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Albedo and vegetation demand-side management options for warm climates

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Abstract

For electric utilities, demand-side management (DSM) can reduce electric load and shift load from peak to off-peak periods. In general, the investor in DSM collects the reward with lower electric bills, excepting a positive externality because of reduced tropospheric and stratospheric air pollution from fossil fuel power plants. In warm climates, DSM options include increasing albedo and vegetation, respectively, by painting surfaces white and planting trees; these DSM options are distinguished from all other DSM options because of ecosystem effects. Ambient temperature falls, mitigating the urban 'heat island', which reduces electric load and ozone formation. The investor in albedo and vegetation DSM options does not collect all of the reward from lower electric bills, since the lower ambient temperature provides savings to all customers who use electricity for air conditioning and refrigeration. Similar to other DSM options, air pollution is also reduced as a result of lower power plant emissions. Complex airshed models and electric utility system dispatch models are applied in this paper to account for some of these ecosystem effects. Unaccounted ecosystem effects remain, stymieing cost effectiveness analysis. © 1998 Elsevier Science B.V.

1. Introduction

Surface albedo is 'the ratio of the hemispheric reflected radiation to the hemispheric incoming radiation' (Taha et al., 1995). Trees provide shade. White surfaces reflect light instead of converting it into heat. Both increase the albedo, lowering the ambient temperature, mitigating the 'urban heat island' effect (Akbari et al., 1989). Albedo and vegetation have ecosystem effects; they lower ambient temperature of the urban heat island, lowering electricity costs for everyone; trees increase biogenic emissions; and ozone formation is altered. These public goods have positive and negative externalities. Lowered ambient temperature and biogenic emissions are effects unlike any other DSM options.

Taha (1997) modeled the tropospheric ozone impacts of increasing albedo and urban forestration in the Los Angeles airshed. Liu (1994) used

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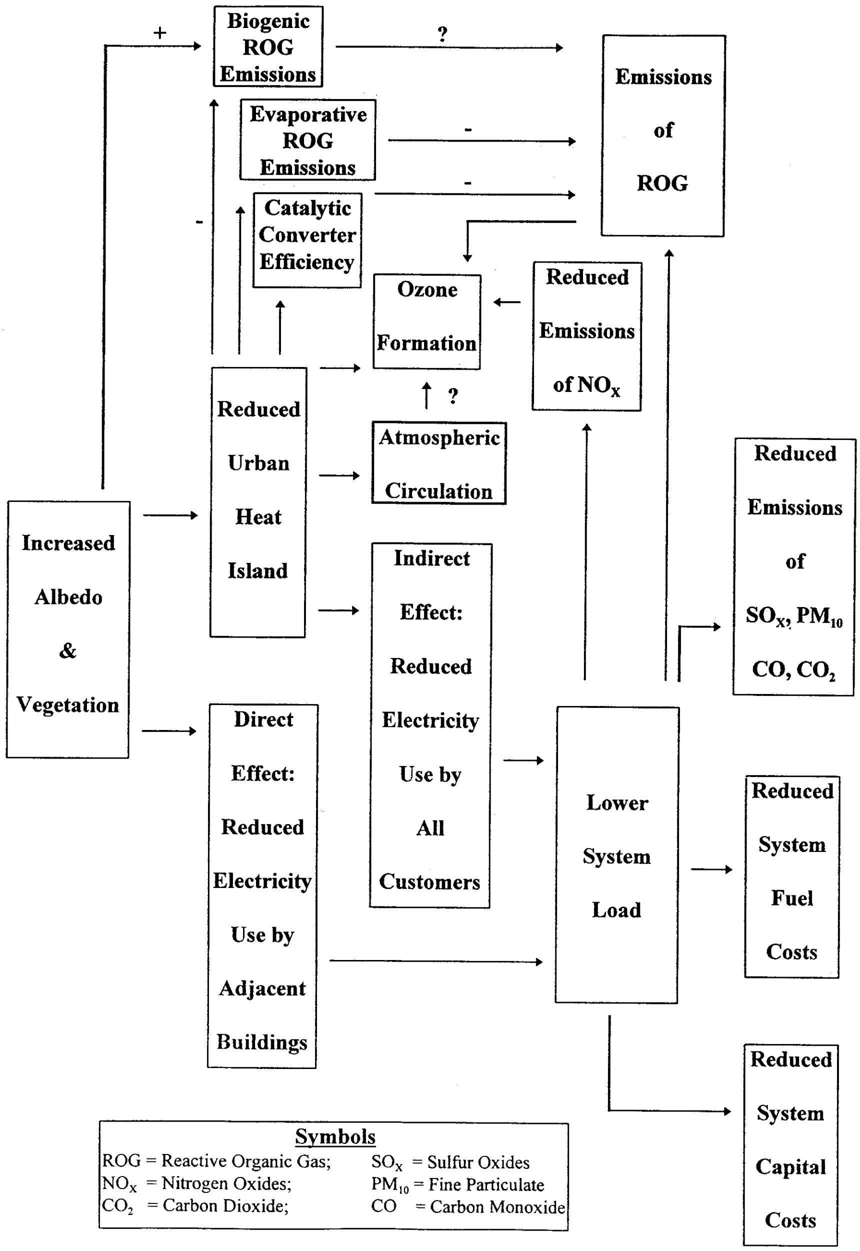

Fig. 1. The effects of increased Albedo and vegetation.

satellite imagery to derive albedo values for a grid map of the surface. Benjamin et al. (1996; 1997) and Benjamin and Winer (1997) derived biogenic emission rates of reactive organic gas (ROG). Taha (1997) applied a meteorological model (Hudischewsky and Douglas, 1994; Kessler and Douglas, 1992) to relate changes in surface albedo to atmospheric circulation and mixing, as an input to the Urban Airshed Model (Environmental Protection Agency, 1990). The complex inter-relationship among land use and the airshed is shown in the upper left portion of Fig. 1.

