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Evaluating Energy and Non-energy Impacts of Energy Conservation Programs: A Supply Curve Framework of Analysis

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EVALUATING ENERGY AND NON-ENERGY IMPACTS OF ENERGY CONSERVATION PROGRAMS: A SUPPLY CURVE FRAMEWORK OF ANALYSIS[†]

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Abstract

Historically, the evaluation of energy conservation programs has focused primarily on energy savings and costs. The recent, increased interest in global environmental problems (e.g., acid rain, ozone depletion, and the greenhouse effect) has made decision makers, as well as program evaluators, sensitive to the environmental impacts of all programs, including energy conservation programs. Economic impacts of programs remain important policy concerns. Many state and local jurisdictions are concerned with the net effects of energy policies on economic growth, jobs, and tax revenues, as well as the impacts of growth and development on local energy issues (e.g., construction of new power plants). Consequently, policy makers need a methodology to compare easily the energy and non-energy impacts of a specific program in a consistent way, for both retrospective analysis and for prospective planning.

We present the general concepts of a proposed new approach to multi-attribute analysis, as an extension of the concept of "supply curves of conserved energy." In their simplest form, energy conservation supply curves rank and display the savings from conservation measures in order of their cost-effectiveness. This simple concept is extended to reflect multiple decision criteria and some important linkages between energy and non-energy policy decisions (e.g., a "supply curve of reduced carbon emissions," or a "supply curve of net local job-creation"). The framework is flexible enough, so that policy makers can weigh and compare each of the impacts to reflect their concerns, and see the results in terms of program rankings. The advantages of this analysis framework are that it is simple to use, flexible, and replicable.

Introduction

Energy conservation programs often have multiple goals that reflect the views of multiple actors (e.g., consumers, the construction and financing industries, utilities, citizen advocacy groups, and local, state, and federal government agencies) involved in program implementation. For example, a program promoting the construction of energy-efficient houses may offer the following benefits: reduced home operating costs, increased home resale values, improved thermal comfort, increased demand for energy-efficient housing, reduced electricity peak loads, reduced reliance on imported oil, increased job development, and improved environmental quality. The recent increased interest in global environmental problems (e.g., acid rain, ozone depletion, and the greenhouse effect) has made decision makers, as well as program evaluators, sensitive to the environmental impacts of all programs, including energy conservation programs. Economic impacts of programs remain important policy concerns. Many state and local jurisdictions are concerned with the net effects of energy policies on economic growth, jobs, and tax revenues. Consequently, policy makers need a methodology to compare easily the energy and non-energy impacts of a specific program in a consistent way. Accordingly, the paper should be useful for evaluators who are interested in the development of new evaluation criteria and in assisting decision makers in the utilization of this framework.

The analysis of multiple policy objectives and impacts is not new. This theme has been central to the decision analysis literature, especially in the mid-1960s and 1970s, as a result of dissatisfaction with economic growth as the sole measure of social well-being (Hyman *et al.*, 1988). Multiple-objective analysis has been used in such fields as water resources planning, urban and regional planning, environmental planning, and environmental impact assessment. Most of this work has involved the use of checklists (simple enumerations of the possible impacts of a project), matrices (listing the potential impacts corresponding to specific project activities), and mathematical modeling and simulation (especially, for tracing anticipated effects over time and space). In the case of energy-related environmental impact assessment, certain deficiencies exist that require a new set of analytical tools: (1) a project is usually considered "fixed," so that relatively few changes are considered (e.g., a power plant will be built, and the only change considered is the size of the plant); (2) a project is seldom compared with other projects, except to the option of not doing anything; (3) mitigating project impacts is often not accompanied by a re-analysis of the resultant impacts (e.g., the provision of low-income jobs without reexamining housing affordability); and (4) the relationships among the various impacts are seldom considered (i.e., the secondary effect of changes in the level of one impact, due to mitigation, on a second type of impact are not considered) [1]. In response to these deficiencies, an analytical framework is required to assess simultaneously the most important attributes of projects. The framework described in this paper will help decision makers make better informed tradeoffs among attributes, so that energy conservation policies can more effectively address the global environmental and energy problems presently confronting our society.

In the following pages, we present the general concepts of our proposed framework for multi-attribute analysis (conservation supply curves), discuss the issues surrounding this framework of analysis, provide examples of how this methodology can be applied to non-energy attributes, and describe current work by the authors on the application of supply curves to energy and non-energy attributes.

