

3

Economics Methods

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3.1 Introduction

Economic-evaluation methods facilitate comparisons among energy technology investments. Generally, the same methods can be used to compare investments in energy supply or energy efficiency. All sectors of the energy community need guidelines for making economically efficient energy-related decisions.

This chapter provides an introduction to some basic methods that are helpful in designing and sizing cost-effective systems, and in determining whether it is economically efficient to invest in specific energy efficiency or renewable energy projects. The targeted audience includes analysts, architects, engineers, designers, builders, codes and standards writers, and government policy makers—collectively referred to as the *design community*.

The focus is on microeconomic methods for measuring cost-effectiveness of individual projects or groups of projects, with explicit treatment of uncertainty. The chapter does not treat macroeconomic methods and national market-penetration models for measuring economic impacts of energy efficiency and renewable energy investments on the national economy. It provides sufficient guidance for computing measures of economic performance for relatively simple investment choices, and it provides the fundamentals for dealing with complex investment decisions.

3.2 Making Economically Efficient Choices¹

Economic-evaluation methods can be used in a number of ways to increase the economic efficiency of energy-related decisions. There are methods that can be used to obtain the largest possible savings in energy costs for a given energy budget; there are methods that can be used to achieve a targeted reduction in energy costs for the lowest possible efficiency/renewable energy investment; and there are methods that can be used to determine how much it pays to spend on energy efficiency and renewable energy to lower total lifetime costs, including both investment costs and energy cost savings.

The first two ways of using economic-evaluation methods (i.e., to obtain the largest savings for a fixed budget and to obtain a targeted savings for the lowest budget) are more limited applications than the third, which aims to minimize total costs or maximize NB (net savings) from expenditure on energy efficiency and renewables. As an example of the first, a plant owner may budget a specific sum of money for the purpose of retrofitting the plant for energy efficiency. As an example of the second, designers may be required by state or federal building standards and/or codes to reduce the design energy loads of new buildings below some specified level. As an example of the third, engineers may be required by their clients to include, in a production plant, those energy efficiency and renewable energy features that will pay off in terms of lower overall production costs over the long run.

Note that economic efficiency is not necessarily the same as engineering thermal efficiency. For example, one furnace may be more “efficient” than another in the engineering technical sense, if it delivers more units of heat for a given quantity of fuel than another. Yet it may not be economically efficient if the first cost of the higher-output furnace outweighs its fuel savings. The focus in this chapter is on economic efficiency, not technical efficiency.

Economic efficiency is illustrated conceptually in Figure 3.1 through Figure 3.3 with an investment in energy efficiency. Figure 3.1 shows the level of energy conservation, Q_c , that maximizes NB from energy conservation, i.e., the level that is most profitable over the long run. Note that it is the point at which the curves are most distant from one another.

Figure 3.2 shows how “marginal analysis” can be used to find the same level of conservation, Q_c , that will yield the largest NB. It depicts changes in the total benefits and cost curves (i.e., the derivatives of the curves in Figure 3.1) as the level of energy conservation is increased. The point of intersection of the marginal curves coincides with the most profitable level of energy conservation indicated in Figure 3.1. This is the point at which the cost of adding one more unit of conservation is just equal to the corresponding benefits in terms of energy savings (i.e., the point at which “marginal costs” and “marginal benefits” are equal). To the left of the point of intersection, the additional benefits from increasing the level of conservation by another unit are greater than the additional costs, and it pays to invest more. To the right of the point of intersection, the costs of an addition to the level of conservation exceed the benefits and the level of total NB begins to fall, as shown in Figure 3.1. Figure 3.3 shows that the most economically efficient level of energy conservation, Q_c , is that for which the total cost curve is at a minimum.

The most economically efficient level of conservation, Q_c , is the same in Figure 3.1 through Figure 3.3. Three different approaches to finding Q_c are illustrated: (1) finding the maximum difference between

¹This section is based on a treatment of these concepts provided by Marshall and Ruegg in *Economics of Solar Energy and Conservation Systems*, Kreith and West, ed., CRC Press, 1980.

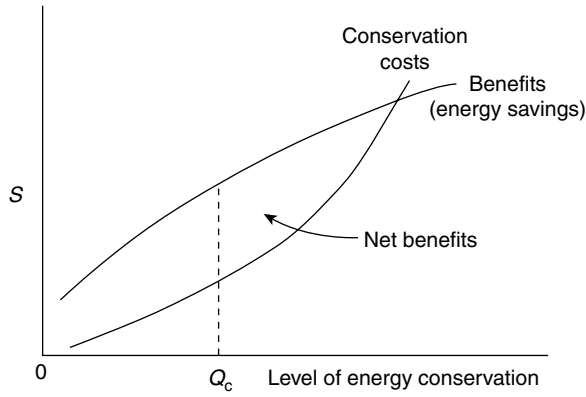


FIGURE 3.1 Maximizing net benefits.

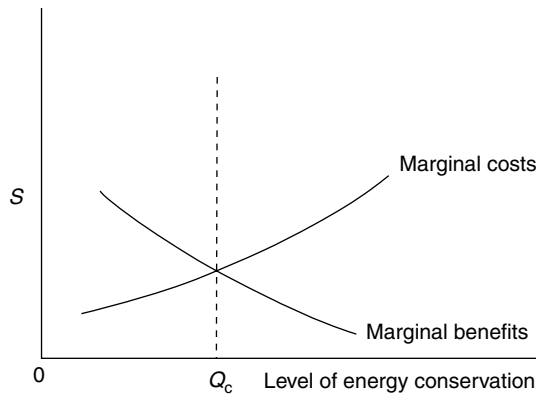


FIGURE 3.2 Equating marginal benefits and marginal costs.

