New benefit-cost methodology for evaluating renewable and energy efficiency programs of the US Department of Energy

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Abstract

This paper describes a new methodology developed in 2009 for performing retrospective benefit-cost studies of Energy Efficiency and Renewable Energy (EERE) research and technology development (R&D) programs of the US. Department of Energy (DOE). The methodology uses a four-part benefits framework that includes economic, environmental, security, and knowledge benefits, and a technology cluster approach to address larger parts of major programs or entire programs. It improves on and extends an earlier approach developed by the US National Research Council (NRC) and applied in a 2001 NRC study, *Energy Research at DOE: Was It Worth It?*

The new EERE methodology was designed to answer the following questions about the EERE programs: To what extent have the programs thus far produced economic benefits in terms of resource savings relative to program costs? To what extent have the programs yielded environmental benefits, with a focus on health benefits from reduced air emissions? To what extent have the programs yielded energy security benefits in terms of reducing imported oil and reducing threats to the US energy infrastructure? To what extent have the programs built a knowledge base within each respective field and outside those fields? What has been the return on public investments in these energy programs thus far?

The new EERE methodology set forth in a draft Guide was applied in 2009 in four benefit-cost cluster studies to address the key evaluation questions in the following EERE program areas: Wind Energy, Solar Energy, Geothermal Energy, and Vehicle Technologies. This paper describes the methodology and gives an overview of its initial applications.

Keywords: evaluation, benefit-cost cluster study, energy, environment, security, knowledge.

WIT Transactions on Ecology and the Environment, Vol 131, © 2010 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/EEIA100091

1 Introduction

Since 1978, DOE's research and development (R&D) programs in energy efficiency and renewable energy (EERE) have achieved many technical successes that have resulted in commercialized technologies and products found in today's markets, but most of these programs had not yet had independent assessments of returns on their R&D investments as of 2009. The last economic assessment of EERE programs was a 2001 NRC study [1]. At the same time, it was recognized by program managers that a major Federal energy program which has demonstrated benefits determined through systematic retrospective evaluation is better positioned to communicate its value to Congress, stakeholders and the public, than one which has not.

In 2009, EERE program staff set about to improve and extend the NRC evaluation approach based on recommendations made by reviews of the NRC study, and to apply it to a selection of EERE programs and subprograms. Goals were to develop a consistent, modified NRC approach for determining realized economic and other net benefits that would achieve the following: (1) model government additionality in detail, on a case-by-case basis, (2) refine and expand environmental benefits, particularly health benefits from reduced air pollution, (3) estimate security benefits as feasible, (4) expand the quantitative treatment of knowledge benefits, and (5) calculate returns to a program cluster, i.e., a whole EERE program or subprogram, rather than to a single project.

To this end, a new approach was developed, a draft "how-to" Guide [2] was prepared to implement the approach, experienced evaluators were identified, and four initial benefit-cost cluster studies were commissioned for completion early in 2010. After a detailed review by experts, recommended modifications are to be made to the methodology, and a final version of the Guide issued. This paper captures development through preparation of the draft reports; the related presentation will update developments through the review and resulting modifications in the reports and the Guide.

2 The evaluation framework

The evaluation framework used for the new EERE benefit-cost studies allows for a more comprehensive treatment than traditionally provided by benefit-cost assessments of energy programs.

2.1 Four categories of net benefits

As illustrated by table 1, there are four categories of benefits and costs included, rather than a focus only on savings and cost from changes in use of energy and other resources. The first row, net economic benefits, is expected to be estimated primarily in monetary terms. Program costs are included as an offset to benefits. The second row, net environmental benefits, is expected to include a monetary estimate of health effects associated with any reductions in air emissions, as well as non-monetary, quantitative measures of changes in green house gases, and non-monetary quantitative and qualitative treatment of any other environmental effects. The third row, net security benefits, at this time is expressed as equivalent barrels of imported oil avoided. The fourth row, knowledge benefits, includes quantitative, non-monetary estimates, derived mainly from patent and publication bibliometric techniques.

Table 1: Net benefits matrix.

