# Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

## ENERGY & ENVIRONMENT DIVISION

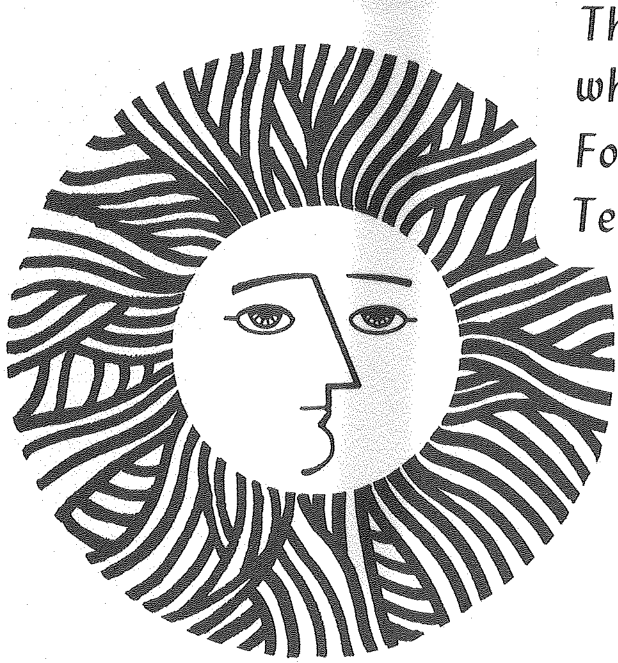


AN ANALYSIS OF THE ENERGY IMPACTS OF THE DOF APPROPRIATE ENERGY TECHNOLOGY SMALL GRANTS PROGRAM: METHODS AND RESULTS

Bart Lucarelli, Jeff Kessel, Josh Kay, Janet Linse, Susan Tompson, and Mark Homer

August 1981







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## DISCLAIMER

LBL-12253 Rev.

# AN ANALYSIS OF THE ENERGY IMPACTS of the DOE APPROPRIATE ENERGY TECHNOLOGY SMALL GRANTS PROGRAM: METHODS AND RESULTS

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# TABLE OF CONTENTS

## LIST OF TABLES

# LIST OF FIGURES

## ACKNOWLEDGMENTS

Completing this study required the assistance and cooperation of many people. We are especially grateful to the regional program managers of DOE, who supplied us with proposals and progress reports for the 57 projects. Thanks are due Bob Chase and Herb Sperry (Region I), Jane del Gado and Morrel Thompson (Region II), Tony Pontello (Region III), Mickey Peltus (Region IV), Robbie Dalton and Richard Scharschberger (Region V), Guntis Terauds (Region VI), Jack Stacy and Bob Lewis (Region VII), Tom Stroud (Region VIII), Meg Schachter (Region IX), and Frank Brown (Region X). We are also extremely grateful to the 57 project managers, all of whom diligently responded to our many requests for technical and economic data. Without the active involvement of both the program and project managers, we could not have completed the study.

We also thank Rudy Beran of the U.C. Berkeley Statistics Department for reviewing the statistical analysis in an earlier draft of the report and Don Elmer of Lawrence Berkeley Laboratory for reviewing the report. Finally, we wish to thank Laurie Sampietro and Charlotte Standish of the LBL Solar Group for typing the final report with dispatch and accuracy in the face of a tight deadline. Although these individuals contributed greatly to the completion of the report, we, the authors, are responsible for errors, omissions, and the opinions that are presented.

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# EXECUTIVE SUMMARY

## A. OBJECTIVES

Lawrence Berkeley Laboratory (LBL) has completed this energy impact study for the Department of Energy (DOE), Office of Inventions and Small Scale Technology (OISST). The study outlines methods for assessing the energy savings of projects funded by DOE in the Appropriate Technology Program (AT) and the way to apply these methods to obtain estimates of energy impacts. Initially, LBL intended:

(1) to develop a consistent procedure for evaluating energy savings from small-scale energy projects; and

(2) to apply the procedure to a large sample.

Later, at the request of DOE, LBL expanded the research to include a third objective:

(3) to apply statistical methods to the sample estimates and infer energy savings for the entire program.

## B. RESEARCH APPROACH

Figure 1 presents the research approach schematically. The study was completed in three phases: sample selection, project evaluation, and statistical estimation.

Sample Selection. From a population of 584 projects, 57 were selected without random sampling. As a result, the estimates of program energy savings may have a systematic bias. The sample was selected from the first set of projects funded in the national program. Since then, DOE has improved the method of selecting projects, and those funded under later programs should have greater energy saving potential than does the 57-project sample. Thus, we consider our sample to be a conservative prediction of the energy saving potential of later AT programs.

Project Evaluation. For each project, two categories of energy savings, direct and indirect, have been assessed. Direct energy savings (DES) are those savings of fossil energy that will result from the successful completion of each project. Indirect energy savings (IES) are the lifetime energy savings that will be realized if an energy system is replicated because of either demonstration or commercialization.

For a project to have IES, the system must meet two criteria:

(1) cost-effectiveness; and

(2) intent by someone to market or publicize the system.

Both DES and IES are first estimated at the point of end use in million Btu (MBtu) and then converted into a barrels-of-oil equivalent (BOE) that includes end-use energy plus energy lost in generation and transmission. Once converted into BOE, DES and IES are added together to provide an estimate of the energy saving potential of each project.

Statistical Estimation. Statistical methods were applied to the project results to estimate program energy savings. On the assumption that the sample is unbiased, we computed the average BOE energy saving per $1000 of DOE funding, which we refer to as the sample mean, and the standard error of the mean. From these two computations, confidence intervals at the 50, 75, and 90 percent levels of probability were constructed. Average program energy savings at each probability level were then estimated.

## C. RESULTS AND CONCLUSIONS

The results of the statistical analysis are presented in Table E-1 for the three confidence levels. If the sample mean is the same as the population mean, then the FY 1979 program, which granted $8 million, can attain energy savings of 22.8 million BOE over the lifetimes of the project and replicate energy systems. The program energy saving is 1.2 million BOE annually (not determinable from Table E-1).

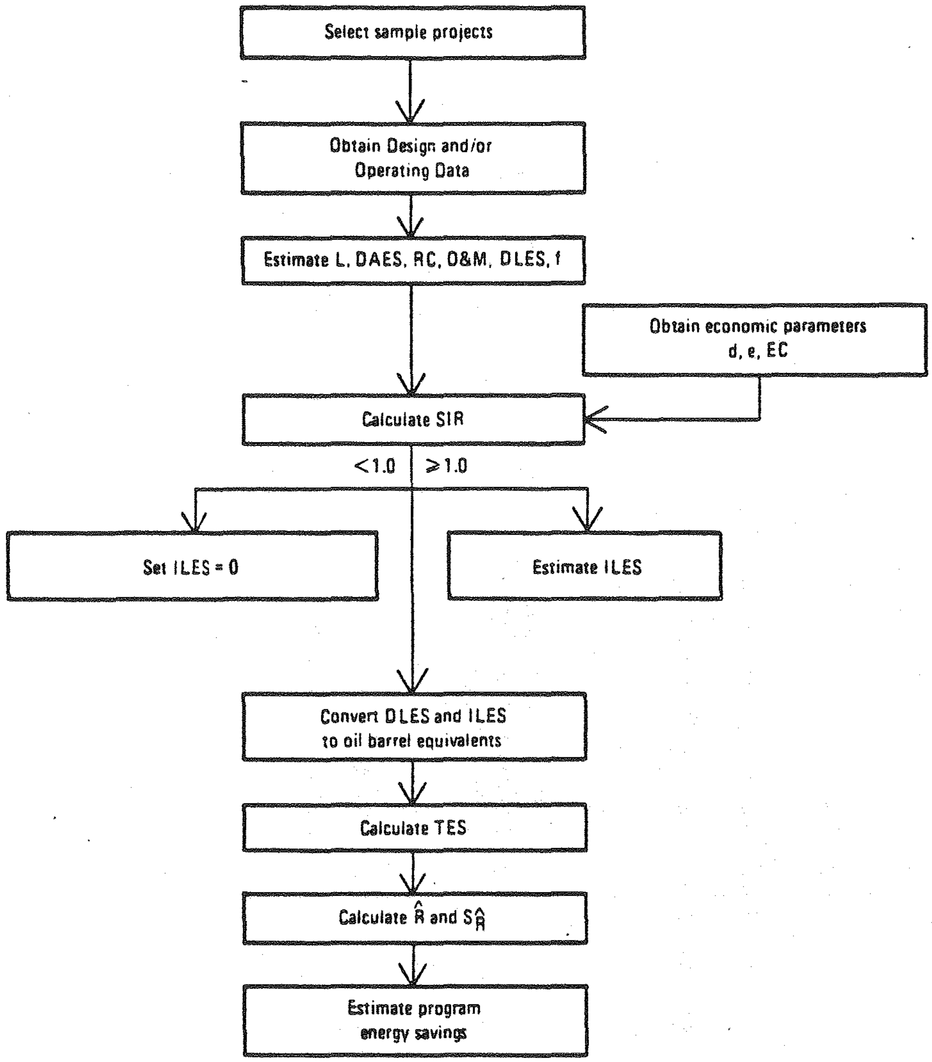
Table E-1 illustrates at each confidence level a wide range of program energy saving potentials, which reflects the wide variations among the energy saving potentials of individual projects. For instance, at a 75 percent confidence level, program energy savings are estimated to be 9 to 36 million BOE. At the same confidence level, the program can attain these savings at a cost ranging from only $.20 to $.85 per BOE, a very low cost to DOE.