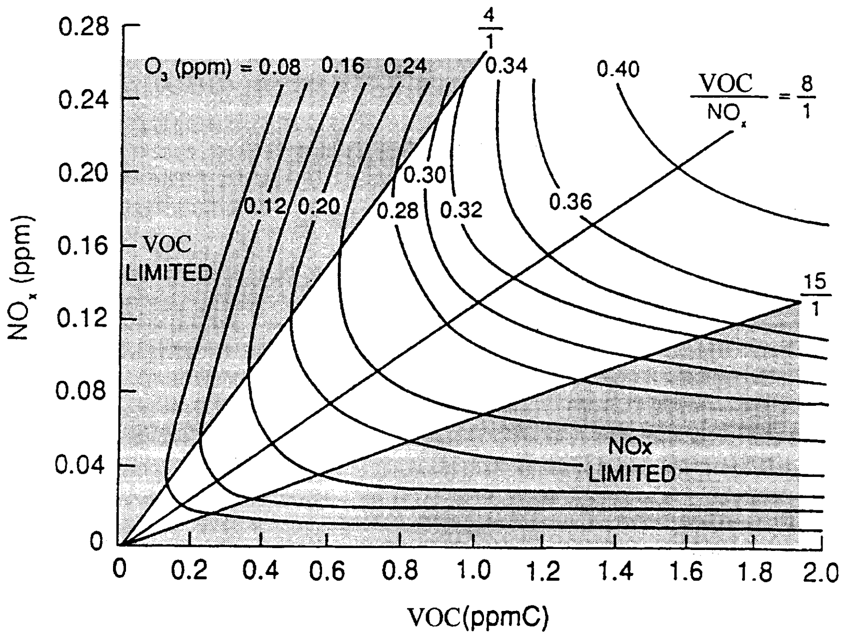

Fig. 2. Source: National Academy of Sciences, 1991.

Fishman et al. (1995) estimated both direct and indirect reductions in electric system loads, which are dependent on the ambient temperature. Building owners can directly reduce electric load in their buildings by planting trees or painting surfaces white to reduce the amount of air conditioning necessary to control indoor air temperature. Unlike other DSM options, the electricity savings are not all captured by the DSM investor. A cooler ambient temperature increases the efficiency of air conditioning throughout the urban area, lowers the amount of electricity for refrigeration, and changes activity patterns that reduce indoor use of electricity, indirectly reducing the electric load and providing a positive externality to all electricity customers within the urban heat island. The direct and indirect effects are shown in the lower portion of Fig. 1.

This paper estimates the reduction in electricity generation as a result of the reduction in power system load. This paper also estimates the reduced emissions of nitrogen oxides (NO_x) and reactive organic gas ROG[1] that result from the reduced production of electricity. The reductions in electric load also reduce other air pollutants that accompany the production of electricity: sulfur oxides (SO_x) inhalable particulate (PM_{10}), carbon monoxide (CO) and carbon dioxide (CO_2), also estimated here. Finally, this paper presents reduced electric system fuel costs, and monetized values of reduced externalities from the lowered air pollution emissions. These effects are shown in the right side of Fig. 1.

1.1. Ecosystem and economic system feedbacks on ozone formation

The formation of ozone is a complex (National Academy of Sciences, 1991), non-convex (Repetto, 1987) process with non-depletable inputs and joint products (Hall and Hall, 1997). Fig. 2 shows that both NO_x and VOC are precursors to ozone (Finlayson-Pitts et al., 1986; 1993). Each curve, or isopleth, shows combinations of NO_x and VOC[2] that result in the same level of

[1] Appendix A is a glossary of acronyms.

[2] Hydrocarbons—reactive organic gases (ROG), reactive organic compounds (ROC), volatile organic compounds (VOC) and non-methane organic compounds (NMOC) are different terms that have been used to classify sets of chemicals found in the atmosphere which can combine with NO_x to form ozone.