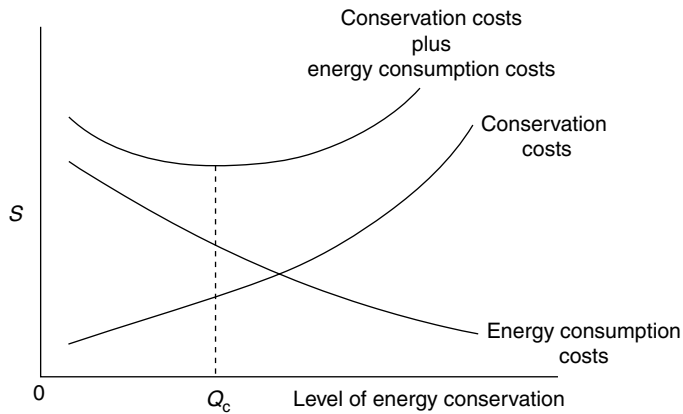


FIGURE 3.3 Minimizing life-cycle costs.

benefits and costs, (2) finding the point where marginal benefits equal marginal costs, and (3) finding the lowest life-cycle costs (LCCs).

3.3 Economic-Evaluation Methods²

There are a number of closely related, commonly used methods for evaluating economic performance. These include the LCC method, levelized cost of energy, NB (net present worth) method, benefit-cost (or savings-to-investment) ratio method, internal rate-of-return method, overall rate-of-return method, and payback method. All of these methods are used when the important effects can be measured in dollars. If incommensurable effects are critical to the decision, it is important that they also be taken into account. But, because only quantified effects are included in the calculations for these economic methods, unquantified effects must be treated outside the models. Brief treatments of the methods are provided; some additional methods are identified but not treated. For more comprehensive treatments, see Ruegg and Marshall (1990) and other sources listed at the end of the chapter.

3.3.1 Life-Cycle Cost Method

The life-cycle costing (LCC) method sums, for each investment alternative, the costs of acquisition, maintenance, repair, replacement, energy, and any other monetary costs (less any income amounts, such as salvage value) that are affected by the investment decision. The time value of money must be taken into account for all amounts, and the amounts must be considered over the relevant period. All amounts are usually measured either in present value or annual value dollars. This is discussed later under “Discounting” and “Discount Rate.” At a minimum, for comparison, the investment alternatives should include a “base-case” alternative of not making the energy efficiency or renewable investment, and at least one case of an investment in a specific efficiency or renewable system. Numerous alternatives may be compared. The alternative with the lowest LCC that meets the investor’s objective and constraints is the preferred investment.

Following is a formula for finding the LCCs of each alternative:

$$LCC_{A1} = I_{A1} + E_{A1} + M_{A1} + R_{A1} - S_{A1}, \quad (3.1)$$

where LCC_{A1} is the life-cycle cost of alternative A1, I_{A1} is the present-value investment costs of alternative A1, E_{A1} is the present-value energy costs associated with alternative A1, M_{A1} is the present-value nonfuel operating and maintenance cost of A1, R_{A1} is the present-value repair and replacement costs of A1, and S_{A1} is the present-value resale (or salvage) value less disposal cost associated with alternative A1.

The LCC method is particularly useful for decisions that are made primarily on the basis of cost effectiveness, such as whether a given energy efficiency or renewable energy investment will lower total cost, (e.g., the sum of investment and operating costs). It can be used to compare alternative designs or sizes of systems, as long as the systems provide the same service. The method, if used correctly, can be used to find the overall cost-minimizing combination of energy efficiency investments and energy supply investments within a given facility. However, in general, it cannot be used to find the best investment, because totally different investments do not provide the same service.

3.3.2 Levelized Cost of Energy

The levelized cost of energy (LCOE) is similar to the LCC method, in that it considers all the costs associated with an investment alternative and takes into account the time value of money for the analysis period. However, it is generally used to compare two alternative energy supply technologies or systems,

²These methods are treated in detail in Ruegg and Marshall *Building Economics: Theory and Practice*, Chapman and Hall, New York, NY, 1990.

e.g., two electricity production technologies. It differs from the LCC in that it usually considers taxes, but like LCC, it frequently ignores financing costs.

The LCOE is the value that must be received for each unit of energy produced to ensure that all costs and a reasonable profit are made. Profit is ensured by discounting future revenues at a discount rate that equals the rate of return that might be gained on other investments of comparable risk, i.e., the opportunity cost of capital. In equation form, this is represented as:

$$\sum_{t=1}^{t=N} \text{LCOE} * Q_t / (1 + d')^t = \sum_{t=0}^{t=N} C_t / (1 + d)^t, \quad (3.2)$$

where N is the analysis period, Q_t is the amount of energy production in period t , C_t is the cost incurred in period t , d' is the discount rate or opportunity cost of capital. If d' is a real discount rate (excludes inflation) then the LCOE will be in real (constant) dollar terms, whereas the LCOE will be in nominal (current) dollar terms if d' is a nominal discount rate. The discount rate, d , is used to bring future costs back to their present value. If those costs are expressed in real dollars, then the discount rate should be a real discount rate; if they are in nominal dollars, the discount rate should be a nominal discount rate.