The results of the analysis are useful for evaluating the near term potential (5 years or less) of the program to save energy at low cost. On the other hand, the findings are not estimates of long term potential, and they do not provide estimates of the potential for reducing U.S. oil imports. Moreover, the results measure effectiveness in meeting only one of the many objectives Congress had set for the program. Other objectives are: maximizing use of local resources, minimizing adverse environmental impacts, and generating jobs. In a comprehensive evaluation, the program should be judged according to all the objectives set for it by Congress and not merely for energy saving potential.

Opportunities exist for DOE to increase the energy impact of the program while meeting the multiple objectives. For example, DOE can:

- require each applicant to include in the proposal clear plans for replicating any system under development;
- increase the grantee's accountability for completing the project according to the original work plan;
- provide additional funding early to promising projects; and
- publicize the results and technical details of successful projects.

Fig. 1-1 **Methodology for Appropriate Energy Technology Project Analysis**




**Abbreviations**

- L : lifetime of energy system (years)
- DAES : direct annual energy savings, achieved by project energy system(s) (MBtu)
- RC : replicate cost, the cost of energy system when commercialized ($)
- O&M : annual system operation & maintenance cost ($)
- DLES : lifetime energy savings = L x DAES (MBtu)
- f : DOE funding for project (1000 $)
- d : discount rate (%)
- e : fuel escalation rate (%)
- EC : base year fuel cost ($/MBtu)
- ILES : indirect lifetime energy savings, the savings achieved by short term commercialization of the project energy system
- SIR : savings/investment ratio, the ratio of the present value of net revenues to the present value of investment costs
- TES : DLES + ILES
- $\hat{R}$ : sample mean of total energy savings per 1000 $ of funding, defined to be $\Sigma\ (TES)_i / \Sigma f_i$ (MBtu/1000 $)
- $S_{\hat{R}}$ : standard error of the sample mean

TABLE E-1

Estimates of Energy Saving Effectiveness and Program Energy Savings

at Three Confidence Levels (90%, 75%, and 50%)

| Confidence Level | Range of Values (BOE/$1000 DOE Funding) | DOE Investment per Potential Barrels of Oil Savings | Program Energy Savings (Million BOE) |
|---|---|---|---|
| 90% | 485 to 5225 | $.19 to $2.05 | 3.9 to 41.8 |
| 75% | 1195 to 4515 | $.20 to $ .85 | 9.6 to 36.1 |
| 50% | 1870 to 3840 | $.25 to $ .55 | 15.0 to 30.7 |

# CHAPTER 1

## OVERVIEW OF THE ENERGY IMPACT ANALYSIS

### INTRODUCTION

In 1977, Congress directed the Department of Energy (DOE) to create a financial assistance program for individuals, small businesses, communities, Indian tribes, and nonprofit organizations to develop technologies that use renewable energy resources. With this mandate, DOE created the Appropriate Technology Program (AT). To date, AT has funded over 1300 projects applying simple, small scale energy technologies that promote renewable energy resources or conserve fossil fuels.

This report presents an assessment of the energy savings potential of AT. The results will help DOE evaluate the overall effectiveness of the program and will identify ways of increasing the energy savings. To estimate energy impacts, we first calculated the energy savings and evaluated the cost-effectiveness of a sample of projects funded in Fiscal Year (FY) 1979. Then, an estimate of program savings was extrapolated from the sample by statistical inference.

Estimating program energy savings was made difficult by the comprehensiveness of the mandate that encouraged the development of a diverse array of technologies and resources having differing objectives. For example, AT has funded projects (among others) that:

- demonstrate the use of improved wood stoves for space heating;
- develop new types of solar collectors for marketing;
- test the feasibility of using small wind systems to generate electricity for residential use; and
- construct and operate anaerobic digesters.

Diversity is increased further because projects address local needs, cater to different markets, and use local resources and expertise whenever possible.

As a result of diversity, estimating the energy impact of the program requires extensive project analysis. Still, we do not argue that the program be changed to a simpler format to facilitate evaluation. On the contrary, the complex characteristics are major strengths of AT. The diverse project mix allows DOE to experiment at a very low cost with many techniques for developing renewable energy resources and conservation technologies. Low project costs result from the use of simple technologies and recycled materials and from cost-sharing by the grantees. Finally, the emphasis on meeting local needs and on using local resources and labor increases the credibility of each project and the prospect that other people may replicate the project in other locales. The high visibility of each project is valuable in disseminating not only successful results but also in preventing other people from duplicating the mistakes of unsuccessful projects.

## OBJECTIVES OF THE RESEARCH

DOE recognized early the need for assessing the energy impact of the program and contracted with Lawrence Berkeley Laboratory (LBL) in 1978 to develop evaluation methods applicable to 20 projects funded by AT in Federal Region IX. LBL completed the research in October 1979 and published the results (Lucarelli et al., 1979). The next step was to evaluate the energy savings of the national grants program.

LBL set two objectives for this second energy impact study:

(1) to develop a consistent procedure for evaluating the energy impacts of small energy projects and

(2) to apply the procedure to a large sample and quantify the sample energy savings.

After the sample was selected, we added a third objective at the request of DOE:

(3) to infer, using statistical methods, program energy savings from the project sample.

## DEFINITIONS AND METHODS

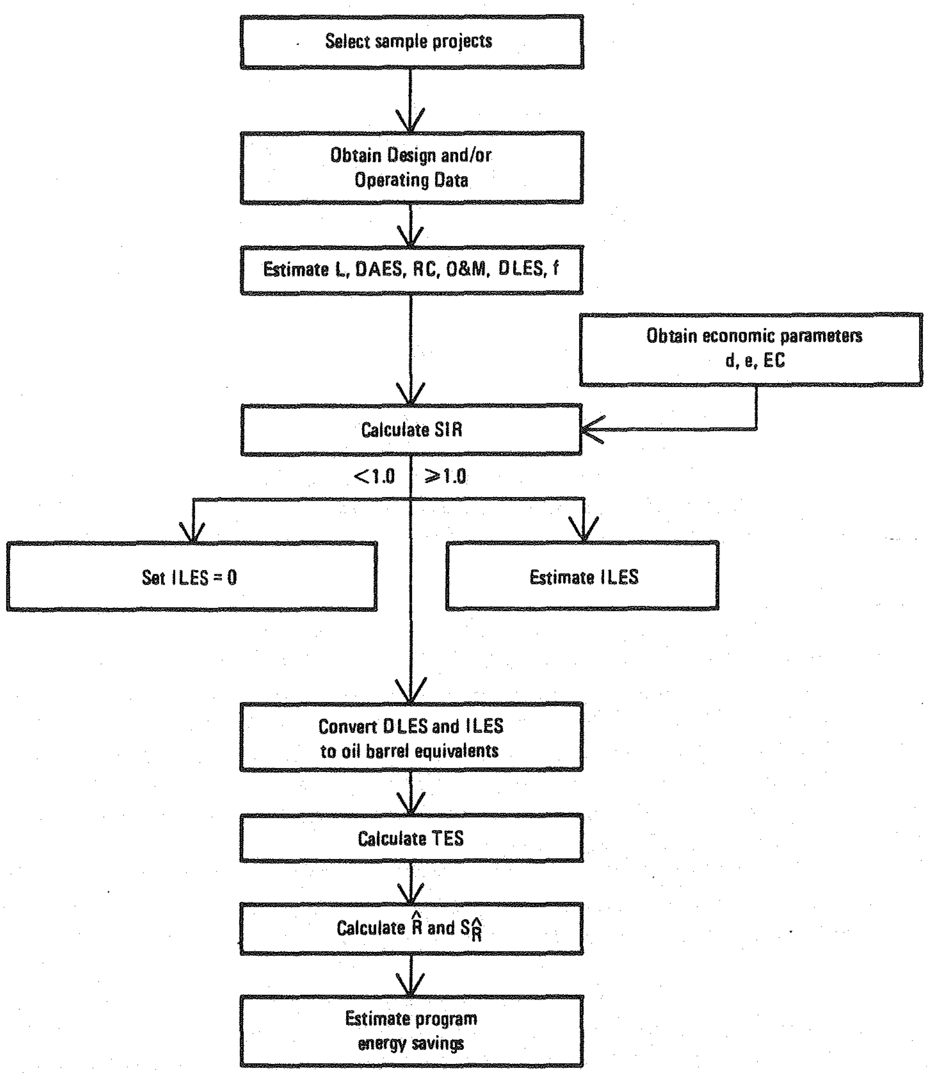
The first step was to assess the energy savings potential of 57 projects from a national population of 584. Program energy savings were then estimated from project savings using statistical inference. Details of the approach are presented schematically in Figure 1-1 and are discussed below under three headings: sample selection, project evaluation, and statistical estimation.