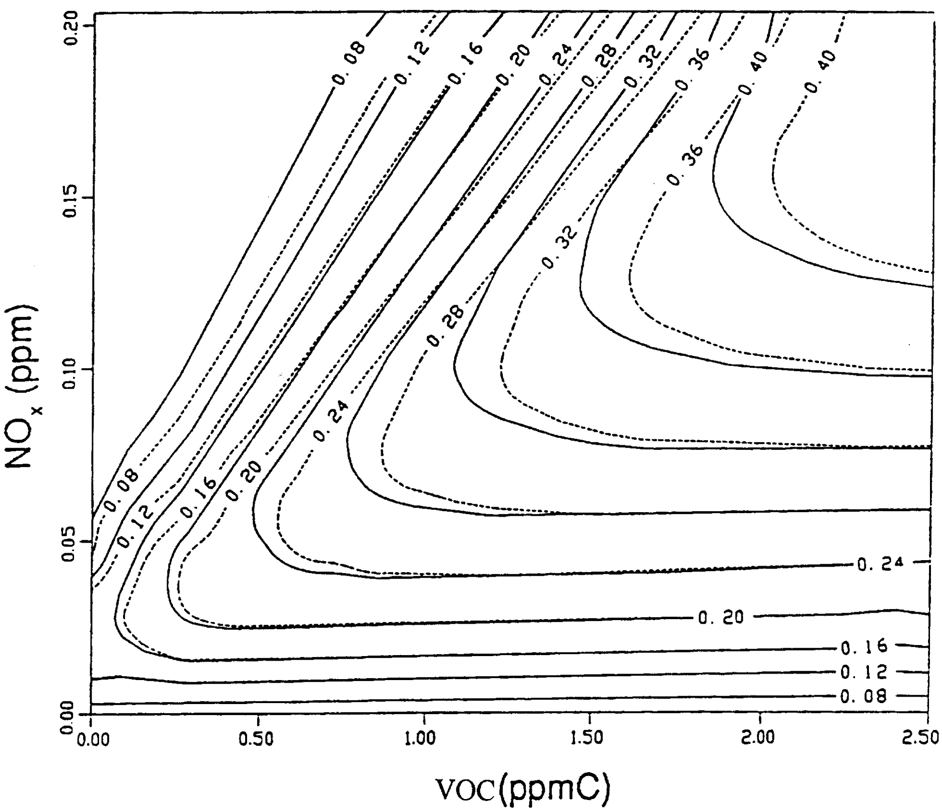

Fig. 3. Source: National Academy of Sciences (1991) from F.W. Lurman, Sonoma Technology, Santa Rosa, California.

ozone in a smog chamber. In the shaded portions of Fig. 2, labeled VOC limited, a reduction in NO_x could actually increase ozone formation. The shaded regions correspond to the third stage of production if we view ozone formation as a production function with NO_x and VOC as inputs.

Transport and the reactivity of categories of non-methane organic compounds alter the relationship in the real environment, so that each location in an airshed has its own set of isopleths. Fig. 3 shows how different percentages of various VOCs alter the isopleths. The solid curves represent one set of isopleths while the dotted curves represent another. Volatile organic compounds have reactivities that vary by a factor of ten. All points on the abscissa, however, have the same relative proportion of different types of compounds. Adding the parts per million of carbon (ppmC), measured on the abscissa in Fig. 3, across compounds is somewhat like adding different types of workers to measure labor for a standard production function. While economists assume that labor is homogeneous, that is not the case, but at least economists have wage rates to help standardize the measure. Without wages to calculate a weighted measure of labor, economists would face the same problem, since larger amounts of labor in empirical work typically have different percentages of office workers to, say, assembly-line workers. The isopleths are generated empirically in experiments that hold constant the ratios of volatile organic compounds. A different combination of volatile compounds leads to a different set of isopleths. Fig. 4 shows how the local weather conditions and emissions from various locations combine to form different sets of isopleths in different locations. The Urban Air-