3.3.3 Net Present Value or Net Benefits Method

The net present value (NPV) method finds the excess of benefits over costs, where all amounts are discounted for their time value. (If costs exceed benefits, net losses result.)

The NPV method is also often called the *net present worth* or *net savings* method. When this method is used for evaluating a cost-reducing investment, the cost savings are the benefits, and it is often called the *net savings* (NS) method.

Following is a formula for finding the NPV from an investment, such as an investment in energy efficiency or renewable energy systems:

$$\text{NPV}_{A1:A2} = \sum_{t=0}^N \frac{(B_t - C_t)}{(1 + d)^t}, \quad (3.3)$$

where $\text{NPV}_{A1:A2}$ is NB, i.e., present value benefits (savings) net of present value costs for alternative A1 as compared with alternative A2, B_t is benefits in year t , which may be defined to include energy savings, C_t is costs in year t associated with alternative A1 as compared with a mutually exclusive alternative A2, and d is the discount rate.

The NPV method is particularly suitable for decisions made on the basis of long-run profitability. The NPV (NB) method is also useful for deciding whether to make a given investment and for designing and sizing systems. It is not very useful for comparing investments that provide different services.

3.3.4 Benefit-to-Cost Ratio or Savings-to-Investment Ratio Method

The benefit-to-cost ratio (BCR) or savings-to-investment ratio (SIR) method divides benefits by costs or by savings by investment. When used to evaluate energy efficiency and renewable energy systems, benefits are in terms of energy cost savings. The numerator of the SIR ratio is usually constructed as energy savings, net of maintenance and repair costs; and the denominator as the sum of investment costs and replacement costs less salvage value (capital cost items). However, depending on the objective, sometimes only initial investment costs are placed in the denominator and the other costs are subtracted in the numerator—or sometimes only the investor's equity capital is placed in the denominator. As with the three preceding methods, this method is based on discounted cash flows.

Unlike the three preceding methods that provided a performance measure in dollars, this method gives the measure as a dimensionless number. The higher the ratio, the more dollar savings realized per dollar of investment.

Following is a commonly used formula for computing the ratio of savings-to-investment costs:

$$SIR_{A1:A2} = \frac{\sum_{t=0}^N [CS_t(1+d)^{-t}]}{\sum_{t=0}^N (I_t(1+d)^{-t})}, \quad (3.4)$$

where $SIR_{A1:A2}$ is the SIR for alternative A1 relative to mutually exclusive alternative A2, CS_t is the cost savings (excluding those investment costs in the denominator) plus any positive benefits of alternative A1 as compared with mutually exclusive alternative A2, and I_t is the additional investment costs for alternative A1 relative to A2.

Note that the particular formulation of the ratio with respect to the placement of items in the numerator or denominator can affect the outcome. One should use a formulation appropriate to the decision maker's objectives.

The ratio method can be used to determine whether or not to accept or reject a given investment on economic grounds. It also can be used for design and size decisions and other choices among mutually exclusive alternatives, if applied incrementally (i.e., the investment and savings are the difference between the two mutually exclusive alternatives). A primary application of the ratio method is to set funding priorities among projects competing for a limited budget. When it is used in this way—and when project costs are “lumpy” (making it impossible to fully allocate the budget by taking projects in order according to the size of their ratios)—SIR should be supplemented with the evaluation of alternative sets of projects using the NPV or NB method.

3.3.5 Internal Rate-of-Return Method

The internal rate-of-return (IRR) method solves for the discount rate for which dollar savings are just equal to dollar costs over the analysis period; that is, the rate for which the NPV is zero. This discount rate is the rate of return on the investment. It is compared to the investor's minimum acceptable rate of return to determine whether the investment is desirable. Unlike the preceding three techniques, the internal rate of return does not call for the inclusion of a prespecified discount rate in the computation; rather, it solves for a discount rate.

The rate of return is typically calculated by a process of trial and error, by which various compound rates of interest are used to discount cash flows until a rate is found for which the NPV of the investment is zero. The approach is the following: (1) Compute NPV using Equation 3.3, except substitute a trial interest rate for the discount rate, d , in the equation. A positive NPV means that the IRR is greater than the trial rate; a negative NPV means that the IRR is less than the trial rate. (2) Based on the information, try another rate. (3) By a series of iterations, find the rate at which NPV equals zero.

Computer algorithms, graphical techniques, and—for simple cases—discount-factor tabular approaches, are often used to facilitate IRR solutions (Ruegg and Marshall 1990:7172). Expressing economic performance as a rate of return can be desirable for ease in comparing the returns on a variety of investment opportunities, because returns are often expressed in terms of annual rates of return. The IRR method is useful for accepting or rejecting individual investments or for allocating a budget. For designing or sizing projects, the IRR method, like the SIR, must be applied incrementally. It is not recommended for selecting between mutually exclusive investments with significantly different lifetimes (e.g., a project with a 35% return for 20 years is a much better investment than a project with the same 35% return for only two years).