Sample Selection. Researchers normally use either simple or stratified random sampling to objectively select a sample from which population estimates can be made. Although we attempted to select a representative sample, we did not use random sampling, but our own judgment.* Projects were not selected by their apparent energy savings potential, but the nonrandom sampling approach may have resulted in a systematic bias in population estimates. Another problem with the sample is that it was drawn from only 8 of the 10 federal regions. Regions IV and VIII were not represented.

Project Evaluation. For each project, two categories of energy savings, direct and indirect, have been assessed:

* Initially, we intended to provide DOE with only a case study analysis of representative projects. As the needs of DOE changed, we were requested to expand our work and provide an estimate of program energy savings. Unfortunately, the sample had already been selected, and the analysis was nearing completion. Our estimates are therefore the best information available at this time, but future studies that use a random sampling approach can provide more precise estimates of program energy savings.

Fig. 1-1 **Methodology for Appropriate Energy Technology Project Analysis**




**Abbreviations**

| | |
|---|---|
| L | : lifetime of energy system (years) |
| DAES | : direct annual energy savings, achieved by project energy system(s) (MBtu) |
| RC | : replicate cost, the cost of energy system when commercialized ($) |
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| DLES | : lifetime energy savings = L x DAES (MBtu) |
| f | : DOE funding for project (1000 $) |
| d | : discount rate (%) |
| e | : fuel escalation rate (%) |
| EC | : base year fuel cost ($/MBtu) |
| ILES | : indirect lifetime energy savings, the savings achieved by short term commercialization of the project energy system |
| SIR | : savings/investment ratio, the ratio of the present value of net revenues to the present value of investment costs |
| TES | : DLES + ILES |
| $\hat{R}$ | : sample mean of total energy savings per 1000 $ of funding, defined to be $\Sigma\ (TES)_i/\Sigma f_i$ (MBtu/1000 $) |
| $S_{\hat{R}}$ | : standard error of the sample mean |

| |
|---|
| Direct energy savings (DES) are those savings of fossil energy that will result from the successful completion of the project. |

To obtain DES, the annual savings were computed and then multiplied by the economic lifetime of the system.

| |
|---|
| Indirect energy savings (IES) are the lifetime energy savings that will be realized if the energy system is replicated because of demonstration or commercialization. |

Both DES and IES were estimated at the point of energy use, referred to as end use.

The different methods used in assessing DES for all projects are not specifically documented in this report because of the large sample size. However, a listing of relevant data is provided in Table 1-1. In general, we obtained from the grantees the facts on energy performance, which we verified by consulting technical literature and experts in the field. Where differences existed or where performance data did not exist, the opinions of experts and our own best judgments had to suffice.

Our approach to estimating IES was cautious. First, a project had to be cost-effective before being analyzed for IES.*

| |
|---|
| To be cost-effective, an energy system must generate over its lifetime net revenues equal to or greater than first cost. Net revenues are gross revenues (dollar value of energy savings) minus operating and maintenance costs above those required by an alternative fossil fuel system. |

The savings-to-investment ratio (SIR), which is the ratio of net revenues to investment cost, was used to indicate cost-effectiveness.

Cost-effective projects were then studied for IES potential, which was usually dependent upon the grantee's plans for marketing or outreach. If the plans were reasonable and systematic, we computed an indirect potential for the project. We then added DES and IES, expressing the total in million Btu (MBtu). The total was converted first to a primary energy equivalent, which includes both end-use energy and losses because of generation and transmission, and then to barrels of oil equivalent (BOE).

Statistical Estimation. Program energy savings were estimated from the DES and IES of the sample projects. Assuming that the sample was unbiased, we computed the sample mean and the standard error of the mean, where the mean measured the average energy savings of the sample per $1000 of DOE funding. From the sample mean and standard error, confidence intervals at the 50, 75, and 90 percent levels of probability were constructed. A range for program energy savings at each probability level was then computed.

* We excluded four projects from this decision rule. The four projects had already achieved some IES despite their lack of cost-effectiveness.

## LIMITATIONS OF THE STUDY

First, a limitation already mentioned is that the sample is not random and may not be representative. If the sample is not representative, the population estimates will be inaccurate and the inferences unjustified in probability terms. Second, a large fraction of the total energy savings are indirect and will be achieved only if the assumptions concerning project replication are correct. The cost-effectiveness of each project and the grantee's intent to demonstrate or commercialize the system were carefully evaluated to avoid overstating the IES.

Third, most of the projects serve multiple economic and social objectives and, in many cases, act to increase energy awareness and energy self-sufficiency on the community level. Because of the limited scope of the study, these important but sometimes intangible benefits were not considered. For instance, the projects may have important employment impacts that should be quantified. Moreover, although the energy impacts are impossible to measure, some education projects may have an important influence in shaping public attitude toward energy use. In short, any comprehensive analysis of the value of the program must consider these less tangible benefits.

## ORGANIZATION OF THE REPORT

The next four chapters present the methods and results of the study. Chapter 2 presents and discusses estimates of DES for the 57 projects. Chapter 3 discusses methods and results of the economic analysis. Chapter 4 examines the IES. Because of the large size of the sample, neither project descriptions nor specific details of each project analysis are included. Instead, two examples from the analysis are presented in Chapters 2, 3, and 4 to illustrate methods. The results of the analysis and key project data are summarized in Table 1-1. Chapter 5 presents estimates of program energy savings and the methods used to obtain them. The report concludes with a discussion of how improved project selection can increase program energy savings and presents two approaches for conducting future energy impact studies.

## SUMMARY TABLE OF APPROPRIATE ENERGY TECHNOLOGY PROJECT ANALYSIS

TABLE 1-1

| Project Number | Region | Technology | End Use | Sector of Application | Fuel Displaced | Funding Level ($1000) | Project Lifetime (years) | Project Type | Direct Energy Savings (MBtu) | Savings/ Investment Ratio (SIR) | Indirect Energy Savings (MBtu) | Barrels of Oil Equivalent (bbls) | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| NJ-861 | II | SOL | FP | COM | FO | 4.6 | 20 | PSD | 2,100 | 0.9 | 0 | 398 | |
| IA-94 | VII | SOL | PH | AGR | EL | 0.9 | 20 | PSD | 412 | 2.4 | 0 | 234 | |
| MO-201 | VII | SOL | PH | AGR | LP | 5.5 | 20 | PSD | 51 | NA | 0 | 10 | |
| NJ-255 | II | SOL | SH/PH | COM | NA | 14.0 | NA | PSD | 0 | NA | NA | 0 | |
| OH-1221 | V | SOL | WH | COM | NG | 24.5 | 20 | CSTM | 10,000 | 0.9 | NA | 1,897 | |
| IN-701 | V | SOL | NA | RES | EL | 10.0 | 20 | LR | 0 | NA | 0 | 0 | |
| PA-6 | III | SOL | PH | IND | FO | 28.2 | 20 | CSTM | 16,500 | >1 | 16,500 | 6,259 | |
| VA-180 | III | SOL | PH | RES | NG | 8.1 | 15 | PSD | 630 | 1.1 | 22,050 | 4,301 | |
| OH-478 | V | SOL | WH | RES | NG | 1.9 | 25 | ED | 0 | NA | 12,603 | 2,390 | |
| AR-1372 | VI | SOL | PH | COM | NG | 6.3 | 20 | PTM | 332 | 72.7 | 6,648 | 1,323 | |
| NM-626 | VI | SOL | PH | COM | NG | 10.8 | 20 | PSD | 558 | 12.2 | 8,370 | 1,674 | |
| OH-418 | V | SOL | WH | RES | NG | 16.4 | 20 | ED | 40 | 0.1 | 800 | 159 | |
| MO-198 | VII | SOL | SH | RES | NG | 7.3 | 1 | FS | 0 | NA | 0 | 0 | |
| IA-6 | VII | BIO | SH | AGR | NG | 14.4 | 10 | CSTM | 36,000 | 22.9 | 2,700,000 | 518,897 | |
| IL-397 | V | BIO | SH | PUB | NG | 50.0 | 20 | CSD | 730,000 | 2.9 | 0 | 138,448 | |

1: Number contains state abbreviation

3: Solar = SOL, Biomass = BIO, Wind = WIN, Hydropower = HYD, Energy Storage/Transfer = EST, Conservation = CON, Education = ED, Geothermal = GEO

4: Space Heating = SH, Space Cooling = SC, Water Heating = WH, Lighting = LT, Cooking = CK, Clothes Washing = CW, Clothes Drying = CD, Dish Washing = DW, Transportation = TR, Process Heat = PH, Food Production = FP, Waste Treatment = WT

5: Residential = RES, Commercial = COM, Industrial = IND, Public = PUB, Agricultural = AGR

6: Electricity = EL, Natural Gas = NG, Fuel Oil = FO, Liquified Propane = LP

9: Feasibility Study = FS, Lab Research = LR, Prototype Component Development = PCD, Prototype System Development = PSD, Prototype Testing and Monitoring = PTM, Commercial System Testing and Monitoring = CSTM, Commercial System Demonstration = CSD, Commercialization = COM, Educational/Workshop = ED

13: Col. 13 sums columns 10 and 12. To convert given MBtu to oil bbls, first convert to primary energy by multiplying by 1.1 for projects that displace gas or oil, or by 3.3 for projects that displace electricity. Then divide by 5.8 to convert from primary MBtu to barrels of oil.