Category of benefit and cost	Realized (retrospective) net benefits
economic	monetary + qualitative
environmental	monetary + physical units of energy + number of deaths avoided and other health measures + qualitative
security	physical units of energy + qualitative
knowledge	bibliometric measures

The values of each of the four categories of net benefits are to be presented separately. Then, an estimate is to be provided that combines the monetary results of net economic benefits (first row) with monetary estimates of health benefits (second row). For the 2009 studies, this is the only combined presentation of monetary benefits that is to be provided, due to greater uncertainty in attempting to estimate the other categories in monetary terms. Future benefit-cost studies may be extended to include additional monetary estimates of other categories of net benefits.

2.2 Cluster approach

A cluster approach compares benefits of selected elements of a defined technology area to investment costs of the entire associated program or major sub-part of it. The purpose is to provide an estimate of the minimum return for the whole program or major sub-part, without performing detailed analysis of all of its funded research projects or technologies. The approach works well for high-risk R&D programs where a few projects tend to be the big winners and investment in an array of projects is necessary to find successful ones. It is a potentially cost-effective approach to demonstrate that benefits from only a few elements in a cluster more than offset total program cluster investment costs.

The retrospective cluster approach begins with identifying a program or subprogram (i.e., a cluster) of evaluative interest. Next, a few technologies/ projects within the cluster are identified that appear to be among the more successful technically and commercially, and these are selected for detailed benefit-cost analyses. Those not selected for detailed treatment are treated qualitatively, including negative effects, if any. Finally, combined benefits of the technologies evaluated in detail are compared against entire cluster cost, and the results are conditioned by the qualitative results. Fig. 1 illustrates the comparison of benefits for selected elements of a technology cluster to costs of the elements and to entire cluster costs.

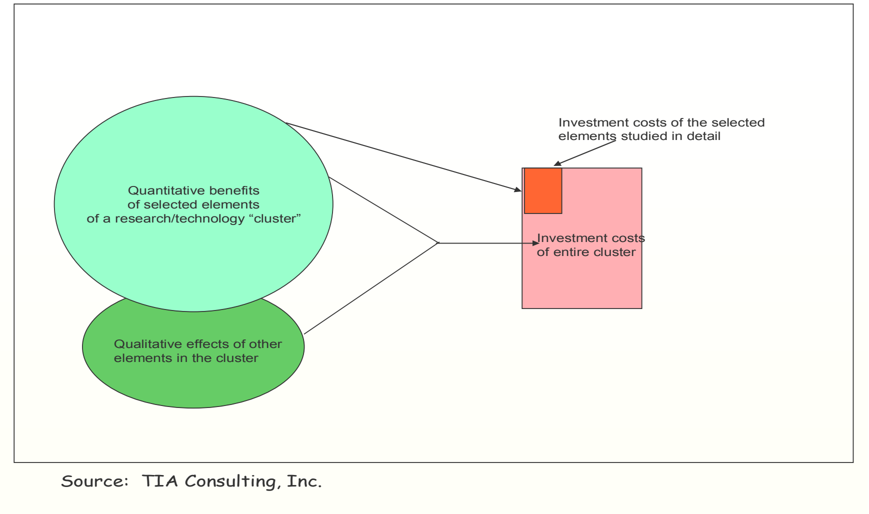

Figure 1: Comparing benefits of a technology cluster to entire cluster costs.

2.3 Estimating economic benefits and costs

2.3.1 Mansfield model provides a theoretical anchor for estimating returns

A model developed by the late economist Prof. Edwin Mansfield [3] serves as a unifying model across studies for valuing private and social economic returns from investment in new technology. Mansfield's approach includes market spillover effects which occur as others in the same industry as the innovator, within competitive markets, use the innovator's knowledge to imitate the innovation and drive down prices to consumers. Included are effects on customers of the investing/innovating firm and final consumers of related products and services within the industry. Not included are effects that occur as firms outside the innovator's industry draw from the same knowledge base to produce other goods and services in other industries. Also not included are more general effects of an enhanced knowledge base on the capacity to innovate in other areas.

2.3.2 Comparing a new technology in the cluster against the next best alternative

The merits of a new technology are judged against the next best alternative, i.e., the best choice that could be made in lieu of choosing the new technology. For a retrospective benefit-cost analysis, the next best alternative is defined by looking back to the time the investment decision was made for the new technology. There are several factors that affect the selection of the next best alternative that may help to inform the selection across studies in a consistent manner. One of these factors is whether the investment decision was constrained or unconstrained, that is, whether the choice was restricted, such as by regulatory requirements, or completely open. Another factor is whether the technology is new to the world or an improvement over an existing system. Yet another factor is whether the technology is a total system or a component of a system or a process used to make a system or component. The Guide provides an aid for defining the next best alternative for comparison.