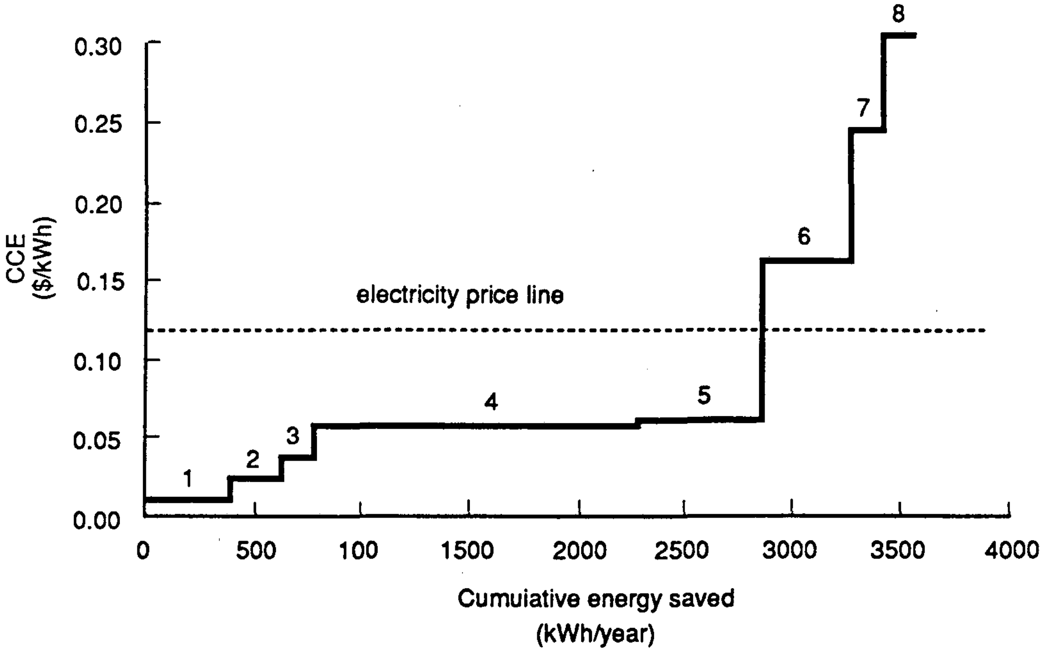
Conservation Supply Curves

As part of the ongoing work at Lawrence Berkeley Laboratory (LBL) in least-cost utility planning, an analytical framework has been developed that allows a more consistent comparison of demand-side measures, along with traditional energy supply options, as resources for meeting the demand for energy services in a reliable and cost-effective manner [2]. This framework evaluates the net contribution of demand-side measures and programs, as a function of cost, to offset energy and capacity requirements that would otherwise be needed to provide a given level of energy services. This framework is based on the "conservation supply curve" and has been used primarily in the building sector but is applicable to non-building areas (Meier, 1982, Meier *et al.*, 1983, Meier and Usibelli, 1986). The conservation supply curve is a simplified graphic representation of estimated potential energy savings as a function of the cost of saving each unit of energy (Fig. 1). This supply curve shows the total size of a conservation resource, and the portions of the resource that are associated with different levels of cost per unit of energy. Individual technical improvements are shown in a step-function, in decreasing order of cost-effectiveness (in the case of Fig. 1, by the cost of conserved energy, CCE) [3]. The absolute height of each step indicates the CCE of the conservation measure; the width of each step the potential electricity savings that can be obtained from it. A reference line (e.g., the electricity price line in Fig. 1) is usually drawn above the horizontal axis (showing cumulative savings), indicating the value of the cost of conserved energy that is to be considered as a guideline for selecting projects (i.e., the reference line sets a limit for cost-effectiveness). Examples of a reference value include the average electricity price or the utility's long-run marginal cost. This way of presenting demand-side data makes it easy to see which conservation measures will potentially save significant amounts of energy and which measures are economically most attractive.

Several types of data are needed to construct conservation supply curves and use them to determine technical conservation potentials:

- How much energy can these technologies save by end use (e.g., heating, cooling, water heating, and lighting)?
- How much energy can these technologies save (individually and in aggregate, for a sector, region, and/or service territory)?
- What technologies and operational changes (e.g., lowering the thermostat on water heaters) are available to improve the efficiency characteristics of each end-use?
- What do these technologies cost to purchase, install, operate and maintain?
- How long do they last before they need to be replaced?

From the data that answer these questions, it is possible to calculate the cost of conserved energy for each measure. The savings from each measure can then be ordered by increasing cost of conserved energy and aggregated to give the total conservation potential. This yields a conservation



Measure	CCE ($/kWh)	Incremental Cost ($)	Measure Lifetime (years)	Measure Energy Savings (kWh/year)	Cumulative Savings (kWh/year)
1. Water heater blanket	0.009	25	10	400	400
2.High efficiency washing machine	0.023	50	15	240	640
3. Thermal traps on pipes	0.036	35	10	140	780
4. Average heat pump	0.055	750	15	1500	2280
5. Best heat pump available	0.059	300	15	560	2840
6. Hot water pipe drain system	0.16	225	15	150	3260
7. De-superheater on air conditioner	0.24	700	15	420	3410
8. Shower bath economizer	0.30	300	10	140	3550

Figure 1. Conservation Supply Curve and Table for One House

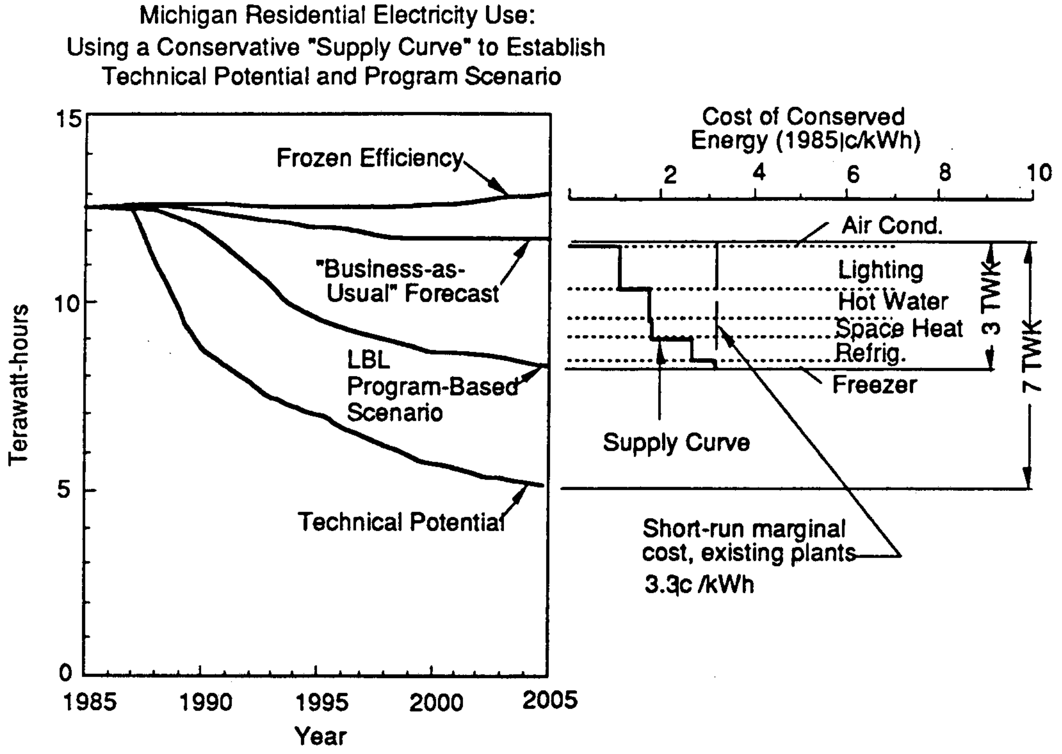
The numbers in the supply curve represent conservation measures listed in the table below the curve. Only the first five measures are cost-effective. The base case is a house with a conventional electric resistance storage water heater.