**SUMMARY TABLE OF APPROPRIATE ENERGY TECHNOLOGY PROJECT ANALYSIS** TABLE 1-1 (cont.)

| Project Number | Region | Technology | End Use | Sector of Application | Fuel Displaced | Funding Level ($1000) | Project Lifetime (years) | Project Type | Direct Energy Savings (MBtu) | Savings/ Investment Ratio (SIR) | Indirect Energy Savings (MBtu) | Barrels of Oil Equivalent (bbls) | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| MD-53 | III | BIO | SH | RES | FO | 42.5 | 30 | CSD | 66,000 | 2.5 | 0 | 12,517 | |
| AK-043 | X | BIO | SH | RES | LP | 9.0 | 15 | PTM | 528 | -.2 | 0 | 100 | |
| MA-642 | I | BIO | SH | RES | FO | 20.0 | 1 | COM | 3,300 | 43.2 | 0 | 569 | |
| NY-00 | II | BIO | FP | IND | EL | 25.0 | 20 | PSD | 459 | .5 | 0 | 261 | |
| VT-1 | I | BIO | SH | RES | FO | 24.6 | NA | PTM | 0 | NA | NA | 0 | |
| OK-1271 | VI | BIO | PH | IND | NG | 10.0 | NA | LR | 0 | NA | 0 | 0 | |
| OH-1089 | V | BIO | TR | AGR | GS | 19.8 | NA | FS | 0 | NA | 0 | 0 | |
| WV-134 | III | BIO | TR | RES | GS | 36.9 | NA | PCD | 0 | NA | 0 | 0 | |
| CT-409 | I | BIO | WT | COM | NG | 4.8 | NA | PSD | 0 | NA | 0 | 0 | |
| MD-159 | III | BIO | WT | IND | EL | 25.0 | 20 | CSD | 0 | 1.9 | 0 | 0 | |
| VT-559 | I | BIO | SH | COM | LP | 9.3 | 30 | CSTM | 0 | 7.5 | 0 | 0 | |
| RI-859 | I | BIO | SH | RES | FO | 19.4 | NA | FS | 0 | NA | 0 | 0 | |
| KS-71 | VII | BIO | SH | RES | NG | 6.7 | NA | PTM | 0 | NA | 0 | 0 | |
| WA-289 | X | BIO | WT | PUB | EL | 9.0 | NA | FS | 0 | NA | 0 | 0 | |
| MI-113 | V | WIN | FP | AGR | EL | 6.7 | 30 | CSD | 1,536 | 0.8 | 0 | 874 | |

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**SUMMARY TABLE OF APPROPRIATE ENERGY TECHNOLOGY PROJECT ANALYSIS** TABLE 1-1 (cont.)

| Project Number | Region | Technology | End Use | Sector of Application | Fuel Displaced | Funding Level ($1000) | Project Lifetime (years) | Project Type | Direct Energy Savings (MBtu) | Savings/ Investment Ratio (SIR) | Indirect Energy Savings (MBtu) | Barrels of Oil Equivalent (bbls) | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| TX-522 | VI | WIN | NA | NA | NA | 9.8 | NA | LR | 0 | NA | 0 | 0 | |
| NH-539 | I | WIN | NA | COM | EL | 41.0 | 20 | CSD | 9,102 | 0.9 | 0 | 5,179 | |
| NY-539 | II | WIN | WT | PUB | EL | 48.7 | 20 | CSD | 3,512 | 0.7 | 0 | 1,998 | |
| OH-673 | V | WIN | NA | RES | EL | 9.9 | 20 | CSD | 610 | 0.2 | 0 | 347 | |
| VI-7 | II | WIN | NA | RES | EL | 9.3 | 20 | CSD | 356 | 1.0 | 4,276 | 2,635 | |
| IL-849 | V | WIN | NA | PUB | EL | 27.0 | 20 | ED | 543 | 0.1 | 0 | 310 | |
| MI-122 | V | WIN | SH | RES | NG | 22.5 | 20 | PSD | 1,024 | 0.1 | 0 | 195 | |
| OK-152 | VI | WIN | FP | AGR | EL | 3.4 | 30 | CSD | 33 | 0.1 | 0 | 2 | |
| MN-382 | V | WIN | NA | AGR | EL | 19.6 | 20 | CSD | 1,146 | 0.6 | 0 | 652 | |
| TX-1296 | VI | GEO | SH | COM | EL | 11.4 | 20 | PSD | 655 | 1.5 | 4,586 | 2,982 | |
| TX- 1267 | VI | GEO | SH | PUB | NG | 8.0 | NA | FS | 0 | NA | 0 | 0 | |
| ME-903 | I | HYD | NA | PUB | EL | 27.0 | 20 | PSD | 107,851 | 18.8 | 35,495 | 81,559 | |
| NE-3 | VII | EST | SH | RES | EL | 9.8 | 20 | PSD | 3,079 | 1.4 | 0 | 1,752 | |
| IL-50 | V | EST | SC | RES | NG | 23.8 | 1 | PTM | 0 | NA | 0 | 0 | |
| MN-296 | V | EST | SC | RES | EL | 12.0 | NA | PCD | 0 | NA | 0 | 0 | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| PA-645 | III | CON | WT | PUB | NG | 6.9 | 1 | PSD | 64 | -4.6 | 0 | 12 | |
| IN-904 | V | CON | SH | COM | NG | 16.9 | 1 | PCD | 0 | NA | 0 | 0 | |
| LA-132 | VI | CON | CW | IND | NG | 31.6 | 25 | COM | 7,884 | 53.0 | 5,802,755 | 1,102,018 | |
| CA-390 | IX | CON | WH | COM | NG | 8.0 | 25 | CSD | 6,000 | 4.9 | 4,416,100 | 838,674 | |
| NM-766 | VI | CON | SH | RES | NG | 10.2 | 20 | PSD | 0 | NA | 0 | 0 | |
| NM-126 | IX | CON | SH | RES | NG | 1.9 | 30 | CSTM | 0 | NA | 0 | 0 | |
| OH-580 | V | CON | SH | RES | EL | 33.3 | 13 | CSTM | 2,106 | 4.8 | 0 | 1,198 | |
| IL-206 | V | CON | SH | COM | NG | 48.2 | 20 | PSD | 0 | 4.0 | 22,500 | 4,267 | |
| IA-23 | VII | CON | SC | RES | EL | 2.7 | 20 | PTM | 55 | 0.8 | 55 | 31 | |
| NY-278 | II | CON | SH | RES | NA | 12.1 | 12 | PSD | 0 | 0.6 | 0 | 0 | |
| VT-102 | I | CON | SH | RES | FO | 8.0 | 12 | PSD | 95 | 0.2 | 284 | 18 | |
| ME-914 | I | CON | WH | COM | LP | 20.0 | 10 | CSD | 576 | 0.6 | 0 | 109 | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |

1: Number contains state abbreviation

3: Solar = SOL, Biomass = BIO, Wind = WIN, Hydropower = HYD, Energy Storage/Transfer = EST, Conservation = CON, Education = ED, Geothermal = GEO

4: Space Heating = SH, Space Cooling = SC, Water Heating = WH, Lighting = LT, Cooking = CK, Clothes Washing = CW, Clothes Drying = CD, Dish Washing = DW, Transportation = TR, Process Heat = PH, Food Production = FP, Waste Treatment = WT

5: Residential = RES, Commercial = COM, Industrial = IND, Public = PUB, Agricultural = AGR

6: Electricity = EL, Natural Gas = NG, Fuel Oil = FO, Liquified Propane = LP

9: Feasibility Study = FS, Lab Research = LR, Prototype Component Development = PCD, Prototype System Development = PSD, Prototype Testing and Monitoring = PTM, Commercial System Testing and Monitoring = CSTM, Commercial System Demonstration = CSD, Commercialization = COM, Educational/Workshop = ED

13: Col. 13 sums columns 10 and 12. To convert given MBtu to oil bbls, first convert to primary energy by multiplying by 1.1 for projects that displace gas or oil, or by 3.3 for projects that displace electricity. Then divide by 5.8 to convert from primary MBtu to barrels of oil.

# CHAPTER 2

# ASSESSMENT OF DIRECT ENERGY SAVINGS

## INTRODUCTION

This chapter discusses direct energy savings (DES) of the 57 projects and the methods used to determine those savings. DES are a portion of total energy savings and used in calculating cost-effectiveness. Moreover, DES provide the basis for estimating indirect energy savings (Chapter 4) once the extent of system replication has been estimated.

DES are the amount of energy saved by a project over the lifetime of the energy system involved. Not all projects have DES. Some projects, such as feasibility studies or laboratory research efforts, do not use a system to meet an end use and thus cannot attain DES. Others had no savings because they failed to meet their objectives.

The chapter has three sections. The first section defines DES and discusses methods used to calculate them. The second presents two projects to illustrate these methods. The third section presents the results of the analysis and discusses project characteristics that indicate a potential for DES.