2.3.3 Determining program additionality for each technology

A keenly important aspect of estimating the return on EERE's investment, i.e., the "return on public investment," is to provide evidence-based analysis of additionality. This entails delineating the part of benefits from the cluster technologies that is attributable to the cluster costs, and documenting evidence of cause and effect. The public program in question, for instance, may have accelerated technology entry into the marketplace; it may have improved the performance characteristics of the technology; it may have changed the technology's cost; it may have increased market size; it may have had other effects. The Guide provides an aid for organizing the additionality analysis and for mapping attribution to a technology timeline to show when and how an identified effect is estimated to have occurred.

Potential rival explanations of the estimated benefits must be addressed, such that it is the Program's effect that is identified in the additionality assessment and not other causes. Eliminating rival explanations is important because otherwise the benefits claimed for the Program could be due to other factors. For example tax credits may constitute a rival explanation for market expansion of a renewable energy technology – in opposition to an explanation that the market expansion resulted from R&D-induced advances in system performance.

2.3.4 Computing measures of economic performance

A positive public return means that part of societal benefits is attributable to EERE's program and that those attributed benefits exceed EERE's program cluster cost. The selected economic performance measures shown in fig. 2 – NB, B/C, and IRR – are used to provide estimates of the economic impact of the EERE program clusters. Results are computed for two discount rates – 3% and 7%, both defined as real rates, exclusive of inflation, in accordance with Federal guidance [4, 5]. Sensitivity analysis is performed by testing the outcome to alternative plausible values of other key variables.

The economic performance measures are computed based on monetary estimates about which the confidence level is relatively high. For the 2009 studies, these include the monetary estimates of economic impact and the monetary estimates of health effects from the environmental effects of reduced emission of certain air pollutants.

2.4 Estimating environmental benefits and costs

The focus of the quantitative estimation of environmental benefits in the EERE benefit-cost studies is on (1) estimating Green House Gas (GHG) effects, and (2) estimating public health benefits (i.e., avoided mortality, morbidity, and related costs) of reducing air emissions from fossil-fuel combustion. Effects on water

- Net Benefits: time-adjusted benefits minus costs

  $NB = \Sigma B_{PV} - (\Sigma C_{PV} + \Sigma I_{PV})$

  where ΣB_{PV} = sum of present value benefits; ΣC_{PV} = sum of present value non-investment cost; and ΣI_{PV} = present value investment cost

- Benefit-to-Cost Ratio: time-adjusted benefits (net of time-adjusted non-investment costs) divided by time-adjusted investment cost

  $B/C = (\Sigma B_{PV} - \Sigma C_{PV}) / \Sigma I_{PV}$

- Internal Rate of Return (IRR): the solution interest rate (i) that equates the values of the streams of benefits and costs over time

  $\Sigma B_{(i)} = (\Sigma C_{(i)} + \Sigma I_{(i)})$

Source: TIA Consulting, Inc.

Figure 2: Three measures of economic performance.

resource use, water discharges, land resource use, and solid waste generation, if significant, are treated qualitatively.

2.4.1 Estimating Greenhouse Gas (GHG) emissions

Avoided GHG emissions from reduced combustion of fossil fuels, an important goal for EERE, is an aspect of environmental effects to be covered by the 2009 studies, with attention to carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The 2009 draft study Guide recommends the use of the EPA Greenhouse Gas Equivalencies Calculator (available at www.epa.gov /cleanenergy/energy-resources/calculator.html) [7] to assist in assessing the consequences of the GHG effects.

2.4.2 Estimating health effects

To estimate health effects from changes in air pollution emissions attributed to the program cluster evaluated, the US Environmental Protection Agency's (EPA) COBRA model (Co-Benefits Risk Assessment Model, described in US EPA [6]) is used. To apply COBRA, it is necessary to enter the estimated changes in air emissions of particulate matter (PM), sulphur dioxide (SO_2), nitrogen oxide (NO_x), and volatile organic compounds (VOCs) into the model. Because not all air pollutants are taken into account by the model, the results obtained from using COBRA for the analysis is taken as a lower bound estimate of impact of health effects and their economic value. Table 2 shows the health effects included in COBRA, by type of effect. The model provides estimates of the incidence of each type of effect and related healthcare costs.