supply curve [4].

A primary focus of demand-side planning is on the technologies that convert energy into energy services (e.g., heating, cooling, and lighting). These end-use technologies and the efficiency improvements that can be realized are the basic building blocks for calculating technical conservation potentials. Conservation supply curves, which quantify these potentials, can be constructed for efficiency investments in a single end-use device (e.g., a refrigerator or HVAC chiller) or for a group of end-use technologies that form a logical unit (e.g., a single prototype building and its end-uses). These curves are called "micro supply curves." Supply curves can also be aggregated over the stock of a particular building type or end-use device, or over the entire building and equipment stock in a geographic region ("macro supply curves") [5]. Figure 1 is an example of a micro supply curve and its associated data table.

"Program supply curves" extend the concept of technical conservation potentials by indicating the amount of energy that could be saved through the implementation of specific programs (entailing certain savings, costs, and market penetration rates of the technical measures). Program supply curves differ from the technical supply curves in the following ways. First, the cost data reflected in program supply curves include, in addition to the costs of the measures, program costs to implement these measures (e.g., administration, advertising, and financial incentives). Second, the programs usually involve a group of measures, rather than a single type of measure. Accordingly, the analysis becomes more complex. Third, market penetration rates are estimated based on past experience and direct input from experts who manage, operate, and evaluate such programs. Penetration rates are estimated as a function of the type of incentive (e.g., low-interest loan, rebate, and voucher) as well as of varying incentive levels. Figure 2 shows a program supply curve for Michigan's residential sector, indicating that 3400 GWh could be saved (out of a possible technical potential savings of 6600 Gwh), when compared to a "business-as-usual" forecast (Krause, 1988)).

In summary, conservation supply curves graphically represent energy efficiency options as a demand-side energy resource and provide a frame of reference for decision makers. They



Michigan Residential Electricity Use:
Using a Conservative "Supply Curve" to Establish
Technical Potential and Program Scenario

Figure 2. Program Supply Curve for Michigan Residential Sector.

The program supply curve indicates over 3 Twh could be saved by residential conservation measures in Michigan (out of a possible technical potential savings of about 7 Twh), compared to the business-as-usual forecast. Note that the supply curve has been rotated and is on the right side of the figure.

should not be construed as "magic models" that provide easy answers to complicated problems. The aim of these curves is to inform and structure decision making, not to replace or obscure it. Accordingly, the prospective user (decision maker or analyst) needs to be aware of some critical issues surrounding supply curves of conserved energy.

Conservation Supply Curve Issues

The following issues are critical to understanding the design and application of conservation supply curves:

- Variability, bias, and uncertainty in reference values
- Development and maintenance of representative data bases
- Persistence of energy savings
- Sensitivities of CCE and savings potentials
- Time dependence of supply curves
- Interaction of conservation measures
- Urban-scale policy options
- Allocation of costs
- Lost opportunities and timing of program implementation
- Economic bias

The choice of the **reference value** varies, depending on what is being compared and the perspective of the investor: for instance, the marginal cost of energy may best reflect the utility company perspective while the average cost of energy may best reflect the consumer perspective. Moreover, the reference value also varies as energy conservation investments are made: since the first units of new energy supply to be avoided are the most expensive, the reference line may slope (or "step") downward as more energy savings are obtained. Finally, the reference line is used to indicate to decision makers which energy conservation measures (programs) are economically attractive. Accordingly, a bias may be inserted into the decision making process: projects that are not economically attractive but are good investments for non-energy reasons (e.g., they provide jobs to low-income people) are placed in a separate category. In order to avoid this bias, one can remove the reference line or find another way to incorporate these concerns; the former approach must be weighed with the loss in guidance provided by reference values.

Supply curves are dependent on the **development and maintenance of representative data bases.** For the relatively simple case of analyzing energy use in residential buildings, data bases do exist; however, gaps in data remain (e.g., persistence of energy savings, program penetration rates, and operations and maintenance costs and savings), the data base needs to be continually updated, and judgments are still used in "guesstimating" data where there are no empirical data. Data on other sectors are less available; more judgment is required for analyzing these sectors. Because of data gaps, sensitivity analysis is often used to delineate the boundaries of uncertainty (e.g., two supply curves may be created, reflecting "best" and "worst" estimates).