## DEFINITIONS AND METHODS

A project has DES if it meets two criteria.

(1) The project must be successfully completed or show signs of nearing successful completion.

(2) The project must install an energy system that produces or conserves energy to meet an end use, meaning the production of an economic good or the supply of a service.

By these criteria, projects that produce energy only for the purposes of system development and testing do not have DES. Most projects attain DES by displacing an amount of fossil energy that would otherwise be used for an existing end use, such as space heating. For a new building that incorporates solar technology, however, the amount of fossil energy that would be needed to operate without the solar technology is computed, and this figure is used as the estimate of DES.

The specific fuel (natural gas, electricity, fuel oil) displaced by a project was usually determined from past use at the project site. When fuel information was not available, the fuel that would have been used in that region was selected.

The amount of energy saved by each project was determined using a variety of sources:

- operating and monitoring data on the installed energy system;
- utility bills before and after the system was installed; and
- calculations based on design properties of the system and on comparisons with similar systems.

From these data, energy savings were estimated on an annual basis. The DES were calculated by multiplying annual savings by the projected lifetime of the system. In other words, DES are the amounts of fossil energy saved by the projects over the lifetime of the implemented energy systems.

Ideally, every project that employs an energy system should have several years of operating data upon which to base an estimate of DES. At the time of this study, most projects were just being completed. In the absence of sufficient operating data, we relied on the operating data available, on discussions with the grantee and consultants, and on comparisons of the project system with similar systems for which operating data was available.

## EXAMPLE PROJECTS

To illustrate the methods for calculating DES two projects are discussed below.

### Example 1

The first project, located in Marlin, Texas, uses hot water from an existing geothermal well to heat the nearby office of the Marlin Chamber of Commerce. DOE awarded the Chamber of Commerce $11,400 to design and install a heat exchanger at the well, associated piping, and a heating coil in the existing, forced-air heating system, which remains in place as backup for the geothermal system (Marlin, 1979). The Chamber of Commerce contributed an additional $3,500 to the project and will use the project to attract industry by promoting the inexpensive heat (Johnson, 1980).

The most accurate estimate of DES would have been made by comparing utility bills before and after installation of the system (with corrections made for differences in weather). Because these records are not yet available, DES were estimated from design operating properties made available by the engineering firm hired to design the system.

When in operation, the system raises 1500 cfm of air by 30$^{o}$F (Johnson, 1980). This warm air flow is equivalent to 49,250 Btu/hr or 14.4 kW. An electric heating system with an efficiency of 0.9 requires an input of 16.0 kW to supply this heat to an occupied space (14.4/0.9 = 16.0).

In order to estimate annual energy savings (AES), we assumed a heating season of 120 days consisting of 5 hours per day, 5 days per week. The AES were found by multiplying the number of days in the heating season by the daily use by the power displacement.

AES = (120 days/yr)x(5 hr/day)x(16kw) = 9600 kwh/yr.

The project engineer estimated the system lifetime to be 20 years. Therefore, the direct energy savings (DES) are:

DES = (20yrs)x(9600 kwh/yr) = 192,000 kwh = 655.2 MBtu*

Example 2

The second example, a project that develops a solar kiln for drying lumber, illustrates a different technology and another method for estimating DES. DOE awarded John Vincent of New Mexico $10,000 to develop the kiln and demonstrate it to the local woodworkers, who use cabinet grade pine to build a Spanish-style furniture. Although New Mexico grows sufficient pine for this trade, no kilns exist in New Mexico that can dry pine to the necessary quality. Therefore, dried pine must be imported from Oregon at a cost of $1.75/BF (board foot), compared to $.30/BF for undried pine produced in New Mexico (Vincent, 1979). The high cost of imported pine, which threatens the existence of these marginal, small-scale furniture makers, is directly related to the use of natural gas for drying the lumber and of diesel fuel for transporting wood from Oregon to New Mexico.

The kiln consists of a wood-framed shed with walls of corrugated metal. A solar collector adjoining the shed uses halved beer cans to provide the heat exchange surface for heating air. The south and west walls of the kiln are painted black to maximize solar gain. The kiln operates without fans, and air flow is totally by natural convection through vents in the top and bottom of the shed. The kiln has a capacity to produce 10 TBF (thousand board feet) of dried lumber per year given the level of solar insolation in northern New Mexico (Vincent, 1979). However, a typical woodworker in the area requires only 4 TBF annually. This requirement was used as the estimate of the annual production of the kiln.

The kiln saves energy by displacing natural gas that would be used for drying lumber and diesel fuel used for transporting the lumber on a round trip between Oregon and New Mexico. A typical gas kiln will consume 1.8 MBtu of natural gas per 1 TBF of 2-inch ponderosa pine (Argonbright, 1980). According to one lumber wholesaler, a typical lumber truck has a hauling factor of .005 gal/TBF-mi (Gerry, 1980).

Natural gas savings were estimated to be:

(4 TBF/yr)x(1.8 MBtu/TBF) = 7.2 MBtu/yr.

Diesel fuel savings were estimated to be:

* The electrical energy is converted to MBtu by using the thermodynamic equivalence of 1 kWh = 3412.4 Btu = 0.0034124 MBtu. Note that the primary energy savings of the nation are larger than this figure because 3.3 units of primary energy are needed to deliver 1.0 unit of electrical energy because of generation and transmission losses. Thus the direct primary energy savings by this project are (3.3)x(655.2 MBtu) = 2,165 MBtu. This conversion to primary energy units is later expressed in BOE units in Chapter 5.

(7800 mi/round trip)x(4 TBF/yr)x(.005 gal/TBF-mi)x (.14 MBtu/gal) = 20.7 MBtu/yr.

The estimate of AES is 27.9 MBtu/yr, which is the sum of natural gas and diesel fuel savings. Assuming a lifetime of 20 years results in a DES of 558 MBtu.

## RESULTS

Table 1-1, Column 10 lists the DES for all 57 projects. Tables 2-1 and 2-2 summarize the results by technology and project type, respectively. Although other classifications are possible, we believe technology and project type are the two characteristics most likely to be related to project energy savings.

Projects with DES were those that demonstrated or marketed a commercial device or prototype. Most projects without DES were feasibility and laboratory research studies that tested an energy system without using the energy saved. Although these latter projects have no DES, they may have a large energy savings potential through their indirect effects. For example, if a project shows an energy system to be economically and technically feasible, other people might implement similar systems. These spin-off energy savings are considered in Chapter 4 and referred to as indirect energy savings (IES). However, a determination of cost-effectiveness precedes the estimation of IES. The following chapter considers project cost-effectiveness and presents the methods and results of the economic analysis.

Table 2-1

Technology Applied by Projects With and Without Direct Energy Savings

| Technology | With Direct Savings | Without Direct Savings | Total |
|---|---|---|---|
| Solar | 9 | 4 | 13 |
| Conservation | 7 | 5 | 12 |
| Biomass | 6 | 10 | 16 |
| Hydro | 1 | 0 | 1 |
| Geothermal | 1 | 1 | 2 |
| Wind | 9 | 1 | 10 |
| Energy Storage | 1 | 2 | 3 |
| Total | 34 | 23 | 57 |

Table 2-2

Project Type and Direct Energy Savings

| Type of Project* | With Direct Savings | Without Direct Savings | Total |
|---|---|---|---|
| FS | 0 | 5 | 5 |
| LR | 0 | 3 | 3 |
| PCD | 0 | 3 | 3 |
| PSD | 12 | 5 | 17 |
| PTM | 3 | 4 | 7 |
| CSD | 11 | 0 | 11 |
| CSTM | 4 | 2 | 6 |
| COM | 2 | 0 | 2 |
| ED | 2 | 1 | 3 |
| Total | 34 | 23 | 57 |

*See Table 1-1, Key 9, for full description.

# CHAPTER 3

# ECONOMIC ANALYSIS

## INTRODUCTION

This chapter presents the methods for assessing the cost-effectiveness of each project on a life-cycle basis. The results of the economic analysis are used in the next chapter to select projects that can have indirect energy savings (IES). Except in cases where IES have already been achieved, only cost-effective projects are assumed to have them. The economic analysis serves another purpose, that of indicating projects that have an exceptional potential for achieving IES with relatively small amounts of government assistance.

In general, a project is cost-effective if it applies an energy system that generates on a life-cycle basis net revenues equal to or greater than first costs. To make our analysis consistent with others done for DOE, we followed DOE guidelines for conducting a life-cycle cost analysis of energy projects (Ruegg et al., 1978)(Federal Register, 1980). Each project was analyzed on a before-tax basis, and income tax credits and deductions which might affect cost-effectiveness were not considered. The next sections of this chapter cover in detail the methods, key assumptions, and findings of the analysis.

## DEFINITIONS AND METHODS

Life-cycle costing (LCC) was used to evaluate the cost-effectiveness of each project, including all relevant costs and revenues for an energy system over its economic life. The LCC method was applied in four steps.

<u>(1) Estimation of first costs.</u> First costs are the costs of purchasing and installing a small-scale energy system less capital savings from not using a fossil fuel system. Whenever possible, we based first cost on the actual cost of the system. In cases where the project was to develop a prototype system, first costs were estimated either from the grantee's best estimate of what his system would cost when commercially available or from comparisons to similar systems already being marketed. The cost of a commercial system, estimated from the cost of a prototype, was usually less than the grant, which in many cases included costs of design, development, and testing.