2.4.3 Treating other environmental effects

For other environmental effects – such as changes in water consumption effects, water discharge, land resource use, and solid waste generation – the 2009 draft

Table 2: Health effects included in COBRA.

Health effect	Description
Mortality	Number of deaths
Chronic bronchitis	Cases of chronic bronchitis
Non-fatal heart attacks	Number of non-fatal heart attacks
Respiratory hospital admissions	Number of cardiopulmonary-, asthma-, or pneumonia-related hospitalizations
Cardio-vascular related hospital admissions	Number of cardiovascular-related hospitalizations
Acute bronchitis	Cases of acute bronchitis
Upper respiratory symptoms	Episodes of upper respiratory symptoms (runny or stuffy nose; wet cough; and burning, aching, or red eyes)
Lower respiratory symptoms	Episodes of lower respiratory symptoms: cough, chest pain, phlegm, or wheeze
Asthma emergency room visits	Number of asthma-related emergency room visits
Minor restricted activity days (MRAD)	Number of minor restricted activity days (days on which activity is reduced but not severely restricted; missing work or being confined to bed is too severe to be MRAD)
Work days lost	Number of work days lost due to illness
Asthma exacerbations	Shortness of breath, wheezing, and coughing (in asthmatic individuals)

study Guide recommends the provision of data on physical units together with commentary description and explanation if feasible, and a qualitative treatment if quantitative estimates are not feasible.

2.5 Estimating security benefits and costs

Security benefits are attributed to reducing disruptions in the nation's energy supply. They also are attributed to reducing threats to the nation's energy infrastructure. In addition, and in the longer run, national security benefits may also result from reducing GHG emissions, by avoiding the host of overwhelmingly negative long-range national security consequences that have been predicted in response to global warming. These effects also are extremely difficult to assign values – particularly economic values – with any confidence. Associations among changes in energy efficiency, energy supply, energy prices, and security impacts involve many assumptions, with causal relationships far more uncertain than for those entailed in estimating the other categories of benefits included in the 2009 studies and addressed by the related draft Guide. Attempts at monetary valuation of those benefits would be subject to far greater margins of error than for the other monetary estimates contained in the studies. For this reason, the 2009 recommended EERE approach is to avoid monetary estimates of security benefits, and, to the extent feasible, to use an estimate of the reduction in physical units of barrels of oil equivalent deriving from use of renewable energy, increased efficiency, and energy conservation as a rough indicator of security benefits. In addition, if the technology cluster has knowable implications for the security of the nation's energy infrastructure, a qualitative description of these effects is to be provided.

2.6 Estimating knowledge benefits

The creation and dissemination of knowledge outputs are central to EERE's programs. These knowledge outputs embody the results of program R&D in papers, patents, presentations, models, resource maps, prototypes, technology demonstrations, test data, research tools, trained and experienced people, and networks of researchers working collaboratively. The take-up and use of these knowledge outputs by industry enables the production of more energy efficient and environmentally friendly products and new and improved renewable energy systems. Moreover, the acquisition of EERE knowledge outputs by the broader community increases interest in and willingness to adopt energy innovations, and enables researchers in other organizations to make further advances.

The knowledge base created by an EERE program or subprogram is more extensive than that captured by the technology-specific cases of the corresponding benefit-cost analysis. Therefore, each study incorporates an assessment of the program/subprogram's knowledge creation and dissemination. Techniques used to document knowledge creation and flow include bibliometrics (patent citation analysis and publication co-author and citation analysis); analysis of documents and databases; and interviews with experts.

Patent analysis has been used extensively to trace technological developments and is emphasized in the assessment of knowledge benefits. The analysis is based on the idea that the prior art embodied in a patent referenced by a later patent provides part of the foundation for the later invention. A correlation between patent citations and measures of technological and scientific importance has been documented; highly cited patents tend to contain technological information of particular interest or importance. A summary of validation studies supporting patent analysis for assessing knowledge benefits and dissemination is found in Breitzman and Mogee [8]. Backward patent tracing is used to determine the extent to which DOE-funded research in the program/subprogram area has formed a foundation for technologies in the target area developed by leading commercial innovators in the industry. Forward patent tracing is used to investigate the impact of DOE-attributed patents resulting from the program/subprogram on subsequent technological developments, regardless of where they occur – whether in or outside the technology and industry area of primary EERE program interest.