The representativeness of data used for constructing supply curves is of concern when data are not available for an entire sector (e.g., residential buildings) or for an entire geographic region (e.g., U.S.). For example, a field monitoring study might have an excellent data base on air-conditioning in 25 single-family houses in a particular utility service area, however, these data may not be representative for other building types or for other regions with different temperature and humidity environments. Similarly, supply curves may not be transferable from one region to another if, for example, the data are site-specific, or if the building prototypes are different in the two regions [6].

There is relatively little information, at present, on the **persistence of energy savings** as a result of technical measures and programs. In order to be appropriately valued as a resource, the technical performance of energy conservation measures must remain reliable over time. However, long-term studies of the field performance of conservation measures (especially, retrofit measures) are virtually nonexistent. Similarly, program evaluation studies indicate that energy savings from a program can vary over time due to changes in participant characteristics, changes in external environment, and slight variations in the program (Hirst and Keating, 1987).

The cost of conserved energy and, therefore, the estimate of cost-effective savings potential are both sensitive to variations in four key parameters: the measure's cost, the annual energy savings, the amortization time, and the discount rate. Of all these variables, the discount rate has the greatest effect. Real discount rates vary depending on the class of investors and their economic perspective (e.g., in the Pacific Northwest, the Northwest Power Planning Council uses a social discount rate of 3% and the Washington State Energy Office uses a consumer discount rate of 10.5%). Variations in assumed discount rates are often far greater than the uncertainties in lifetimes, energy savings, or investment costs (Meier *et al.*, 1983). Also, by choosing high discount rates, measures (or programs) with small costs and large benefits in the short term are favored. And measures that have long lead times with modest costs now but low present value savings will not be favored (e.g., land use planning measures and planting of trees in urban areas). Because energy decision making is a political process that creates numerous incentives to focus on the short term, the assumptions made about discount rates can magnify this focus, and the result may be a strong distortion. Thus, this framework may too limiting for options that produce significant results in the distant future (20 years or more).

Supply curves are **time-dependent** and should be considered "snapshots" in time; therefore, supply curves need to be reexamined periodically (e.g., every 2-3 years). Each supply curve is highly dependent on the base case (initial conditions). Initial estimates of costs, savings, and lifetimes may all change: new technologies appear, the performance of existing technologies continues to change, building stocks evolve, and market penetration rates of individual technologies change, resulting in the need for revised supply curves.

The **interaction of measures** has an impact on the economic ranking of the measures (the order of the measures is important because those ranked below the reference value are the preferred measures). The amount of savings that can be obtained from a particular measure usually depends on what other measures, if any, have been implemented before (i.e., the order of the measures may affect the estimated incremental savings and costs of each measure). To deal with this potential source of confusion, two approaches are sometimes used. One is to calculate for each technical measure the cost of conserved energy that would result if it were the only measure implemented. The other approach is to use an iterative procedure that reorders measures and recalculates savings until the total cost of implementing the entire set of measures is minimized. This ordering, which is done by computer, results in an investment schedule for the different measures. The options are ordered by increasing marginal cost of conserved energy. One can obtain different ranking of measures by changing the approach one uses.

Urban-scale policy options are difficult to analyze using supply curves because these options typically encompass a number of measures and programs that need to be examined as a whole package. Such policy options include: traffic management, affordable housing, land use planning, renewable resource development, and energy-efficient residential and commercial buildings. Because of the problem of interaction of measures, as discussed above, feasible and attractive elements of broader packages of measures (e.g., district heating and cooling measures) may be overlooked as more specific measures (e.g., HVAC efficiency improvement measures) are favored.

When multiple fuels and peak demand savings are involved, the supply curve analysis becomes more complicated, especially with regard to the **allocation of costs**. Some measures intended mainly to save electricity may also result in gas savings: for example, a more efficient electric dishwasher may lead to reduced gas use for the water heater. Similarly, some measures reduce peak demand, in addition to saving electricity. For utilities, the key analytical issue is how to allocate the costs to the gas and electricity portions of the savings (or to the electricity use and demand portions of the savings), in determining the measure's cost-effectiveness (e.g., CCE) and, therefore, its ranking with respect to other measures [7]. One option is to convert the fuel and electricity savings into resource (Btu) savings and compare total resource energy savings to costs (or add peak power savings to energy savings, convert this amount into dollars, and then compare the aggregated dollar savings with total costs); however, this aggregation may be limiting if one is concerned about savings for a specific fuel source (or about peak demand savings). A second option is to "credit" incidental gas savings (or peak power savings) for those measures where they occur, as a reduction in the measure's cost. An illustration of this option is presented later in the paper for non-energy attributes.

Supply curves disregard lost opportunity resources and timing of program implementation. **Lost opportunity resources** are those which, while not cost-effective at current prices, will be cost-effective over their lifetime (e.g., new construction, extensive remodeling of existing spaces, solar access, and decisions on the location of new housing) (Robison *et al.*, 1989). "Lost opportunities" should be avoided, however, they will not be chosen in the supply curve analysis unless they are under the reference line. Similarly, the **timing of program implementation** is not reflected in the supply curve framework: in certain cases, two or more programs could (or should) be implemented together for administrative efficiency or practicality reasons (e.g., construction of new energy-efficient housing and solar access guidelines).

It is important to note that supply curves have an **economic bias** common to other conventional economic perspectives: non-economic and immeasurable values (e.g., quality of life, and comfort) cannot be incorporated in economic analyses. This problem reinforces our previous warning: the aim of these curves is to inform and structure decision making, not to replace or obscure it. The user of the supply curve tool must be aware of its limitations and the need to integrate non-economic and immeasurable values into the decision making process.