<u>(2) Estimation of annual net revenues.</u> Net revenues are the dollar value of energy or other output produced or saved over the life-cycle of a system minus operating, maintenance, and replacement costs. Similar to first costs, these revenues are computed on a net basis, taking into account any savings accrued by the prospective user from not using a fossil fuel alternative.

<u>(3) Conversion of costs and revenues to present values.</u> The costs and revenues considered above occur at different times. To convert these values into time-equivalent amounts, future costs are discounted by a real rate of interest, which reflects the real time value of money. In

other words, future benefits resulting from an investment are worth less to an investor today because he could have invested his funds in an alternative investment for more immediate returns.

To maintain consistency between our analysis and other DOE studies, the following DOE guidelines for conducting an LCC analysis were observed:

- All future costs and revenues are expressed in real 1980 dollars: that is, they are net of inflation (Ruegg et al., 1978).
- Nonenergy costs and revenues are assumed to increase annually at the rate of inflation, i.e., at a 0 percent real rate of increase.
- The real discount rate is 10 percent (Federal Register, 1980).
- Base year energy prices are either the actual price per unit paid by the grantee or regional DOE estimates of energy prices for 1980 (Federal Register, 1980).*
- Energy prices escalate at a real annual rate of from 3 to 5 percent, depending on the region in which the project is located, on the fuel displaced, and on the sector of application (Federal Register, 1980).

<u>(4) Determination of cost-effectiveness.</u> A system is deemed cost-effective if on a life-cycle basis the net present value of before-tax revenues equals or exceeds first costs. As an indicator of cost-effectiveness, the savings-to-investment ratio (SIR), which is the ratio of the net present value of before-tax revenues to first costs, was used. By definition, energy systems with a SIR equal to or greater than 1.0 are cost-effective.

The before-tax SIR is a rough indication of whether a specific energy system that relies on renewable energy resources can compete against a fossil fuel alternative without government subsidies, but is no indication of whether anybody will invest. To determine whether a firm or individual will invest in an energy system requires a detailed analysis of the economic sectors in which the system can be used and of the applicable investment criteria and tax laws. Because many of the projects develop systems that can be applied in more than one sector, economic analysis on an after-tax basis is unduly cumbersome and beyond the scope of this report.

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* The DOE energy prices are average prices paid for each fuel in a specific region. The prices underrate the actual value of the energy savings from each project because they do not measure the marginal cost to the economy of imported oil, which is what each project really displaces. Average market prices also hide tax subsidies, which have kept the prices of fossil fuels artificially low.

THE TWO EXAMPLES

To illustrate how the cost-effectiveness of each project was computed, we return to the two examples introduced in Chapter 2. The computations are described in a paragraph followed by data showing the basic computations.

Example 1

The Marlin Chamber of Commerce building is heated for only 600 hours each year (Johnson, 1980), making the geothermal system economically infeasible. However, such limited use is not typical. Most factories operate for two or three shifts per day. Shopping malls and hotels have daily heating demands of from 18 to 24 hours. Therefore, for the economic analysis, we assumed that a firm with a heating demand of 16 hours per day during a typical heating season (2000 hours per year) had located at the site and had installed a system similar in design and cost to the one installed in the Chamber of Commerce building. The project engineer estimated the cost of the system at $9000 installed (excluding design costs) and operating and maintenance costs to be $100 per year. Annual energy savings (AES) were estimated to be:

AES = (2000 hrs/600hrs)x(32.8 MBtu/yr) = 109.2 MBtu/yr.

The steps and details of our analysis are shown below.

(1) First cost: $9000

(2) Operating and maintenance (O&M) costs: $100

(3) Annual energy savings: 109.2 MBtu

(4) Cost of energy in 1980: $12.16/MBtu

(5) Present value of O&M costs (10 percent discount rate, 0 percent real rate of increase): $850

(6) Present value of energy savings (10 percent discount rate, 5 percent real rate of increase): $14,365

(7) Present value of net revenues [(6)-(5)]: $13,515

(8) SIR [(7)/(1)]: 1.5

Example 2

The first step in estimating cost-effectiveness of the solar kiln was estimating the cost of building a second unit (excludes design cost). The grantee thought that a second unit could be built for $1400 or less because of short cuts he discovered while building the first kiln (Vincent, 1980). The second step was to compute net revenues. In contrast to the geothermal example, net revenues for the solar kiln do not include only direct energy revenues. Instead, the dollar value of energy savings are the annual savings that will accrue to woodworkers from buying green rather than cabinet grade pine and after subtracting operating, maintenance, and replacement costs of the kiln. The savings are substantial - $5800 per year for a woodworker using 4 TBF (thousand board feet) of lumber each year. The data below are used to compute SIR.

(1) First cost: $1400

(2) Gross revenues: $5800

(3) Operating and maintenance costs: $3200

(4) Net revenues [(2)-(3)]: $2600

(5) Life of project: 20 years

(6) Present value of net revenues (10 percent discount rate, 20 year life): $22,125

(7) SIR [(4)/(1)]: 15.8

RESULTS

Table 1-1, Column 11 presents the SIRs for the 57 projects. Tables 3-1 and 3-2 present our findings by technology and project type, respectively. Of the 57 projects, 20 were not evaluated because they either developed an energy system that proved technically infeasible or failed for other reasons. Although these projects failed to accomplish their objectives, they may have been worthwhile investments because they attempted to prove that an energy saving system or concept could work. By investing relatively lightly in these projects, DOE determined that future investments are not justified.

Of the 37 projects evaluated, 19 were found to be cost-effective. SIRs ranged from -4.6 to 53. (Projects with O&M costs greater than net revenues had a negative SIR.) Moreover, a correlation was found between the technology of a project and cost-effectiveness. Many of the solar and conservation projects were cost-effective; of the 25 solar and conservation projects, 10 had a SIR greater than 1 (See Table 3-1).

Wind projects, on the other hand, were poor cost competitors. Of ten wind projects evaluated only one was cost-effective. The one cost-effective project was a wind-electric project located on the Virgin Islands, where electricity rates are very high. (See Table 1-1, VI-7.) The project was located at an apartment complex, and the site had an excellent annual wind regime. The wind generator was small (1.5kW), and the full output was used on site (Graham, 1980).

The uneconomical wind projects are either too small to achieve economies of scale, or they face inadequate demand at the site for the energy produced. Wind electric systems for a single-family home require costly investments in batteries, inverters, voltage control devices, and wiring, in addition to generator and tower costs. System costs are increased even more by zoning restrictions on tower height and by structural requirements for anchoring the tower (Benjamin, 1980). In the case of agricultural water pumping, windmills are underused because of the seasonal demand for irrigation (Goulden, 1980).

Cost-effective projects tend to demonstrate or test an existing commercial system. Because of the speculative nature of cost and operating data for undeveloped systems, we assumed that unless convincing cost data were available, projects in the early stage were not cost-effective. Nevertheless, most of the developers of these early projects made small but significant improvements in understanding the technical requirements of a specific energy system and in developing ways to improve system operations; later the projects may become cost-effective.

To summarize, the economic analysis identified 19 projects that either developed or demonstrated cost-effective systems. The 19 projects will be examined in greater detail in Chapter 4 to determine whether they have indirect energy savings.

Table 3-1

Number of Projects by Technology and Cost-Effectiveness

| Technology | Cost-Effective | Not Cost-Effective | Total |
|---|---|---|---|
| Solar | 5 | 8 | 13 |
| Conservation | 5 | 7 | 12 |
| Biomass | 5 | 11 | 16 |
| Hydro | 1 | 0 | 1 |
| Geothermal | 1 | 1 | 2 |
| Wind | 1 | 9 | 10 |
| Energy Storage | 1 | 2 | 3 |
| Total | 19 | 38 | 57 |

Table 3-2

Number of Projects by Type and Cost-Effectiveness

| Type of Project* | Cost-Effective | Not Cost-Effective | Total |
|---|---|---|---|
| FS | 0 | 5 | 5 |
| LR | 0 | 3 | 3 |
| PCD | 0 | 3 | 3 |
| PSD | 6 | 11 | 17 |
| PTM | 1 | 6 | 7 |
| CSD | 5 | 6 | 11 |
| CSTM | 4 | 2 | 6 |
| COM | 2 | 0 | 2 |
| ED | 0 | 3 | 3 |
| Total | 18 | 39 | 57 |

*See Table 1-1, Key 9, for full description.

# CHAPTER 4

# ASSESSMENT OF INDIRECT ENERGY SAVINGS

## INTRODUCTION

Indirect energy savings (IES) occur as a consequence of either demonstrating or encouraging the commercial development of a particular energy system. This chapter assesses the IES of the 57 projects and discusses project characteristics that effect IES.

Two factors that determine whether a project can have indirect savings are:

(1) the cost-effectiveness of the energy system applied by the project; and

(2) the intent of the grantee or other party to demonstrate or to market the system.