The knowledge sections of the four 2009 benefit-cost studies were derived from four separate studies by Ruegg and Thomas [9–12], which traced linkages from the outputs of EERE's R&D programs to downstream developments.

3 Essential study characteristics

The draft methodology Guide drew on the following sources in developing a list of essential study characteristics: a report from the American Evaluation Association (AEA) Task Force on Guiding Principles for Evaluators [13]; a White House guidance memo to heads of agencies and executive departments on emphasizing evaluation [14], other evaluation resources, and EERE-stated preferences for uniformity in report format. The following provides a non-exhaustive list of essential study characteristics:

- Clear statement of evaluation study's design and objectives; appropriate design given the objectives; and appropriate objectives given the nature and stage of the program
- Clear statement of benefit-cost framework and conceptual models used
- Clear description of the program cluster, its components, logic, and cost
- Clear account of the technologies selected for detailed case study, rationale for selection, and relationship of those selected to the larger cluster
- Appropriate designation of the next-best alternative to use as a baseline for estimating the differential effects of each technology selected
- Assessment of the context and external influences that may constitute rival explanations of outcome; adequate control for rival explanations of outcomes
- Use of valid protocols and procedures in data collection
- Adequate identification/documentation of data quality and related issues of uncertainty; inclusion of discussions of levels and sources of uncertainty in the study report; and appropriate reflection of uncertainty in the analyses
- Critical assumptions are stated and documented, and study limitations are identified
- Systematic and appropriate analyses to achieve objectives within the conceptual framework
- Findings are evidence-based. Conclusions are in sync with findings. Implications flow from findings and conclusions, consistent with methodology.
- Findings are conservative, in that they likely understate the actual benefits from the cluster investment
- Evaluation objectives are achieved.

4 The 2009 benefit-cost studies

DOE/EERE commissioned four benefit-cost studies in 2009, to be conducted according to the new draft EERE methodology. These initial benefit-cost studies [15–18] are listed in table 3, identified by the EERE program or subprogram evaluated, by authors and their organizational affiliation, and the group of technologies of focus:

Table 3: Four initial benefit-cost studies performed according to EERE's new draft methodology.

Program/subprogram evaluated	Authors	Author affiliation	Technologies assessed in detail
Advanced Combustion Engine Technologies (part of the Vehicle Technologies Program)	A. Link	University of North Carolina at Greensboro	-Laser and optical diagnostic technologies related to heavy-duty diesel engines
Geothermal Program	M. Gallaher A. Rogozhin J. Petrusa	RTI International	-Polycrystalline diamond compact (PDC) drill bits -Binary cycle power plant technology -TOUGH series of reservoir models -High-temperature geothermal well cements
Solar Photovoltaics (part of the Solar Energy Technologies Program)	A. O'Connor R. Loomis F. Braun	RTI International	-Flat-plate solar array -Photovoltaic manufacturing technology (PVMaT) -Thin film PV
Wind Energy Program	T. Pelsoci	Delta Research Co.	-Turbulence models -Aerodynamics and design codes -Variable speed drives -Blade materials characterization -Airfoil design codes -Demonstration and testing

These reports are in review as this paper is prepared. Following the detailed, expert reviews of the reports, they will be revised accordingly, and published. It is expected that summary results will be available for release as part of the Conference presentation.

5 Next steps

The Guide on the new EERE benefit-cost methodology was left in draft form pending completion and review of the initial set of benefit-cost studies and feedback from the researchers who conducted the studies. That feedback, together with the already completed extensive reviews of the draft Guide by an external review panel and internal DOE reviewers, as well as current EERE requirements, will inform the need for further modifications of the Guide prior to publication.

Acknowledgements

Work presented here was completed for the US Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy by and under contract to Sandia National Laboratories, Albuquerque, New Mexico, USA under Contract DE-AC04-94AL8500. Sandia is operated by Sandia Corporation, a subsidiary of Lockheed Martin Corporation. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

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