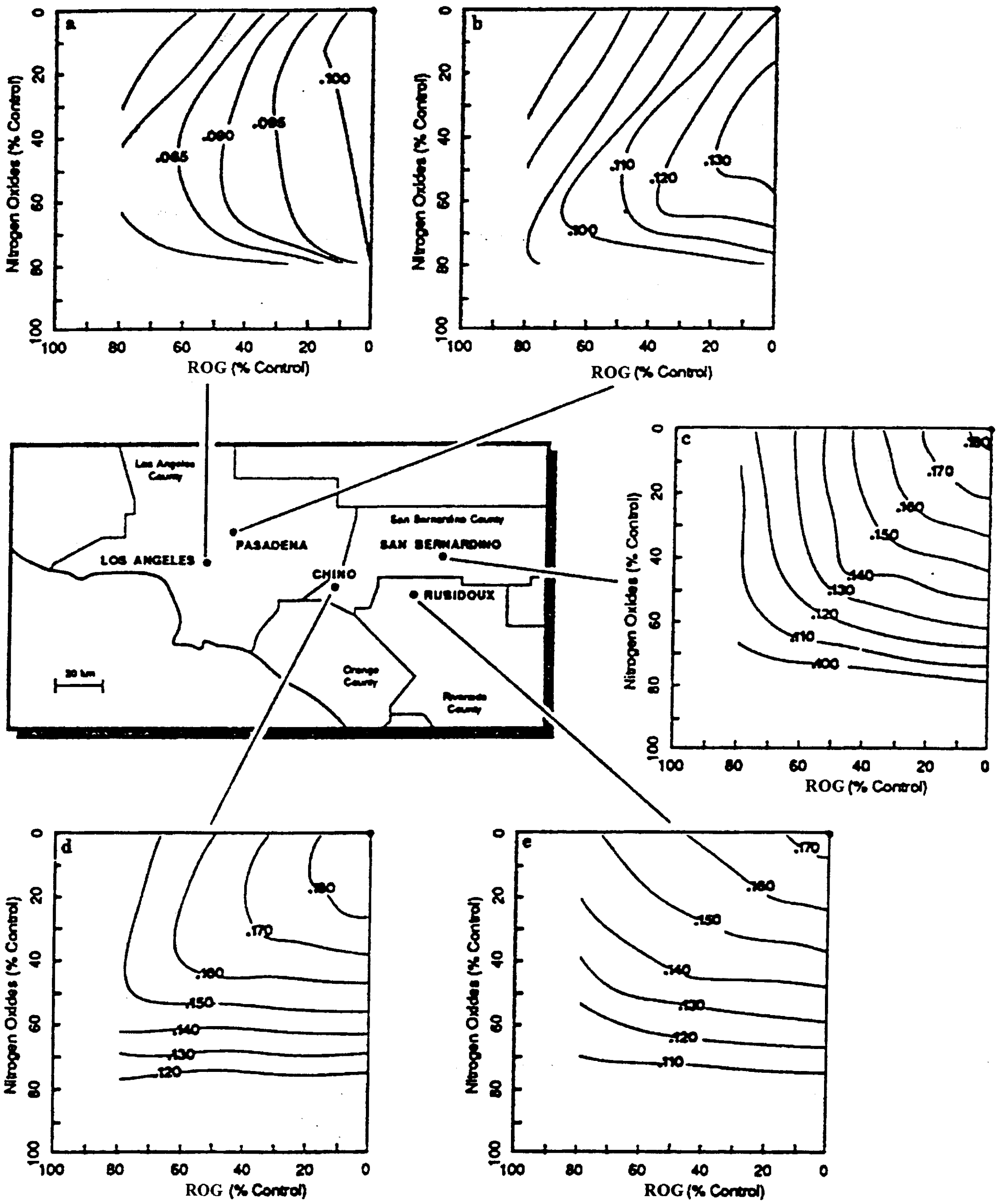

Fig. 4. Source: National Academy of Sciences, 1991.

shed Model (UAM) (Environmental Protection Agency, 1990) combines meteorology and emissions to simulate location specific ozone creation. In some locations and under many conditions there is a beneficial reduction in the formation of ozone from increased albedo and vegetation.

Taha (1997) modified the Sailor (1993) procedure for determining the increase in albedo for

Table 1
Effect of albedo and vegetation on ozone levels and exposure

Case	Maximum increase of ozone (in ppb)	Maximum decrease of ozone (in ppb)	Percentage decrease in exposure exceed-ing standard
Case A1	25	34	5%
Case A2	20	50	10%
Case V 1	25	34	11%
Case V2	10	40	22%
Case VA	15	50	12%

Source: Taha et al. (1995).

each cell in a grid of the surface of the Los Angeles area. The procedure is based on the land use and the increases in albedo are based upon measures such as reflective roofs (Akbari et al., 1997a) and painting asphalt parking lots white. Of 2158 land cells, 392 are candidates for increased albedo. For the portions of cells where albedo modifications are possible, Taha (1997) considered a moderate increase of 15% of the area, and a high increase of 30%.

Taha (1997) identified the fraction of each cell for which increased vegetation is possible, based on the land use of Horie et al. (1990). Of 2158 land cells, 394 are candidates for increased vegetation. After accounting for existing vegetative biomass, the remaining areas of these cells are considered for tree planting, with moderate increases of vegetative cover of 15% and high increases of 30%.

Increases in albedo and vegetation affect meteorology and ozone formation in a number of ways. Increased albedo alters sea breeze, humidity, temperature, wind direction, and mixing heights. Decreased temperature lowers biogenic ROG emissions, evaporative ROG emissions from mobile and stationary sources, and alters the depth of the mixed layer in some locations. Some types of trees have biogenic ROG emission rates that are substantially higher than others (Winer et al., 1992). The results below assume low-emission species are used to increase vegetation. Trees modify meteorology through transevaporation (evaporative cooling), increased roughness, deposition of air-borne chemicals such as ozone and by-products of NO_x, wind direction, and mixing heights in various locations. A lower ambient temperature leads to reductions in ambient air pollution because the rate of tropospheric ozone formation is slower and reactive hydrocarbons from fuels and solvents are less volatile, so ROG emissions are lower (Taha, 1996). Also at high ambient temperatures, the efficiency of catalytic converters is adversely affected, so lower temperatures reduce ROG emissions.

As developed in detail in the following sections, increases in albedo and vegetation reduce the electric system load, and except in certain cases, this typically results in lower emissions from power plants of both NO_x and ROG.

Taha (1997) finds that in most locations in the Los Angeles airshed, the combined effects of increased albedo and vegetation would have lowered peak levels of ozone. The case study is for the August 26–27, 1987, peak ozone episode. Taha accounted for meterological effects with the Colorado State University Meterological Model (CSUMM) (Hudischewsky and Douglas, 1994; Kessler and Douglas, 1992). The CSUMM is used to develop inputs to the UAM (Environmental Protection Agency, 1990). The model simulations show how these five alternative cases would have changed hourly ozone levels in various locations:

1. Case V1 is a 15% increase in vegetation cover.
2. Case V2 is a 30% increase in vegetation cover.
3. Case A1 is a 15% increase in albedo.
4. Case A2 is a 30% increase in albedo.
5. Case VA is the combination of Case A1 and Case V1.

The national ambient air quality standard (NAAQS) for ozone is 120 parts per billion (ppb). Table 1 summarizes, for the five cases, the largest increase and the largest decrease, measured in ppb at the peak hour (15:00 h, August 27). A population weighted average over the airshed during the daytime gives exposure exceeding the NAAQS. Table 1 also summarizes the percentage reduction in exposure for the five cases.

By comparison, if medium emitting trees (rather than low emitters) are used, Case V1 has an increase in some locations of up to 50 ppb.

Table 2
Demand-side management options

Measure	ERPI		LBL		Marginal Cost
	Billions of kWhs		Billions of kWhs		
	Amount	Cumulative	Amount	Cumulative	¢/kWh
1. White surfaces and urban trees	—	—	45	45	0.4
2. Industrial process heating	10	10	—	—	0.7
3. Residential lighting	40	50	56	101	0.8
4. Residential water heating	27	77	38	139	1.2
5. Commercial water heating	7	84	10	149	1.3
6. Commercial lighting	119	203	166	315	1.4
7. Commercial cooking	4	207	7	322	1.4
8. Commercial cooling	83	290	115	437	1.8
9. Commercial refrigeration	15	305	22	459	2.1
10. Industrial motor drive	225	530	—	—	2.6
11. Residential appliances	74	604	103	562	3.2
12. Industrial electrolytic	26	630	—	—	3.3
13. Residential space heating	75	705	105	667	3.5
14. Commercial and industrial space heating	16	721	22	89	3.8
15. Commercial ventilation	32	753	45	734	6.5
16. Commercial water heating	7	760	—	—	10.7
17. Residential cooling	29	789	—	—	11.5
18. Residential water heating	27	816	—	—	13.2

Sources: Rosenfeld et al. (1993); Electric Power Research Institute (1990) and Faruqui et al. (1990).