Extending Supply Curves to Non-energy Impacts

The preceding discussion has focused on energy savings. However, there are a number of other criteria that can be analyzed using this framework; these should be examined in a comprehensive assessment of energy conservation programs. For example, from a utility planning point of view, the following considerations may be important: planning and operating flexibility, reliability, incidence of equipment failure, impacts on transmission and distribution costs, measurability of resource contributions, and predictability of their timing and size. From a societal point of view, the analysis should also take into account environmental impacts, public health and safety, employment effects, impacts on the poor, equity among program participants and nonparticipants, and effects on oil import dependence (energy security). Consumer satisfaction and comfort may also be important considerations. Furthermore, energy programs are often designed to achieve socially desirable goals (e.g., affordable housing), and these considerations can be examined using the supply curve framework of analysis.

In contrast to examining all of these considerations together in our analytical framework, we simplify matters and first look at the case where two criteria are analyzed (energy savings and one type of environmental benefit). We use the cost of conserved energy (CCE) and energy savings for the energy attribute, and cost of conserved carbon (CCC) and reduced atmospheric carbon emissions for the environmental attribute [8]. In this paper, we use hypothetical numbers, but ongoing work will soon begin to quantify the selected impacts (see below).

The first approach compares two (or more) supply curves side-by-side (Fig. 3). In this comparison, the measures (or programs) are first ranked by cost of conserved energy and then separately ranked by cost of conserved carbon. As one can see, program rank may differ in each supply curve, and it is easy to compare the programs based on these attributes [9]. There are three possibilities for each of these measures: (1) they are cost-effective on both criteria, (2) they are not cost-effective on either criteria, and (3) they are cost-effective on only one criterion. They may also be cost-effective on other criteria not shown. In this approach, the decision maker must determine the relative value (weight) of each of these criteria.

A second approach (Fig. 4) uses one supply curve to account for two (or more) criteria, but adjusts the values of the first criterion (in this case, CCE) by the impact of the second value (in this case, CCC). In this comparison, the measures (or programs) are ranked by cost of conserved energy, but the reference value applied to all measures is then adjusted, based on the additional value of reducing carbon emissions. This model assumes that the value attributed to conserving carbon can be converted into dollars and added to the value of conserving energy. A second key assumption is that this added value is proportional to energy savings, and this applies equally to all measures. However, this last assumption might be violated, so that the added value would be measure-specific. In this example, the added value of reduced carbon emissions would vary for

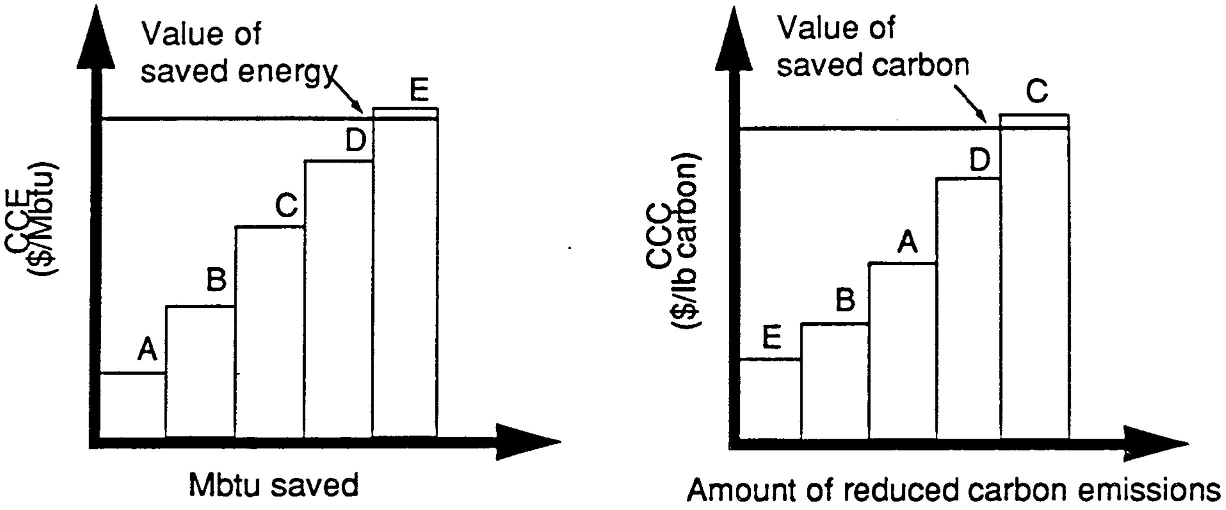


Figure 3. Side-by-Side Supply Curve Comparisons.
The measures (programs) change in order of cost-effectiveness when one switches from a CCE to a CCC perspective.