These two factors were accepted as threshold criteria. In other words, if the energy system of a project was judged cost-effective and if the grantee intended to replicate the project system, then the project was evaluated for indirect potential and a value calculated from information supplied by the grantee. The analytic details are presented in the remainder of this chapter. First, the methods are discussed, followed by the two examples illustrating how the methods are applied. The chapter concludes with a presentation of the results of analysis and an interpretion of the significance for the Appropriate Technology Program (AT).

## DEFINITIONS AND METHODS

The IES of a project are the lifetime energy savings from spin-off systems. The spin-offs, referred to as replicate systems, result from demonstrations that induce other people to install similar systems or from direct marketing of the system. We would have preferred to estimate the actual IES, but in most cases, the projects were still being completed and IES had not yet been attained. We therefore estimated only potentials, based on information supplied by the grantees. IES were estimated for 11 projects that met the criteria of cost-effectiveness and publicity and for 4 projects that were not cost-effective but had already achieved IES.

Determining indirect potential was a difficult task for a number of reasons. First, the projects had differing objectives ranging from publicly demonstrating a commercial system to proving the economic and engineering feasiblity of a prototype system. Second, the grantees differed with respect to entrepreneurial spirit, marketing expertise, and capital resources, qualities that greatly affect indirect impact. Third, the projects addressed different markets, audiences, economic sectors, and regional characteristics. Finally, projects had different time frames for achieving indirect impacts. For instance, a solar workshop project tapped its indirect potential during the course of the workshop program, but a project to develop and market an improved wood stove might take much longer. Therefore, to maintain a consistent approach in dealing with diverse conditions, the following procedures were established.

- The time period over which a project could have an indirect impact was limited to five years. Effects beyond five years were treated as unpredictable.

- If the grantee had a clear idea of the indirect potential and the fraction that could be achieved over a five year period, his estimates of IES were relied upon.

- If the grantee had a clear idea of indirect potential but no idea what fraction he could achieve, we assigned a number based on information obtained during the analysis of the project. In cases where this seemed unduly speculative, we assumed that the project achieved one percent of the overall potential each year over a maximum of five years.

More often than not, we had to rely on the last procedure. To guard against overly optimistic estimates, the lower bound of any range of possible values was selected as the estimate of indirect savings for a project. To illustrate how indirect savings were calculated, the geothermal and solar kiln projects introduced in Chapters 2 and 3 are used again.

## THE TWO EXAMPLES

### Example 1

The geothermal project tapped only 1/8th of the flow of the well, and the remainder is available for development (Johnson, 1980). The Marlin Chamber of Commerce will promote the remaining 7/8ths as a source of inexpensive space heat and thus an incentive for new businesses to locate in the town. The economic analysis showed the geothermal heating system to be cost-effective if used for 2000 hours per year or greater. To estimate IES, we assumed

(1) that the Chamber of Commerce is successful in attracting new industry to Marlin;

(2) that some of the businesses locate near the geothermal well and tap its remaining capacity; and

(3) that the new businesses heat their buildings for at least 2000 hours per year.

We estimated in Chapter 3 that 1/8th of the available well flow used 2000 hours per year could displace 109.2 MBtu of electricity annually. With a 20 year life, the system will save 2184 MBtu of electricity (7 x 2184). If the remaining 7/8ths of the well capacity is used for space heating, then the project wil have an indirect savings of 15,288 MBtu of electricity.

Whether new businesses will actually locate in Marlin is unpredictable. Nevertheless, the Chamber is attempting to attract them and is using the geothermal project as a key sales point (Johnson, 1980). Thus, the IES are reasonably certain of being achieved. Furthermore, the estimates do not account for any demonstration effect that the project may have on nearby communities that might also have a geothermal resource.

Example 2

The solar kiln is highly cost-effective. The grantee has developed a mailing list and intends to have an open house for local woodworkers to show them samples of the dried lumber, how the kiln was constructed, and how it operates (Vincent, 1980). The grantee estimates that northern New Mexico has at least 300 small woodworkers who could operate a solar kiln profitably. Whether they will construct kilns will depend on their available capital and their willingness to invest the time for both construction and operation. Thus, we assumed that 15 kilns would be built over the next five years, which is equal to 1 percent of the 300 woodworkers per year for five years. Our assumption may be overly conservative because the kiln has a very short payback, is simple to build and operate, and may spread to other areas of the country if plans and operating manuals are widely disseminated. Also, five years is at the low end of the range of possibilities.

## RESULTS

Table 1-1, Column 12 presents estimates of IES for the 57 projects. Comparing projects with and without IES shows that projects with IES mostly demonstrate solar, conservation, and biomass technologies. All wind projects except one have very low SIRs and thus do not have IES. Another finding is that only 15 of 57 projects were judged to have the potential to achieve IES. Further, 8 of the 15 projects accounted for almost all of the energy savings, direct and indirect, of the sample.*

However, this finding does not suggest that DOE could have maximized energy savings potential by investing all the money in these eight projects. DOE funded some projects that may yet develop into major energy savers as they move from early stages of development toward commercialization. By providing early support for these projects, DOE may induce large energy savings in the future, although we have avoided speculating about such possibilities. Furthermore, even outright failures provide useful technical information. By supporting risky projects at an early stage of development, DOE reduces the energy saving potential of this particular program, but also achieves the important program goal of developing renewable energy technologies.

* CA-390, LA-132, IL-206, PA-6, VA-180, OH-478, IA-6, and ME-903.

Even if it were advisable, DOE could not select in advance grants with large energy savings because of the large number of proposals to be evaluated each year. In FY 1979, for example, 20,000 proposals were received and 500 were funded. Instead of judging effectiveness based on total energy savings, the overall performance of the program should be measured in terms of energy saved per dollar of DOE funding as a better indication of whether DOE selected projects that gave the country a high return on the tax dollar. With Chapter 5 we turn to the issue of program energy savings and the "real" cost-effectiveness of AT.

Table 4-1

Number of Projects by Technology With and Without Indirect Savings

| Technology | With Indirect Savings | Without Indirect Savings | Total |
|---|---|---|---|
| Solar | 6 | 7 | 13 |
| Conservation | 5 | 7 | 12 |
| Biomass | 2 | 14 | 16 |
| Hydro | 1 | 0 | 1 |
| Geothermal | 1 | 1 | 2 |
| Wind | 1 | 9 | 10 |
| Energy Storage | 0 | 3 | 3 |
| Total | 16 | 41 | 57 |

Table 4-2

Number of Projects by Type With and Without Indirect Savings

| Type of Project* | With Indirect Savings | Without Indirect Savings | Total |
|---|---|---|---|
| FS | 0 | 5 | 5 |
| LR | 0 | 3 | 3 |
| PCD | 0 | 3 | 3 |
| PSD | 5 | 12 | 17 |
| PTM | 4 | 3 | 7 |
| CSD | 2 | 9 | 11 |
| CSTM | 2 | 4 | 6 |
| COM | 1 | 1 | 2 |
| ED | 2 | 1 | 3 |
| Total | 16 | 41 | 57 |

*See Table 1-1, Key 9, for full description.

# CHAPTER 5

# ESTIMATING PROGRAM ENERGY SAVINGS

## INTRODUCTION

From the analysis of the 57 projects, we inferred the energy savings potential of the program in FY 1979. The information presented in this chapter can serve two purposes. First, the savings data can help DOE evaluate and improve the program. Second, DOE can apply the methods of analysis in future studies of energy impacts made by small-scale technologies. The chapter is divided into two sections. The first section describes the methods and limitations of the methods used to estimate program energy savings. The second suggests ways to increase program energy savings and provides direction for future analyses.

## METHODS OF ESTIMATION

Compared to project savings, program savings are a more difficult and speculative calculation. The approach is separated into three steps: sample selection, statistical inference, and estimation of program energy savings.

### Sample Selection

As mentioned earlier, either simple or stratified random sampling should have been used to select an unbiased sample (Cochran, 1977, p.11), but we used judgment sampling, which refers to selection based on someone's judgment that projects chosen are representative of the population.* We chose the sample from project summary booklets prepared by each regional program office. From the summary booklets, which provide a short description of each project, between 10 and 15 projects were selected from each region except IV, VIII, and IX.

The initial sample was 86 projects of which 57 were evaluated for the study. Twenty-nine projects were dropped from the study because of the deadline and not because of high or low energy savings potential. Because the project summaries were brief and contained no information concerning energy saving potential, we are confident that the sample has not been intentionally biased.

However, because nonrandom sample selection can contain unintentional selection bias, the use of probability theory is unjustified, and formal statistical inferences cannot be made about the population (Freedman, et al., 1978, p. 350). However, the estimates presented in Chapters 2 and 4 do provide the basis for an educated guess about program energy savings and, being the best data presently available, are used for this purpose.

* Simple random sampling should be used to select an unbiased sample from a homogeneous population. Random selection is done by reference to a random numbers table. If a population is not homogeneous, stratified random sampling helps to reduce variation between strata and produces large gains in precision.