It is a widely used method, but it is often misused, largely due to shortcomings that include the possibility of:

- No solution (the sum of all nondiscounted returns within the analysis period are less than the investment costs)
- Multiple solution values (some costs occur later than some of the returns)

- Failure to give a measure of overall return associated with the project over the analysis period (returns occurring before the end of the analysis are implicitly assumed to be reinvested at the same rate of return as the calculated IRR; this may or may not be possible)

3.3.6 Overall Rate-of-Return Method

The overall rate-of-return (ORR) method corrects for the last two shortcomings expressed above for the IRR. Like the IRR, the ORR expresses economic performance in terms of an annual rate of return over the analysis period. But unlike the IRR, the ORR requires, as input, an explicit reinvestment rate on interim receipts and produces a unique solution value.³ The explicit reinvestment rate makes it possible to express net cash flows (excluding investment costs) in terms of their future value at the end of the analysis period. The ORR is then easily computed with a closed-form solution as shown in Equation 3.5:

$$ORR_{A1:A2} = \frac{\left[\sum_{t=0}^N (B_t - C_t)(1 + r)^{N-t} \right]^{1/N}}{\left[\sum_{t=0}^N I_t / (1 + r)^t \right]^{1/N}} - 1, \tag{3.5}$$

where $ORR_{A1:A2}$ is the overall rate of return on a given investment alternative A1 relative to a mutually exclusive alternative over a designated study period, B_t represents the benefits from a given alternative relative to a mutually exclusive alternative A2 over time period t , C_t is the costs (excluding that part of investment costs on which the return is to be maximized) associated with a given alternative relative to a mutually exclusive alternative A2 over time t , r is the reinvestment rate at which net returns can be reinvested, usually set equal to the discount rate, N is the length of the study period, and I_t represents the investment costs in time t on which the return is to be maximized.

The ORR is recommended as a substitute for the IRR, because it avoids some of the limitations and problems of the IRR. It can be used for deciding whether or not to fund a given project, for designing or sizing projects (if it is used incrementally), and for budget-allocation decisions.

3.3.7 Discounted Payback Method

This evaluation method measures the elapsed time between the time of an initial investment and the point in time at which accumulated discounted savings or benefits—net of other accumulated discounted costs—are sufficient to offset the initial investment, taking into account the time value of money. (If costs and savings are not discounted, the technique is called “simple payback.”) For the investor who requires a rapid return of investment funds, the shorter the length of time until the investment pays off, the more desirable the investment.

To determine the discounted payback method (DPB) period, find the minimum value of Y (year in which payback occurs) such that the following equality is satisfied.

$$\sum_{t=1}^Y (B_t - C'_t) / (1 + d)^t = I_0, \tag{3.6}$$

where B_t represents the benefits associated in period t with one alternative as compared with a mutually exclusive alternative, C'_t is the costs in period t (not including initial investment costs) associated with an alternative as compared with a mutually exclusive alternative in period t , and I_0 is the initial investment

³As shown in Equation 3.5, the reinvestment rate is also used to bring all investments back to their present value. Alternatively, investments after time zero can be discounted by the overall growth rate. In this case, a unique solution is not guaranteed, and the ORR must be found iteratively (Stermole and Stermole 2000).

costs of an alternative as compared with a mutually exclusive alternative, where the initial investment cost comprises total investment costs.

DPB is often (correctly) used as a supplementary measure when project life is uncertain. It is used to identify feasible projects when the investor's time horizon is constrained. It is used as a supplementary measure in the face of uncertainty to indicate how long capital is at risk. It is a rough guide for accept/reject decisions. It is also overused and misused. Because it indicates the time at which the investment just breaks even, it is not a reliable guide for choosing the most profitable investment alternative, as savings or benefits after the payback time could be significant.

3.3.8 Other Economic-Evaluation Methods

A variety of other methods have been used to evaluate the economic performance of energy systems, but these tend to be hybrids of those presented here. One of these is the required revenue method that computes a measure of the before-tax revenue in present or annual-value dollars required to cover the costs on an after-tax basis of an energy system (Ruegg and Short 1988:2223). Mathematical programming methods have been used to evaluate the optimal size or design of projects, as well as other mathematical and statistical techniques.

3.4 Risk Assessment

Many of the inputs to the above evaluation methods will be highly uncertain at the time an investment decision must be made. To make the most informed decision possible, an investor should employ these methods within a framework that explicitly accounts for risk and uncertainty.

Risk assessment provides decision makers with information about the "risk exposure" inherent in a given decision, i.e., the probability that the outcome will be different from the "best-guess" estimate. Risk assessment is also concerned with the *risk attitude* of the decision maker that describes his/her willingness to take a chance on an investment of uncertain outcome. Risk assessment techniques are typically used in conjunction with the evaluation methods outlined earlier; and not as stand-alone evaluation techniques.

The risk assessment techniques range from simple and partial to complex and comprehensive. Though none takes the risk out of making decisions, the techniques—if used correctly—can help the decision maker make more informed choices in the face of uncertainty.

This chapter provides an overview of the following probability-based risk assessment techniques:

- Expected value analysis
- Mean-variance criterion and coefficient of variation
- Risk-adjusted discount rate technique
- Certainty equivalent technique
- Monte Carlo simulation
- Decision analysis
- Real options
- Sensitivity analysis

There are other techniques that are used to assess risks and uncertainty (e.g., CAP_M, and break-even analysis), but those are not treated here.

3.4.1 Expected Value Analysis

Expected value (EV) analysis provides a simple way of taking into account uncertainty about input values, but it does not provide an explicit measure of risk in the outcome. It is helpful in explaining and illustrating risk attitudes.