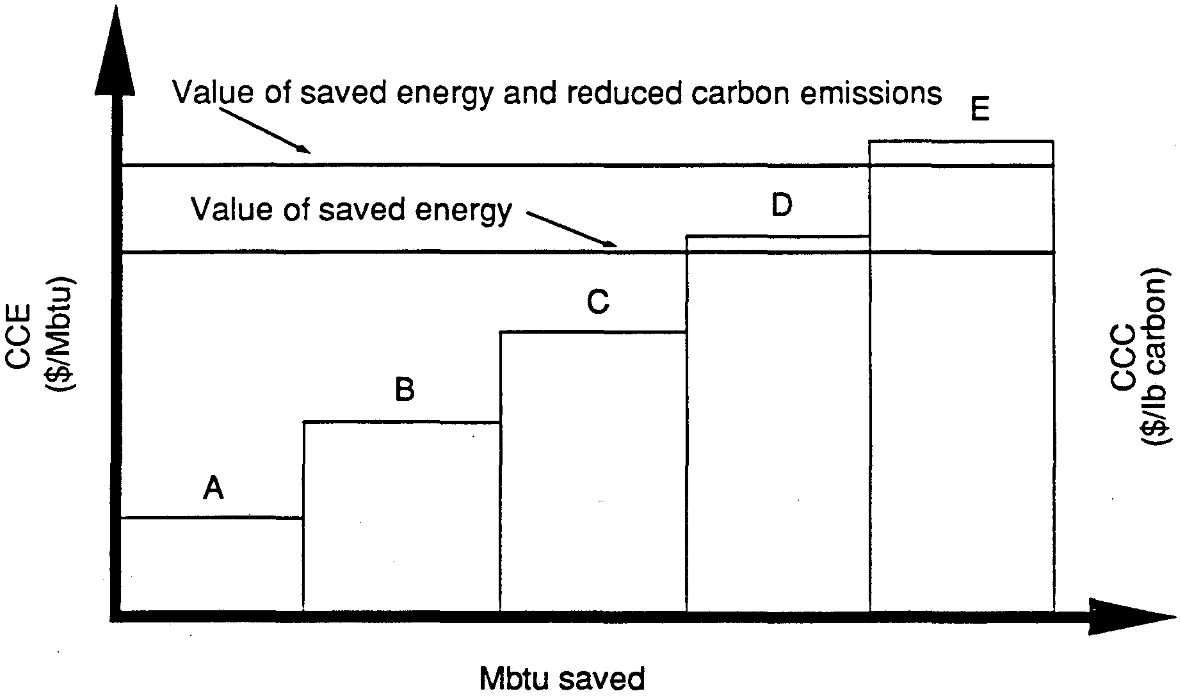


Figure 4. Measure-Independent Changes in a Multi-Attribute Supply Curve. The value of reduced carbon emissions scales directly with the value of saved energy and is not influenced by type of measure (program).

each demand-side measure. For example, the value of reduced carbon emissions would be different for refrigerators (affecting baseload power plant) than for air conditioners (affecting peaking power plant).

A third approach uses measure-specific estimates of the second impact. Costs are adjusted, not the reference value. For example (Fig. 5), if the second measure was thermal energy storage then more carbon may be emitted: while thermal storage for buildings saves energy during peak times (when oil and gas plants usually operate) and reduces peak demand, energy use is increased during off-peak hours (when coal plants are more likely to be operating without oil and gas assistance). The type of utility system is a key factor in determining how much coal or gas/oil is used during off-peak hours; however, we do know that oil contains about 22% less carbon per unit of energy than coal, and natural gas 40% less. On the other hand, if urban tree planting is a measure, carbon emissions will be reduced (because urban trees will shade houses and save cooling energy). As mentioned above, the added value of reduced carbon emissions would vary for each demand-side measure, as a function of the power generating source of emissions.

A fourth approach again uses a single supply curve, but aggregates the values of the first and second (or more) attributes (Fig. 6). In this case, a common index is created (e.g., dollars) so that the attributes can be converted into one single value. The advantage of this approach is that the impact of both attributes are taken into account. It is important to note that the conversion of each attribute into a common index reflects an implicit weighting scheme (e.g., the removal of atmospheric carbon is equivalent to a certain number of dollars).

The method used for analyzing more than two attributes extends the analysis presented in the preceding pages. However, the case becomes more complex, particularly for the last model where a common index is used. The choice is between having one index for ranking programs (assuming a common index exists or can be found), or keeping the supply curves separate so that the decision maker can weigh the different attributes. The option of providing different supply curves may lead to unintended impacts when multiple decision makers are involved (instead of a single (presumably rational) decision maker with a consistent set of values): when goals are