1.2. Modeling the electric utility system

Elfin (Environmental Defense Fund, 1992) is a software package with an electric utility financial (Joskow et al., 1976; Kahn et al., 1976; Hall et al., 1984) and production cost model, based upon extensions (Wu and Gross, 1979) to the Booth–Baleriaux algorithm (Booth et al., 1972a; Booth, 1972b; Baleriaux et al., 1967). The Appendix of Thomas and Hall (1992) contains the core of the Booth–Baleriaux algorithm. Elfin models the generation dispatch order and quantifies the emissions from each unit. By accounting for the location of the units, one can calculate emissions for each grid in the airshed. The calculation of emissions is a direct function of the calculated dispatch order. Consequently, the emission estimates depend on the reordering of dispatch due to Demand-Side Management.

1.3. Private costs of Demand-Side Management

Demand-side management (DSM) includes load shifting and load reduction. Load shifting occurs when residential, commercial and industrial customers shift electricity consumption from peak to off-peak periods. Load reduction means energy conservation that reduces the load without reference to peak or off-peak periods. DSM programs require investments in buildings and equipment that reduce demand and/or shift the pattern of demand among peak and non-peak periods. Table 2 lists load-reducing DSM options, from Rosenfeld et al. (1993); Electric Power Research Institute (1990) and Faruqui et al. (1990) in ascending order of marginal cost. Table 2 gives the potential, not actual, load savings for the U.S. White surfaces and trees have the lowest marginal cost, but the marginal cost shown in Table 2 for trees omits some ecosystem effects that result in negative externalities, as discussed below.

1.4. Empirical results

The empirical results are based upon the combination of the Urban Airshed Model, the Colorado State University Meteorological Model, the DOE II simulation model for electricity efficiency in buildings, the Elfin electric utility operation model, and a model of temporal electricity usage. The relationships among the variables and in the models are presented in Fig. 1, the discussion above and below. Albedo and vegetation alter the meteorology and biogenic emissions. By location biogenic emissions and temperature changes predicted by the meteorological model are input in the Urban Airshed Model. Changes in temperature alter electricity demand through direct and indirect effects, estimated by the DOE II model and the model of temporal electricity usage. The changes in temporal patterns of electricity use are input in the electric utility dispatch model. From the dispatch model and by location, the changes in air emissions from each power plant are input into the Urban Airshed Model. The effect on the ambient ozone concentrations is presented above in Table 1.

The application of the models are to the Los Angeles airshed, which has not met the Federal ambient air quality standards for ozone and fine particulate. Of interest is the impact on ozone during an episode. An episode is an interval when the most severe violation of the NAAQS or ozone occurs. A well-studied episode occurred in August of 1987. The major utilities in the basin are the Southern California Edison (SCE) and the Los Angeles department of water and power (DWP).

The actual impact of DSM on the dispatch of power plants to meet the load depends on the maximum amount of energy and demand a DSM program can save, and how consumer purchase and usage patterns will translate that potential into system load impacts (Eto et al., 1988; Akbari et al., 1997b). Fishman et al. (1995) estimated the load impacts for the five cases discussed above: Cases V1, V2, A1, A2, and VA. They estimated the indirect effects for each utility using piece-wise linear regression of hourly load regressed on ambient temperature; the indirect effects capture part of the public good of lowered ambient temperature. They used the DOE II (Curtis et al., 1984) simulation model for electricity efficiency in buildings to calculate the direct effects; these are the cooling effects to the surrounding buildings which include the private good and some of the public good effects.

The base case for SCE and DWP is given by the California Energy Commission (CEC) Elfin-ready input data approved in the 1992 electricity report (ER 92) proceedings, the state of California's official electricity supply forecast (California Energy Commission, 1993). This study makes two modifications to the CEC input data. One is that there are eight sub periods for analysis, the maximum allowed by Elfin. Two typical types of days are during the work week (Monday through Friday) and during the weekend (Saturday and Sunday). Four sub periods define the typical day during the work week and four sub periods define the typical day during the weekend. Each sub period covers 6 h in the day: 00:00–06:00 h, 06:00–12:00 h, 12:00–18:00 h, and 18:00–00:00 h. The second modification corrects for the CEC ER 92 input data that model emissions based upon Rule 1135, a technology-based standard to reduce power plant NO_x emissions. Rule 1135 of the SCAQMD (South Coast Air Quality Management District, 1993) required the addition of specific emission reduction technology, which changed the relative cost of power plants in the system. Rule 1135 did not, however, require the priority dispatch of cleaner plants. In October 1993, SCAQMD adopted regulations establishing a pollution market for NO_x and SO_x to replace technology-based standards (including Rule 1135) to reduce air emissions from large sources (emitting over 4 t/day of NO_x). The regional clean air incentives market (RECLAIM) provides an economic incentive to limit the quantity of emissions, but ignores the technological mix used to achieve the goal (Hall and Walton, 1996). The modification to the CEC input data is to obtain actual emissions rather than emissions based upon Rule 1135 or emissions discounted to account for reductions by other sources from which the utilities could purchase RECLAIM trading credits (RTCs) under RECLAIM. Elfin has options to modify the load in the base case to account for DSM programs. The hourly load modifications were input as changes in the load such that the load curve is modified prior to dispatch in accordance with the Booth–Baleriaux algorithm, and the DSM program does not count toward the commitment target nor is it added to the spinning reserve requirement, nor does it count toward the reserve margin. The calculated levels of air pollution emissions are for 1992 rather than for the year of the episode, but the changes in emissions should be representative of what would have happened during the episode in August 1987 (Hall and Hall, 1995).