3.4.1.1 How to Calculate EV

An *expected value* is the sum of the products of the dollar value of alternative outcomes and their probabilities of occurrence. That is, where a_i ($i=1, \dots, n$) indicates the value associated with alternative outcomes of a decision, and p_i indicates the probability of occurrence of alternative a_i , the EV of the decision is calculated as follows:

$$EV = a_1p_1 + a_2p_2 + \dots + a_np_n. \tag{3.7}$$

3.4.1.2 Example of EV Analysis

The following simplified example illustrates the combining of EV analysis and NPV analysis to support a purchase decision.

Assume that a not-for-profit organization must decide whether to buy a given piece of energy-saving equipment. Assume that the unit purchase price of the equipment is \$100,000, the yearly operating cost is \$5,000 (obtained by a fixed-price contract), and both costs are known with certainty. The annual energy cost savings, on the other hand, are uncertain, but can be estimated in probabilistic terms as shown in Table 3.1 in the columns headed a_1 , p_1 , a_2 , and p_2 . The present-value calculations are also given in Table 3.1.

If the equipment decision were based only on NPV, calculated with the “best-guess” energy savings (column a_1), the equipment purchase would be found to be uneconomic. But if the possibility of greater energy savings is taken into account by using the EV of savings rather than the best guess, the conclusion is that, over repeated applications, the equipment is expected to be cost effective. The expected NPV of the energy-saving equipment is \$25,000 per unit.

3.4.1.3 Advantages and Disadvantages of the EV Technique

An advantage of the technique is that it predicts a value that tends to be closer to the actual value than a simple “best-guess” estimate over repeated instances of the same event, provided, of course, that the input probabilities can be estimated with some accuracy.

A disadvantage of the EV technique is that it expresses the outcome as a single-value measure, such that there is no explicit measure of risk. Another is that the estimated outcome is predicated on many replications of the event, with the EV, in effect, a weighted average of the outcome over many like events. But the EV is unlikely to occur for a single instance of an event. This is analogous to a single coin toss: the outcome will be either heads or tails, not the probabilistic-based weighted average of both.

TABLE 3.1 Expected Value Example

Year	Equipment Purchase (\$1000)	Operating Costs (\$1000)	Energy Savings				PV ^a Factor	PV (\$1000)
			A_1 (\$1000)	P_1	A_2 (\$1000)	P_2		
0	-100	—	—	—	—	—	1	-100
1		-5	25	0.8	50	0.2	0.926	23
2		-5	30	0.8	60	0.2	0.857	27
3		-5	30	0.7	60	0.3	0.794	27
4		-5	30	0.6	60	0.4	0.7354	27
5		-5	30	0.8	60	0.2	0.681	21
Expected Net Present Value:								25

^a Present value calculations are based on a discount rate of 8%. Probabilities sum to 1.0 in a given year.

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3.4.1.4 Expected Value and Risk Attitude

Expected values are useful in explaining risk attitude. Risk attitude may be thought of as a decision maker’s preference between taking a chance on an uncertain money payout of known probability versus accepting a sure money amount. Suppose, for example, a person were given a choice between accepting the outcome of a fair coin toss where heads means winning \$10,000, and tails means losing \$5,000 and accepting a certain cash amount of \$2,000. EV analysis can be used to evaluate and compare the choices. In this case, the EV of the coin toss is \$2,500, which is \$500 more than the certain money amount. The “risk-neutral” decision maker will prefer the coin toss because of its higher EV. The decision maker who prefers the \$2,000 certain amount is demonstrating a “risk-averse” attitude. On the other hand, if the certain amount were raised to \$3,000 and the first decision maker still preferred the coin toss, he or she would be demonstrating a “risk-taking” attitude. Such tradeoffs can be used to derive a “utility function” that represents a decision maker’s risk attitude.

The risk attitude of a given decision maker is typically a function of the amount at risk. Many people who are risk averse when faced with the possibility of significant loss become risk neutral—or even risk taking—when potential losses are small. Because decision makers vary substantially in their risk attitudes, there is a need to assess not only risk exposure (i.e., the degree of risk inherent in the decision) but also the risk attitude of the decision maker.

3.4.2 Mean-Variance Criterion and Coefficient of Variation

These techniques can be useful in choosing among risky alternatives, if the mean outcomes and standard deviations (variation from the mean) can be calculated.

Consider a choice between two projects—one with higher mean NB and a lower standard deviation than the other. This situation is illustrated in Figure 3.4. In this case, the project whose probability distribution is labeled B can be said to have stochastic dominance over the project labeled A. Project B is preferable to project A, both on grounds that its output is likely to be higher and that it entails less risk of loss. But what if project A, the alternative with higher risk, has the higher mean NB, as illustrated in Figure 3.5? If this were the case, the mean-variance criterion (MVC) would provide inconclusive results.

When there is not stochastic dominance of one project over the other(s), it is helpful to compute the coefficient of variation (CV) to determine the relative risk of the alternative projects. The CV indicates which alternative has the lower risk per unit of project output. Risk-averse decision makers will prefer the alternative with the lower CV, other things being equal. The CV is calculated as follows:

$$CV = \sigma/\mu, \tag{3.8}$$

where CV is the coefficient of variation, σ is the standard deviation, and μ is the mean.

The principal advantage of these techniques is that they provide quick, easy-to-calculate indications of the returns and risk exposure of one project relative to another. The principal disadvantage is that the

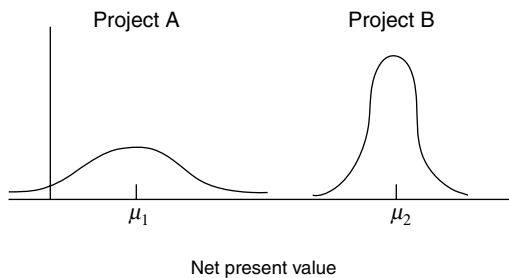


FIGURE 3.4 Stochastic dominance as demonstrated by mean-variance criterion.

