitude. However, efficiency investments and urban trees lead to reductions in utility bills that rural trees do not offer. If rate impacts are comparable, the most attractive options to the utility would then be urban tree planting and efficiency investments that can deliver carbon savings at negative net cost.

7. CONCLUSIONS

Investments in energy efficiency and rural and urban tree planting can help reduce net utility carbon emissions. For utilities and their ratepayers, it is important to deploy these options according to least-cost principles. At this time, data on the cost of conserved carbon from tree planting vary over a wide range, and case studies of successful planting programs are needed to narrow the range of plausible costs. Nevertheless, some broad patterns suggest themselves from our review:

- Utility programs to plant trees or implement energy efficiency offer carbon mitigation at negative to slightly positive unit net cost.
- Rate impacts from utility investments in these carbon-saving measures would be limited to a few percent of the electricity price in many cases.
- Among the three utility options investigated, utility-sponsored energy efficiency programs appear to be the most widely applicable and attractive carbon-saving investment. The majority of these demand-side resources would deliver carbon savings at negative unit cost to the utility.
- Urban trees can in many cases be competitive with the cheapest conservation, but are subject to a larger number of constraints (particularly in siting). For example, efficiency measures can be installed in almost every type of building, while urban trees are most likely to be successful for only a fraction of residential and small commercial buildings.
- Rural tree planting, both in the US and abroad, is an important tool in combating global warming; however from the utility's perspective, this option appears to be less cost-effective than conservation or urban trees.

These conclusions are robust under a wide variety of different assumptions. Future work should attempt to estimate the carbon sequestration and savings potential available from urban and rural trees, in the same way that estimates of the conservation potential have been developed in the past fifteen years

8. ACKNOWLEDGEMENTS

The following colleagues provided helpful comments on this paper: Joe Eto, Chuck Goldman, Chris Marnay, Art Rosenfeld, and Karina Garbesi of the Lawrence Berkeley Laboratory, Evan Mills of the University of Lund, and Jeff Romm, Professor of Forestry at the University of California, Berkeley.

The work described in this paper was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Utility Technologies of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

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