1.5. August (episode) results

To predict the difference in emissions in each of the five cases, subtract emissions from the emissions in the base case. For Case VA, Table 3 summarizes system totals of the NO_x emission rates, after conversion from weekly into daily emission rates.

Table 3
Case VA: daily NO_x emission reductions during August (t/day)

	DWP NO_x	SCE NO_x	Total
Weekday			
0:00–0:600 h	—	0.26	0.26
06:00–12:00 h	0.68	1.26	1.94
12:00–18:00 h	1.08	1.88	2.96
18:00–00:00 h	0.66	1.32	1.98
Daily total	2.42	4.72	7.14
Weekend			
0:00–0:600 h	0.05	—	0.05
06:00–12:00 h	0.20	0.35	0.55
12:00–18:00 h	0.60	2.10	2.70
18:00–00:00 h	0.45	1.00	1.45
Daily total	1.30	3.45	4.75
Average	2.13	4.40	6.53

Fig. 5 depicts the diurnal pattern of NO_x emission reductions in Case VA during August. The area under each curve in Fig. 5 shows the daily total, given in Table 3. As expected, the area under the curve during the weekend is less than the area under the curve during the weekday.

Table 4 shows the peak reduction in demand for the direct (via changes to the painted and/or shaded buildings), indirect (via reductions to the ambient temperature), and total effects. The peak total reduction is not a simple sum of the peak direct and indirect reductions because the hours typically differ between the peak indirect effect and the peak direct effect. In the DWP service territory, the peak reductions in demand are greater during the weekday than during the weekend for all cases.

The only surprise is that the peak reduction in emissions for SCE occurs during the weekend. The reason could have been because of a surprising change in dispatch due to the impact of DSM on the commitment target, a result known to happen (Hall et al., 1995). However the explanation is much simpler. The time pattern for the reduction in emissions corresponds to the time pattern for the reduction in electric loads. Residential air conditioning adds to the load during the weekend, and this addition is not offset by lower commercial load. Perhaps this is because retail space is open on weekends and thermostats are not adjusted upwards during weekends for a sufficient number of office buildings.[3]

In the SCE service territory the weekly pattern of load reductions differs from the DWP service territory. In the SCE service territory the total peak reduction in load is larger during the weekend than during the week because of the direct effects. For SCE, the peak indirect effects are slightly larger during the weekday, except for Case V2 where the reductions are virtually the same during the weekday compared to the weekend. For the direct effects, however, the load reductions are greater during the weekend compared to weekdays. The sum of direct and indirect effects is greater during the weekday in the SCE service territory.

[3] This explanation was suggested by Richard B. Parker.

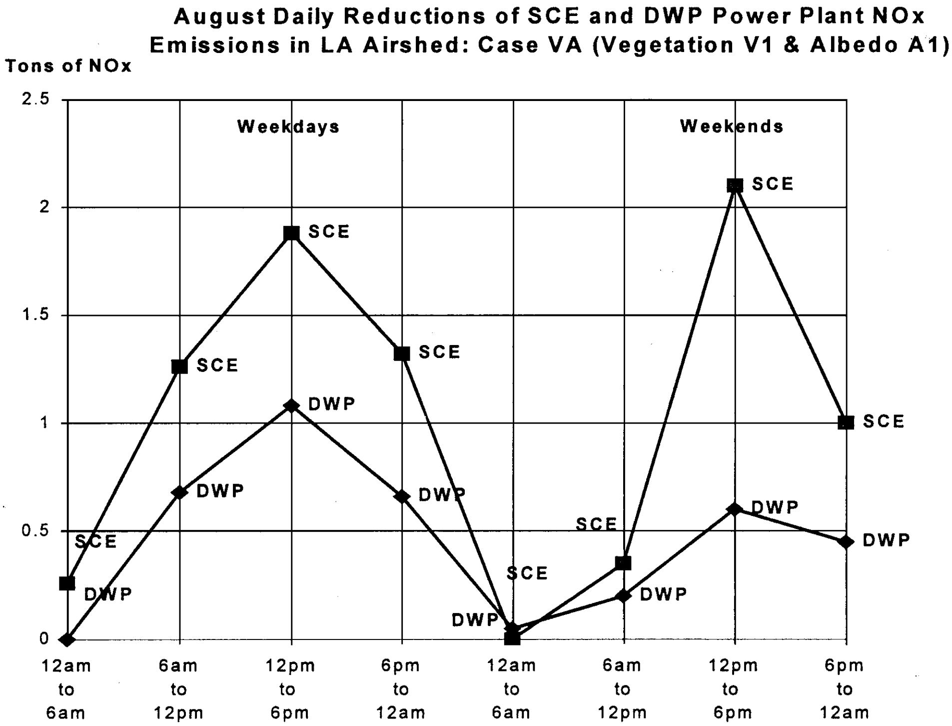

Fig. 5. August daily reductions of SCE and DWP power plant NO_x emmissions in LA Airshed: Case VA (Vegetation V1 & Albedo A1)

The impact of the load reductions on dispatch for the DWP system is straightforward. The utility reduces output from the least efficient baseload plant, Haynes, and reduces peak power generation from Scattergood. For the DWP system, the load reductions translate into reduced emissions primarily from Haynes during the morning, afternoon and evenings. Slight reductions also occur from Scattergood during the weekday mornings and afternoons, and for Cases V2 and VA also during the weekend evenings.