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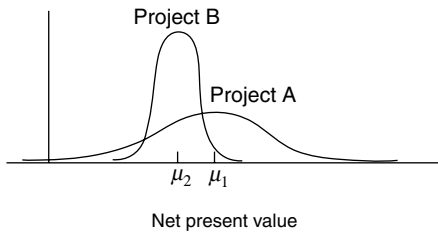


FIGURE 3.5 Inconclusive results from mean-variance criterion.

MVC does not provide a clear indication of preference when the alternative with the higher mean output has the higher risk, or vice versa.

3.4.3 Risk-Adjusted Discount Rate Technique

The risk-adjusted discount rate (RADR) technique takes account of risk through the discount rate. If a project’s benefit stream is riskier than that of the average project in the decision maker’s portfolio, a higher than normal discount rate is used; if the

benefit stream is less risky, a lower than normal discount rate is used. If costs are the source of the higher-than-average uncertainty, a lower than normal discount rate is used and vice versa. The greater the variability in benefits or costs, the greater the adjustment in the discount rate.

The RADR is calculated as follows:

$$RADR = RFR + NRA + XRA, \tag{3.9}$$

where RADR is the risk-adjusted discounted rate, RFR is the risk-free discount rate, generally set equal to the treasury bill rate, NRA is the “normal” risk adjustment to account for the average level of risk encountered in the decision maker’s operations, and XRA is the extra risk adjustment to account for risk greater or less than normal risk.

An example of using the RADR technique is the following: A company is considering an investment in a new type of alternative energy system with high payoff potential and high risk on the benefits side. The projected cost and revenue streams and the discounted present values are shown in Table 3.2. The treasury bill rate, taken as the risk-free rate, is 8%. The company uses a normal risk adjustment of 4% to account for the average level of risk encountered in its operations. The revenues associated with this investment are judged to be more than twice as risky as the company’s average investment, so an additional risk adjustment of 6% is added to the RADR. Hence, the RADR is 18%. With this RADR, the NPV of the investment is estimated to be a loss of \$28 million. On the basis of this uncertainty analysis, the company would be advised to not accept the project.

Advantages of the RADR technique are that it provides a way to account for both risk exposure and risk attitude. Moreover, RADR does not require any additional steps for calculating NPV once a value of the RADR is established. The disadvantage is that it provides only an approximate adjustment. The value of the RADR is typically a rough estimate based on sorting investments into risk categories and adding a

TABLE 3.2 Risk-Adjusted Discount Rate Example

Year	Costs (\$M)	Revenue (\$M)	PV Costs ^a (\$M)	PV Revenue ^b (\$M)	NPV (\$M)
0	80	—	80	—	—80
1	5	20	4	17	13
2	5	20	4	14	10
3	5	20	4	12	8
4	5	20	3	10	7
5	5	20	3	9	6
6	5	20	3	7	4
7	5	20	2	6	4
Total NPV					—28

^a Costs are discounted with a discount rate of 12%.

^b Revenues are discounted with the RADR discount rate of 18%.

“fudge factor” to account for the decision maker’s risk attitude. It generally is not a fine-tuned measure of the inherent risk associated with variation in cash flows. Further, it typically is biased toward investments with short payoffs because it applies a constant RADR over the entire analysis period, even though risk may vary over time.

3.4.4 Certainty Equivalent Technique

The certainty equivalent (CE) technique adjusts investment cash flows by a factor that will convert the measure of economic worth to a “certainty equivalent” amount—the amount a decision maker will find equally acceptable to a given investment with an uncertain outcome. Central to the technique is the derivation of the certainty equivalent factor (CEF) that is used to adjust net cash flows for uncertainty.

Risk exposure can be built into the CEF by establishing categories of risky investments for the decision maker’s organization and linking the CEF to the CV of the returns—greater variation translating into smaller CEF values. The procedure is as follows:

1. Divide the organization’s portfolio of projects into risk categories. Examples of investment risk categories for a private utility company might be the following: low-risk investments: expansion of existing energy systems and equipment replacement; moderate-risk investments: adoption of new, conventional energy systems; and high-risk investments: investment in new alternative energy systems.
2. Estimate the coefficients of variation (see the section on the CV technique) for each investment-risk category (e.g., on the basis of historical risk-return data).
3. Assign CEFs by year, according to the coefficients of variation, with the highest-risk projects being given the lowest CEFs. If the objectives are to reflect only risk exposure, set the CEFs such that a risk-neutral decision maker will be indifferent between receiving the estimated certain amount and the uncertain investment. If the objective is to reflect risk attitude as well as risk exposure, set the CEFs such that the decision maker with his or her own risk preference will be indifferent.

To apply the technique, proceed with the following steps:

4. Select the measure of economic performance to be used, such as the measure of NPV (i.e., NB).
5. Estimate the net cash flows and decide in which investment-risk category the project in question fits.
6. Multiply the yearly net cash flow amounts by the appropriate CEFs.
7. Discount the adjusted yearly net cash flow amounts with a risk-free discount rate (a risk-free discount rate is used because the risk adjustment is accomplished by the CEFs).
8. Proceed with the remainder of the analysis in the conventional way.