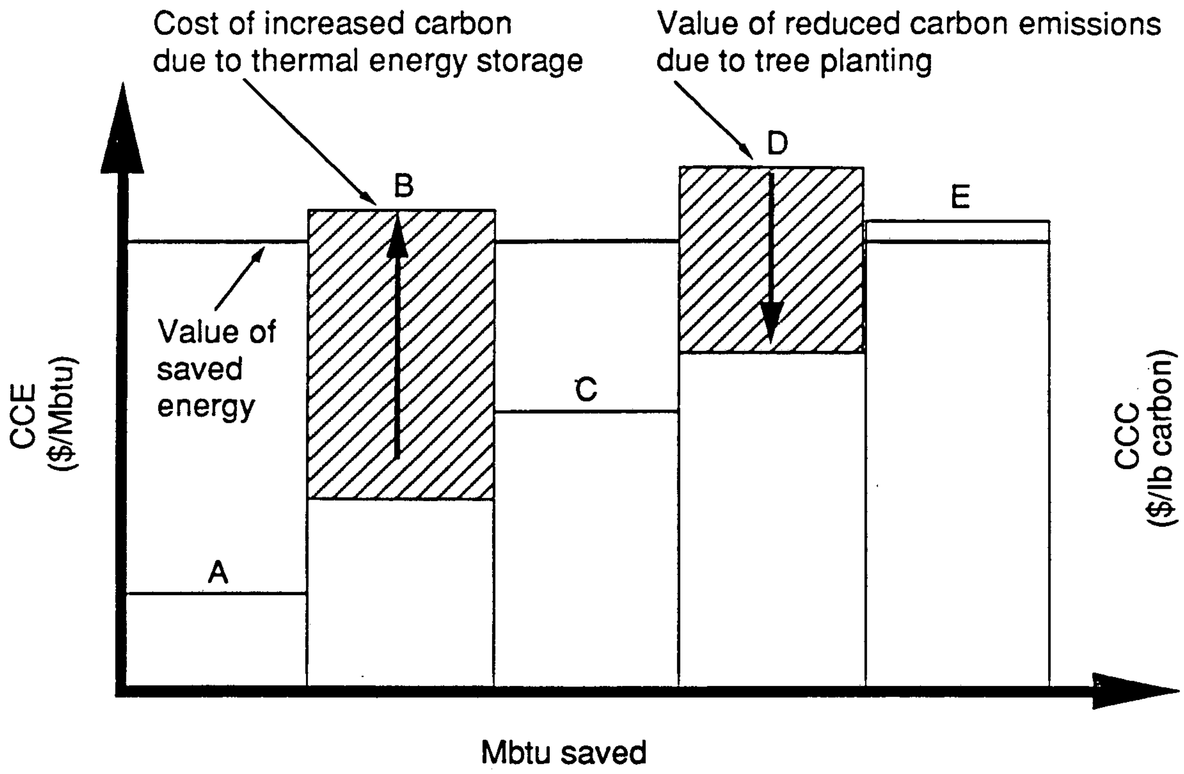


Figure 5. Measure-Specific Changes in a Multi-Attribute Supply Curve.

In contrast to Fig. 4, the value of reduced carbon emissions does not scale directly with the value of saved energy; the net change in the cost of the measure is dependent on type of measure (program). In this case, the incremental change in cost makes measure 2 not cost-effective and makes measure 4 cost-effective (the arrows indicate the direction of change).

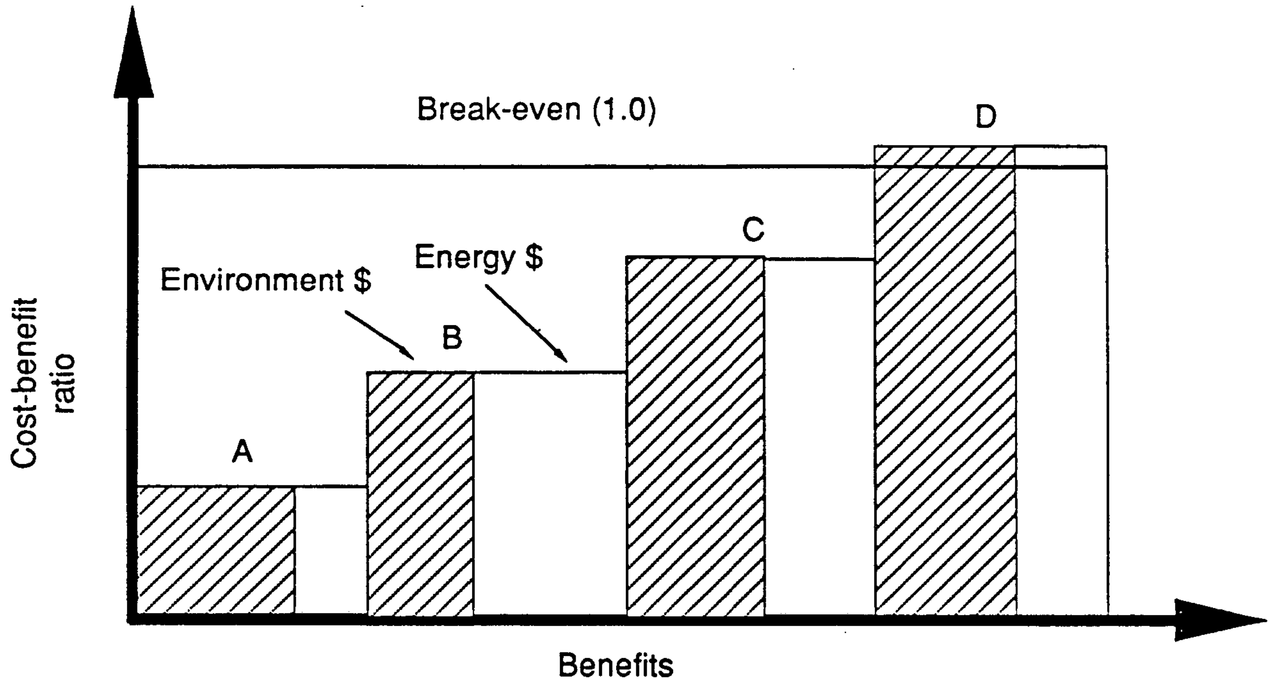


Figure 6. Multi-Attribute Supply Curve Using a Common Index of Value. Each measure (program) provides energy and environmental benefits at a per unit cost. The width of the boxes indicates the percentage of the total dollars saved as a result of a particular attribute. In this example, benefits equals dollars saved, and the cost-benefit ratio is the dollar cost per dollar savings in energy and environment benefits.

evaluated differently at different points in a system (e.g., an intergovernmental network for deciding on energy-saving measures), clarity about the full array of impacts may heighten rather than reduce conflict in the decision making process.

As noted in the introduction, there have been other approaches used in comparing impacts of programs: e.g., checklists, matrices, and mathematical modeling and simulations. The supply curve framework of analysis differs from these approaches by analyzing the impacts of selected projects and ranking them according to an agreed upon criterion (e.g., CCE or CCC), or several criteria, in parallel. One can then choose those projects that meet a socially determined guideline (e.g., the utility's marginal cost of energy, or an air quality district ceiling of particulates (or carbon emissions)).