No major changes in dispatch occur for the SCE system, given the load reductions for the five cases under consideration. All five cases have two or more of the eight time periods during the week when there is an increase in operation of the 'peaking' units: Long Beach 8, Alamitos 7, Etiwanda 5, Huntington 5, Mandalay 3, Vernon Diesels 1–5 and Vernon Gas Turbines 1–2. The utility dispatches these peaking units to meet spinning reserve and commitment targets, when fuel can be saved by shutting down baseload gas units like Alamitos 1 and El Segundo 3. The fuel savings can be substantial when these baseload units are operating at the inefficient first block to maintain the spinning reserve and commitment targets. While there are increases in NO_x emissions from higher operation of the peaking units, there are reductions in NO_x emissions from reduced operation of the other units. As shown in Fig. 5, the net effect is a reduction in NO_x during all time periods.

2. Annual results

This section quantifies two sources of savings to electric utilities from vegetation and albedo, and additional savings to the economy because of reduced externalities. The first saving is a reduction of fuel costs caused by the change in dispatch to meet the reduced load. The second is the economic value of reduced NO_x emissions.

Table 4
Peak Reductions in Load

SCE	Indirect weekday	Indirect weekend	Direct weekday	Direct weekend	Total weekday	Total weekend
Case A1	146.60	143.00	221.50	236.60	362.80	379.60
Case A2	279.30	275.20	372.70	384.90	612.00	639.10
Case V1	371.60	369.20	365.50	398.50	695.70	755.60
Case V2	531.50	532.80	821.80	945.78	1 295.60	1 478.58
Case VA	475.40	470.30	637.40	715.51	1 112.80	1 147.01
DWP						
Case A1	25.03	24.39	126.37	112.77	147.04	133.55
Case A2	52.76	51.76	181.62	159.55	234.38	209.20
Case V1	58.24	57.54	194.71	173.75	252.95	231.29
Case V2	83.26	82.95	372.58	332.46	455.84	413.82
Case VA	80.21	79.02	320.15	285.68	400.36	364.70

Table 5 shows these savings for the year. The lower half shows, in millions of dollars, the savings in fuel costs, expected unserved energy, and system reliability from the DSM strategies. The top half of the table shows the emission reduction savings equal to the reductions in NO_x times the projected price, a saving from selling the RECLAIM[4] trading credit (RTC) at the price (in 1991 \$) of \$680/t of NO_x (California Energy Commission, 1995 page A-II-c-3). Table 5 also shows the value of the economy of reduced NO_x, based upon the value in (1992 \$) of \$10 670/t of NO_x (Small and Kazimi, 1995).

Table 6 shows annual reductions for six air pollutants within the Basin without conversion into dollar value to the economy. Since Table 5 only accounts for NO_x, Table 6 presents a more comprehensive summary of the negative externalities avoided by the DSM options.

2.1. Economic analysis

Federal and state policy directed utilities to subsidize DSM programs, particularly when the marginal cost of the next most efficient DSM option is less than the marginal cost of avoided fuel for power production. Thus, the test has been that the long-run marginal cost of DSM be lower than the short-run marginal cost of electricity. Based upon the marginal cost in Table 2 of 0.4¢/kWh, albedo and vegetation DSM options clearly pass the test, even when compared with the super efficient combined cycle natural gas plants with today's low natural gas prices. This comparison ignores the externalities of tropospheric and stratospheric (Hall and Hall, 1995) air pollution from fossil fuel power plants, but also ignores some negative external costs from trees, discussed below. An argument for this policy intervention is the finding (Ruderman et al., 1987; Koomey et al., 1996) that DSM options are not selected by electricity consumers even when the long-run marginal cost is substantially lower than the price of electricity. One explanation of this result is given by prospect theory (Bhattacharjee et al., 1993; Mayer, 1995, 1996), an alternative to neoclassical economics that stresses preferences for maintaining the status quo over risky options. However this explanation does not provide a basis for market intervention in DSM decisions different from any other investment in new technology. Howarth and Sanstad (1995) survey the arguments for and against market intervention, such as subsidies, to encourage the adoption of DSM. They find that market failures occur because of asymmetric information, transaction costs, and bounded rationality. One can conclude from their analysis in favor of policy intervention to provide consumers information, institutions that lower transactions costs, and perhaps even programs

[4] Regional Clean Air Trading Program (Hall and Walton, 1996). This program allows owners of RTC's to buy and sell credits for emissions of NO_x and SO_x. See [3].

Table 5
Annual savings to the economy and fuel cost savings to utilities

Basin Total		Case A1	Case A2	Case V1	Case V2	Case VA
	Tons of NO_x	94.10	199.90	230.80	487.20	406.00
	$/t	NO_x Reductions in millions $				
CEC	$ 680.00	$ 0.06	$ 0.14	$ 0.16	$ 0.33	$ 0.28
Small/Kazimi	$ 10 670.00	$ 1.00	$ 2.13	$ 2.46	$ 5.20	$ 4.33
		Fuel savings in millions $				
DWP		$ 5.43	$ 7.46	$ 8.24	$ 14.03	$12.41
SCE		$ 14.17	$ 24.15	$ 27.96	$ 53.90	$ 44.87
DWP+SCE	Basin total	$ 19.60	$ 31.61	$ 36.21	$ 67.93	$ 57.28

that improve rational decision making by investors. Presumably bounded rationality arguments also apply to other investments in new technology, so that one might equally conclude for limiting the role of government to information only.[5]