In summary, the certainty equivalent NPV is calculated as follows:

$$NPV_{CE} = \sum_{t=0}^N [(CEF_t(B_t - C_t))/(1 + RFD)^t], \tag{3.10}$$

where NPV_{CE} is the NPV adjusted for uncertainty by the CE technique, B_t is the estimated benefits in time period t , C_t is the estimated costs in time period t , and RFD is the risk-free discount rate.

Table 3.3 illustrates the use of this technique for adjusting net present-value calculations for an investment in a new, high-risk alternative energy system. The CEF is set at 0.76 and is assumed to be constant with respect to time.

A principal advantage of the CE Technique is that it can be used to account for both risk exposure and risk attitude. Another is that it separates the adjustment of risk from discounting and makes it possible to make more precise risk adjustments over time. A major disadvantage is that the estimation of CEF is only approximate.

TABLE 3.3 Certainty Equivalent (CE)

	Yearly Net Cash Flow (\$M)	CV	CEF	RFD Discount Factors ^a	NPV (\$M)
1	−100	0.22	0.76	0.94	−71
2	−100	0.22	0.76	0.89	−68
3	20	0.22	0.76	0.84	13
4	30	0.22	0.76	0.79	18
5	45	0.22	0.76	0.75	26
6	65	0.22	0.76	0.7	35
7	65	0.22	0.76	0.67	33
8	65	0.22	0.76	0.63	31
9	50	0.22	0.76	0.59	22
10	50	0.22	0.76	0.56	21
Total NPV					

^a The RFD is assumed equal to 6%.

3.4.5 Monte Carlo Simulation

A Monte Carlo simulation entails the iterative calculation of the measure of economic worth from probability functions of the input variables. The results are expressed as a probability density function and as a cumulative distribution function. The technique thereby enables explicit measures of risk exposure to be calculated. One of the economic-evaluation methods treated earlier is used to calculate economic worth; a computer is employed to sample repeatedly—hundreds of times—from the probability distributions and make the calculations. A Monte Carlo simulation can be performed by the following steps:

1. Express variable inputs as probability functions. Where there are interdependencies among input values, multiple probability density functions, tied to one another, may be needed.
2. For each input for which there is a probability function, draw randomly an input value; for each input for which there is only a single value; take that value for calculations.
3. Use the input values to calculate the economic measure of worth and record the results.
4. If inputs are interdependent, such that input *X* is a function of input *Y*, first draw the value of *Y*, then draw randomly from the *X* values that correspond to the value of *Y*.
5. Repeat the process many times until the number of results is sufficient to construct a probability density function and a cumulative distribution function.
6. Construct the probability density function and cumulative distribution function for the economic measure of worth, and perform statistical analysis of the variability.

The strong advantage of the technique is that it expresses the results in probabilistic terms, thereby providing explicit assessment of risk exposure. A disadvantage is that it does not explicitly treat risk attitude; however, by providing a clear measure of risk exposure, it facilitates the implicit incorporation of risk attitude in the decision. The necessity of expressing inputs in probabilistic terms and the extensive calculations are also often considered disadvantages.

3.4.6 Decision Analysis

Decision analysis is a versatile technique that enables both risk exposure and risk attitude to be taken into account in the economic assessment. It diagrams possible choices, costs, benefits, and probabilities for a given decision problem in “decision trees,” which are useful in understanding the possible choices and outcomes.

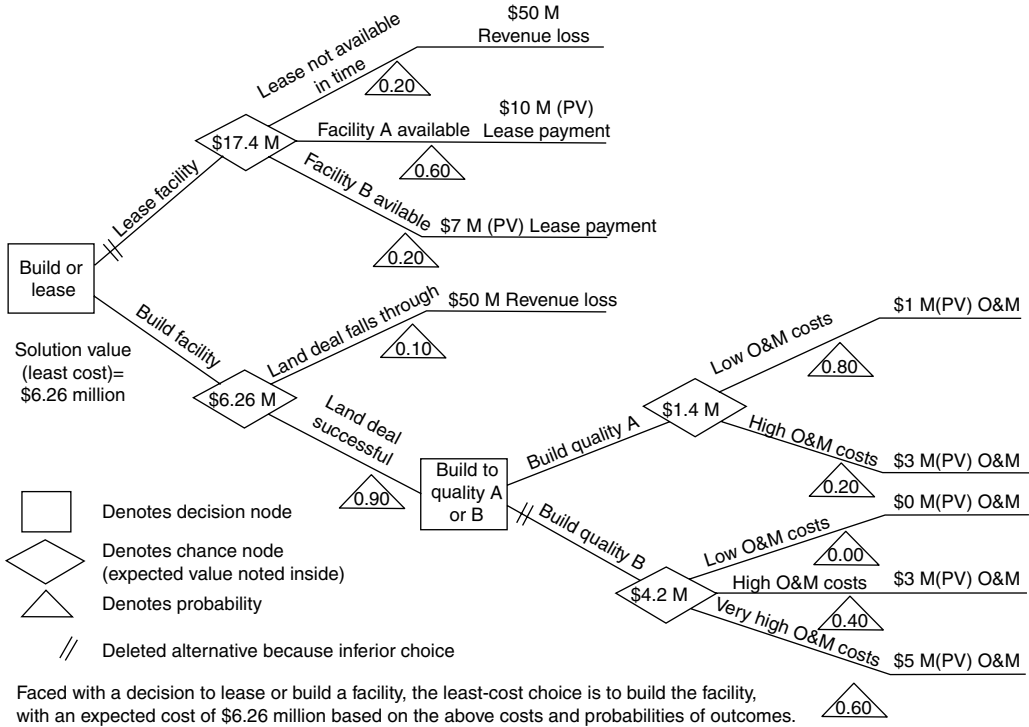


FIGURE 3.6 Decision tree: build versus lease.