## Statistical Inference

To provide a measure of energy saving effectiveness for the sample, the sum of DES and IES was converted into barrels of oil equivalent (BOE) and divided by DOE funding (in $1000s). Energy losses in generating and transmitting energy to the user were accounted for and the figure divided by 5.8 MBtu, which is the Btu equivalent of a barrel of oil. Projects displacing electricity were multiplied by the factor 3.3, which accounts for the energy lost in generating and transmitting electricity from a fossil fuel power plant. For projects displacing natural gas and liquid fuels, the factor 1.1 was used.

Because the sample size is reasonably large, the distribution of the sample mean can be approximated by a normal distribution. On this assumption, the sample mean of the energy effectiveness indicator and its standard error were computed, and confidence intervals around the mean at three confidence levels, 50, 75, and 90 percent, were constructed.

To compute the mean of the indicator R, which is the ratio of sample energy savings to total DOE funding, the following equation was used (Cochran, p.31):

$$\hat{R} = \frac{\sum_{i=1}^{57} BOE_i}{\sum_{i=1}^{57} f_i} = \frac{\overline{BOE}}{\overline{f}}$$

where:

$\hat{R}$ = mean of R

$BOE_i$ = sum of DES and IES in barrels of oil equivalent for the ith project

$f_i$ = DOE funding in $1000s for ith project

The standard error of the sample mean was computed from (Cochran, p. 32):

$$S(\hat{R}) = \frac{\sqrt{1 - \frac{n}{N}}}{\sqrt{n}\,\overline{f}} \sqrt{\frac{\Sigma(BOE_i - \hat{R}f_i)^2}{n - 1}}$$

where:

$S(\hat{R})$ = standard error of the sample mean

N = population size

$(1 - n/N)$ = population correction factor

To compute confidence intervals around the sample mean, the following formula was used (Wonnacott and Wonnacott, 1972, pp. 141-147):

$$\hat{R} \pm Z\ S(\hat{R})$$

where:

Z = number of standard deviations from the sample mean that the interval must extend at a given confidence level

The confidence intervals for this study measure the limits of the energy saving potential per $1000 of DOE funding. The level of confidence within these limits is expressed as the probability that the population mean will fall in the interval about the sample mean (Freedman, et al., 1978, p. 345). For instance, a 75 percent confidence interval has a probability of 75 percent of containing the population mean.

<u>Program Energy Savings</u>

The results of the sample analysis are presented in Tables 5-1 and 5-2. Table 5-1 shows at different confidence levels the interval within which the population mean can be found. At a 75 percent confidence level, the population mean is somewhere between 1190 and 4520 BOE per $1000.* The reciprocal of the mean multiplied by $1000 is the amount of DOE investment (in 1979 dollars) per BOE of energy savings potential for all projects funded in FY 1979. At a 75 percent confidence level, the value ranges from $.20 to $.85 per BOE (See Table 5-2).**

To estimate program energy savings, the sample mean was multiplied by the total FY 1979 grant funding of $8 million in $1000s. The sample mean was therefore multiplied by 8000, and the estimated program savings were then converted into confidence intervals at the 50, 75,and 90 percent levels (See Table 5-2). The results of the analysis can be summarized as follows.

- Projects funded in FY 1979 can save 22.8 million BOE of energy over the lifetimes of the project energy systems and replicate systems if the sample mean, $\hat{R}$, is the same as the mean of the population.

- The program can save 1.2 million BOE of energy annually by 1985. Annual savings were computed by dividing BOE savings for each project by the lifetime of the energy system. Because five years is the maximum period over which IES were considered, the full annual savings will occur five years after project completion.

* BOE per $1000 = barrels of oil equivalent energy savings per $1000 of DOE funding.

** The inexpensive oil results from the use of DOE money as a catalyst to encourage others to replicate an energy system. In our definition of energy savings, we credit the DOE project with these savings.

TABLE 5-1

Confidence Intervals for Sample Energy Savings

at the 90%, 75%, and 50% Probability Levels

| Confidence Level | Sample Mean ($\hat{R}$) | Standard Error of Sample Mean $S(\hat{R})$ | Z Value | Confidence Interval |
|---|---|---|---|---|
| 90% | 2855 | 1445 | 1.64 | $2855 \pm 2375$ |
| 75% | 2855 | 1445 | 1.15 | $2855 \pm 1665$ |
| 50% | 2855 | 1445 | .68 | $2855 \pm 985$ |

TABLE 5-2

Estimates of Energy Saving Effectiveness and Program Energy Savings

at Three Confidence Levels (90%, 75%, and 50%)

| Confidence Level | Range of Values (BOE/$1000 DOE Funding) | DOE Investment per Potential Barrels of Oil Savings | Program Energy Savings (Million BOE) |
|---|---|---|---|
| 90% | 485 to 5225 | $.19 to $2.05 | 3.9 to 41.8 |
| 75% | 1195 to 4515 | $.20 to $ .85 | 9.6 to 36.1 |
| 50% | 1870 to 3840 | $.25 to $ .55 | 15.0 to 30.7 |

Table 5-2 presents estimates of program energy savings at the three confidence levels. For example, at a 75 percent confidence level, program energy savings range from 9.6 million to 36 million BOE.

## IMPROVING PROGRAM ENERGY SAVINGS

These estimates of program energy savings apply only to those projects funded in FY 1979, of course. Also, in this study those projects involved in the development or demonstration of a commercial system had far greater energy savings potential than others, such as laboratory research and education projects. However, to attempt to maximize program energy savings by favoring commercial over R&D and education projects would violate the philosophy and intent of the program. While we do not recommend changing the philosophy, we wish to emphasize that a trade-off is being made when program managers must select projects that meet objectives such as R&D, information dissemination, and public demonstration rather than commercial projects with large energy saving potentials. Therefore, the program should not be judged by its energy savings potential alone but by the multiple objectives set for it by Congress. Nevertheless, even within this context, opportunities do exist for improving the quality and for maximizing the energy impacts of selected projects. Below are four ways in which DOE can improve project energy savings.

### (1) Require outreach plans.

A number of projects developed promising energy systems but contained no plan to commercialize or demonstrate the system. To ensure that these good projects have significant energy impacts, DOE should require of all grantees proposing to develop, test, or demonstrate commercial systems a statement that describes their plans for commercialization or demonstration. In cases where the grantee does not provide an adequate plan, DOE should consider whether the project has sufficient public benefit to merit funding.

### (2) Increase project accountability.

Some grantees reduced the scope of their projects after receiving government funding, sometimes in response to inflation and problems in purchasing and installing equipment. In other cases, reduction was necessary because of sloppiness in conceptualizing the proposal and implementing the project. DOE could reduce the number of such projects by emphasizing that each grantee will be held accountable for the specific work agreement laid out in the proposal. Coupled with ongoing monitoring, emphasis on accountability should minimize the funding of projects that cannot deliver what they promise.

### (3) Provide additional funding to high potential projects.

A few projects tended to account for most of the energy savings potential. In fact, eight projects accounted for almost all of the savings. These high potential projects could have an even higher potential if DOE were to provide additional funding to speed up the process of commercialization and product development. The one-year grant is inadequate in many cases to bring a fledgling energy system or concept from the prototype design or even from the commercial testing stage to a point where mass marketing is feasible. We recognize that the suggestion to establish a recurrent funding for promising projects is not a new idea and may violate existing statutes. Yet, such a program is necessary, and we emphasize the need, hoping that legislation can be enacted to start such a program.

(4) Disseminate information on project results

To speed up the process of technology transfer, DOE should implement a program to disseminate the results of successful projects at low cost to the public. The program should include: (1) identification of audiences or markets for the project results, and (2) effective packaging of project results to answer technical questions about equipment requirements, operating specifications, costs, installation and performance results.

## DIRECTIONS FOR FUTURE RESEARCH

Additional research is needed to determine program potential more precisely. Two approaches possible are

(1) statistically inferring program energy savings from a random sample of projects; and

(2) estimating program energy savings from a population subgroup with high energy savings.

### Statistical Inference

One option for a future energy study is to select a random sample of projects from the population grants funded and to duplicate the statistical analyses applied in this study. With a random sample, the population means and intervals about the sample mean at certain levels of probability can be estimated with a reasonable degree of scientific objectivity.

Two approaches to random sampling need to be considered, simple random sampling and stratified random sampling. As explained above, stratified random sampling might help improve the precision of the population estimates by reducing the variance between strata (Cochran, p.101). DOE is developing an information management system that will contain detailed data on all projects funded by AT. Once completed, the system will facilitate the selection of stratified random samples.

The usefulness of a second statistical analysis can be determined only after consultation with DOE officials concerning acceptable levels of confidence and ranges for population estimates. Then the size sample necessary to achieve the desired confidence and range and the approximate cost of conducting the analysis can be determined; whereupon, DOE can decide whether statistical methods are a cost-effective tool for evaluating program energy savings.

Subjective Sampling

A second, less scientific approach would be to select a small sample of projects (less than 30) that are judged by regional program managers and LBL researchers to have large saving potential. These projects would be evaluated for total energy savings and the estimates used as a lower bound of program energy savings for that particular funding cycle. The weakness of this approach is that savings cannot be confidently extrapolated to future years and to a diverse population strata. Nevertheless, the data may be adequate for DOE to make policy decisions and can be compiled at a lower cost than can data from a statistical analysis using a large sample.

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