Even if consumers acted in accordance with the model of rational consumer choice, there are two reasons why consumers would still under-invest in DSM relative to the economically efficient level of investment. One, electric utility customers face interest rates that are 50% higher than those faced by rate-of-return regulated investor owned utilities. Customers face interest rates 100% higher than those faced by government owned utilities because of tax subsidies for interest on debt, no federal or state income tax, and no property tax. These subsidies are significantly greater than transfers to city government by municipal utilities, and there are local (water agencies for example), state, and federal government owned utilities that have no transfer. The restructuring of electric utilities now underway will only level the playing field between DSM investment by industrial and commercial customers relative to private owners of power production. Residential customers do not face the same interest rates as industrial and commercial customers for identical investments, and there remains the problem of rentals, particularly for master metered buildings.

[5] Special arguments could be made for developing countries or economies in transition (Sowinski et al., 1995).

Two, conventional energy sources—nuclear, coal, oil, natural gas—have substantial external costs and subsidies (Hall, 1990; 1992a,b) not reflected in market prices. For the albedo and vegetation DSM options, a third reason is the ecosystem effects. Albedo and vegetation lower ambient temperature in the urban heat island causing a public good with an additional positive externality. All electricity customers in the urban area have reduced electric bills as a result of the lowered ambient temperature caused by the investment of a single customer. These externalities were accounted for in the results presented above. Biogenic ROG emissions from vegetation work in the opposite direction (see Table 1).

The vegetation DSM option has unaccounted ecosystem effects resulting in negative externalities not included in the marginal cost given in Table 2. Trees require water and in some warm climates such as Southern California there are significant negative externalities from water importation (Hall, 1996). One solution is the use of grey water. Another problem is debris (leaves, trimmings), which could be solved by mulching. Warm climates have severe fire hazards, and fire storms cause trees to explode, sending fire balls as far as one-half a mile away. Presumably the severity of this problem is correlated with the rate of biogenic ROG emission rate of trees. Selection of trees with lower biogenic emission may reduce the fire hazard, and some vegetation acts as a fire retardant. Finally, trees provide positive and negative view externalities. Coastal cities are fine tuning view regulations to minimize view block-

Table 6
Annual emission reductions

Basin total	NO_x	SO_x	PM10	ROG	CO	CO_2
Case A1	94.10	1.20	3.40	0.50	26.10	47 891.60
Case A2	199.90	2.20	6.00	1.30	40.70	82 197.40
Case V1	230.80	2.80	7.60	1.70	48.40	97 499.20
Case V2	487.20	5.60	18.20	6.50	113.50	182 852.40
Case VA	406.00	4.50	13.40	3.70	83.10	156 947.50

age. For all of these reasons, the results below do not provide adequate information for a cost effectiveness analysis of the vegetation DSM option.

As with all DSM options, the reduced emissions from power plants would be an external benefit excepting RTCs for NO_x and SO_x under RECLAIM. The reduction in other emissions remain positive externalities from these DSM options. Trees sequester carbon, another unaccounted positive externality (Chapman et al., 1995).

It is unfortunate that the very institutions capable of accounting for the free rider benefits and public goods from these two DSM options are being dismantled under the rubric of restructuring. In California, the restructuring law that passed the Legislature last year will terminate DSM programs within 5 years. With modifications to the California law, policy could require dispatch decisions to be based upon social costs, and payments to the owners of power plants based upon the accepted price from the bidding process. A federal policy to finance these and other DSM options under the newly emerging structure would be for the Federal Energy Regulatory Commission to consider the value of externalities and public goods when pricing transmission.

The evidence shows annual fuel savings to the Los Angeles area utilities in the order of magnitude of tens of millions of dollars. The reductions in NO_x emissions generate significant savings to the economy, measured in dollars. The results also show reductions in emissions of other pollutants. The marginal cost estimates of shade and albedo are lower than any of the other DSM programs; this marginal cost estimate is incomplete for shade. For all of these reasons, investment in albedo appears to be cost effective, while the cost effectiveness of investment in tree planting and maintenance remains an open question.

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Appendix A. Glossary

California Energy Commission (CEC)
Carbon dioxide (CO_2)
Carbon monoxide (CO)
Colorado State University Mesoscale Model (CSUMM)
Demand-Side Management (DSM)
Department of Energy Building Energy Simulation Model, version 2.1E (DOE-2. 1E)
Electricity Report 1992 (ER 92)
Electricity Report 1994 (ER 94)
Elfin (Electric Utility Financial Model)
Environmental Defense Fund (EDF)

Fine particulate (less than 10 microns in aerodynamic diameter) (PM-10)
Giga-watt hours (GWh)
Lawrence Berkeley Laboratory (LBL)
Los Angeles Department of Water and Power (DWP) or (LADWP)
Millions of watts or mega-watts (mW)
National Ambient Air Quality Standards (NAAQS)
Nitrogen Oxides (NO_x) nitric oxide, NO, and nitrogen dioxide (NO_2)
Non-Methane Organic Compounds (NMOC)
Reactive Organic Compounds (ROC)
Reactive Organic Gas (ROG)
RECLAIM Trading Credits (RTC)
Regional Clean Air Incentives Market (RECLAIM)
South Coast Air Basin of California (SoCAB) same as Los Angeles
Air Basin (Basin)
South Coast Air Quality Management District (SCAQMD)
Southern California Edison (SCE)
Sulfur Oxides (SO_x)
Urban Airshed Model (UAM)
Volatile Organic Compounds (VOC)

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