It is important to note that several alternatives are being pursued to integrate energy and non-energy considerations. For example, the Northwest Power Act gives a 10% benefit to conservation, based in part on the judgment that conservation results in fewer uncontrollable environmental impacts than any other source of electricity (NPPC, 1989) [10]. A second alternative is to ascertain the environmental impact costs/kWh for each supply and demand option and add them to the production cost/kWh of that option [11]. A third alternative is to assign a portion of the evaluation points (e.g., 15% by the New York Public Service Commission) to environmental considerations during competitive bidding for demand and/or supply-side resources (NYPSC, 1989). Finally, computer models are being developed, based on "goal programming" techniques, that try to achieve multiple goals (e.g., energy management and economic development) under a given set of constraints (Kegel and Laitner, 1988).

Future Applications of Supply Curves to Energy and Non-energy Impacts

LBL is providing technical assistance to the Sustainable City project that is funded by the U.S. Department of Energy via the Energy Task Force of the Urban Consortium. Three cities (San Jose, San Francisco, Portland (Oregon)) and one state energy office (State of Washington) are examining a selected number of energy-related projects in their regions that will help save energy, improve the natural environment, and lead to more jobs in their areas. LBL will be using the supply curve framework of analysis to examine the impacts of these projects.

In the future application of supply curves to urban policy options, two key problems need to be addressed (see above). First, urban policy options often contain "packages" of measures, and these may be overlooked in favor of more specific measures. For example, projects with moderate costs and very significant savings in the distant future (more than 20 years) may be overlooked in favor of projects with small costs and large benefits in the near term. Also, some measures may be more appropriate for implementation by state and local government (e.g., building codes and standards) while other measures may be more appropriate for utilities (e.g., construction of a photovoltaic power plant) or federal government (e.g., energy efficiency standards for automobiles).

Second, adequate data bases on non-energy attributes may not be available, and more judgment may be required for analyzing these attributes (e.g., job development, uncertainty, impacts on the poor, aesthetics, value of open space, and environmental impacts). As a result, the supply curve framework may not be appropriate for analyzing non-economic values (e.g., comfort and equity). Accordingly, it is important to estimate which attributes require more judgement than others and how this will affect the rankings and interactions of measures.

In conclusion, we have outlined a conceptual approach for evaluating the energy and non-energy impacts of energy conservation programs. The difficult work ahead is in applying the framework and determining its usefulness to decision makers. We believe that our tool is simple, understandable, and is responsive to the decision making process: tradeoffs can be made easily, depending on the values of the decision makers. However, we do not want to create the illusion that the results of the supply curve analysis are completely objective and that subjective weighing of issues is not necessary. Judgement and other subjective processes are still needed for making intelligent decisions. Thus, the role of the evaluator will be to combine both objective and subjective processes to help decision makers design and analyze energy conservation programs.

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Notes

1. As an example of the fourth deficiency, a city may want to reduce atmospheric carbon emissions by electrification of its transportation system (cars, buses, trucks), industry, and space and water heating systems; however, if a coal plant in another region is the source of electricity for that city, then increased carbon emissions will occur in that region.
2. Demand-side measures include both conservation (end-use efficiency) and load-shifting measures; the latter can contribute to more effective utilization of utility system capacity.
3. The cost of conserved energy (CCE) is the annual cost of implementing a demand-side measure (including operations and maintenance (O&M) costs), divided by the annual energy savings of the measure. It is defined by the following formula:

$$\textit{cost of conserved energy} = \frac{\textit{(investment} \times \textit{capital recovery rate)} + \textit{O\&M annual incremental cost}}{\textit{annual energy saved}}$$

   The capital recovery rate annualizes the investment. In terms of the real annual discount rate d and the lifetime n (years), it is given by the expression:

$$\textit{capital recovery rate} = \frac{d}{1-(1+d)^{-n}}$$

   In addition to the CCE, other useful economic ranking criteria include simple or discounted payback, cost-benefit ratio, net present value, internal rate of return, and lifecycle costs.

4. LBL research has produced data bases of major end-use technologies for the buildings sector. A public domain computer program, CPS 2.0 (now being updated in a PC version as

Arch 1.0), is used to generate sectorwide supply curves that can be modified to reflect regional cost data, climate conditions, and building and equipment stocks.

5. Work on conservation supply curves at LBL has focused primarily on gas and electricity end-uses and demand-side measures for the residential and commercial buildings sectors: e.g., California residences (Meier *et al.*, 1983), residential and commercial buildings in the U.S. as a whole (SERI, 1981), residences in the Pacific Northwest (Usibelli *et al.*, 1983), commercial buildings in California (Usibelli *et al.*, 1985), residential and commercial buildings in Texas (Hunn *et al.* 1986), and the residential sector in Michigan (Krause *et al.*, 1988). However, the framework is equally applicable to other fuels, and to the industrial and transportation sectors.

6. However, some supply curve data may be transferable, such as efficiency data on refrigerators, freezers, and lighting equipment.

7. For state and local government, "quality of life" is the critical issue and, therefore, the allocation of costs is not as important.

8. The units of CCC are ¢/lb carbon (Akbari *et al*, 1988). CCC can be calculated either directly (by measuring the tons of carbon emissions reduced) or indirectly (by resource modeling: the reduction (or increase) in the amount of energy (e.g., coal, oil, hydro, and nuclear) used to fuel the generating plant is estimated and then converted into tons of carbon).

9. In this figure, the reference line is constant; however, the reference line might slope downwards as more energy savings (or reduced carbon emissions) occur, because the most expensive peaking (or "carbon offensive") power plants are deferred first.

10. A similar decision was made by the Wisconsin Public Utilities Commission when it chose to give non-combustion resources, such as hydro and conservation, a 15% advantage over combustion-based resources in least-cost planning (NPPC, 1989).

11. Personal communication from Dick Ottinger, Center for Environmental Legal Studies, Pace University School of Law, April 15, 1989.

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