Although it is not possible to capture the richness of this technique in a brief overview, a simple decision tree, shown in Figure 3.6, is discussed to give a sense of how the technique is used. The decision problem is whether to lease or build a facility. The decision must be made now, based on uncertain data. The decision tree helps to structure and analyze the problem. The tree is constructed left to right and analyzed right to left. The tree starts with a box representing a decision juncture or node—in this case, whether to lease or build a facility. The line segments branching from the box represent the two alternative paths: the upper one the lease decision and the lower one the build decision. Each has a cost associated with it that is based on the expected cost to be incurred along the path. In this example, the minimum expected cost of \$6.26 M is associated with the option to build a facility.

An advantage of this technique is that it helps to understand the problem and to compare alternative solutions. Another advantage is that, in addition to treating risk exposure, it can also accommodate risk attitude by converting benefits and costs to utility values (not addressed here). A disadvantage is that the technique, as typically applied, does not provide an explicit measure of the variability of the outcome.

3.4.7 Real Options Analysis

Real options analysis (ROA) is an adaptation of financial options valuation techniques⁴ to real asset investment decisions. ROA is a method used to analyze decisions in which the decision maker has one or more options regarding the timing or sequencing of an investment. It explicitly assumes that the investment is partially or completely irreversible, that there exists leeway or flexibility about the timing of

⁴Financial options valuation is credited to Fisher Black and Myron Scholes who demonstrated mathematically that the value of a European call option—an option, but not the obligation, to purchase a financial asset for a given price (i.e., the exercise or strike price) on a particular date (i.e., the expiry date) in the future—depends on the current price of the stock, the volatility of the stock's price, the expiry date, the exercise price, and the risk-free interest rate (see Black and Scholes 1973).

the investment, and that it is subject to uncertainty over future payoffs. Real options can involve options (and combinations) to defer, sequence, contract, shut down temporarily, switch uses, abandon, or expand the investment. This is in contrast to the NPV method that implies the decision is a “now or never” choice.

The value of an investment with an option is said to equal the value of the investment using the traditional NPV method (that implicitly assumes no flexibility or option) plus the value of the option. The analysis begins by construction of a decision tree with the option decision embedded in it. There are two basic methods to solve for the option value: the risk-adjusted replicating portfolio (RARP) approach and the risk-neutral probability (RNP) approach. The RARP discounts the expected project cash flows at a risk-adjusted discounted rate, whereas the RNP approach discounts certainty-equivalent cash flows at a risk-free rate. In other words, the RARP approach takes the cash flows essentially as-is and adjusts the discount rate per time period to reflect that fact that the risk changes as one moves through the decision tree (e.g., risk declines with time as more information becomes available). In the RNP approach, the cash flows themselves essentially are adjusted for risk and discounted at a risk-free rate.

Copeland and Antikarov provide an overall four-step approach for ROA:⁵

1. Step 1: Compute a base-case traditional NPV (e.g., without flexibility).
2. Step 2: Model the uncertainty using (binominal) event trees (still without flexibility; e.g., without options)—although uncertainty is incorporated, the “expected” value of Step 2 should equal that calculated in Step 1.
3. Step 3: Create a decision tree incorporating decision nodes for options, as well as other (nondecision and nooption decisions) nodes.
4. Step 4: Conduct a ROA by valuing the payoffs, working backward in time, node by node, using the RARP or RNP approaches to calculate the ROA value of the investment.

3.4.8 Sensitivity Analysis

Sensitivity analysis is a technique for taking into account uncertainty that does not require estimates of probabilities. It tests the sensitivity of economic performance to alternative values of key factors about which there is uncertainty. Although sensitivity analysis does not provide a single answer in economic terms, it does show decision makers how the economic viability of a renewable energy or efficiency project changes as fuel prices, discount rates, time horizons, and other critical factors vary.

Figure 3.7 illustrates the sensitivity of fuel savings realized by a solar energy-heating system to three critical factors: time horizons (zero to 25 years), discount rates (D equals 0%, 5%, 10%, and 15%), and energy escalation rates (E equals 0%, 5%, 10%, and 15%). The present value of savings is based on yearly fuel savings valued initially at \$1,000.

Note that, other things being equal, the present value of savings increase with time—but less with higher discount rates and more with higher escalation rates. The huge impact of fuel price escalation is most apparent when comparing the top line of the graph ($D=0.10$, $E=0.15$) with the line next to the bottom ($D=0.10$, $E=0$). The present value of savings at the end of 25 years is approximately \$50,000 with a fuel escalation rate of 15%, and only about \$8,000 with no escalation, other things equal. Whereas the quantity of energy saved is the same, the dollar value varies widely, depending on the escalation rate.

This example graphically illustrates a situation frequently encountered in the economic justification of energy efficiency and renewable energy projects: the major savings in energy costs, and thus the bulk of the benefits, accrue in the later years of the project and are highly sensitive to both the assumed rate of fuel-cost escalation and the discount rate. If the two rates are set equal, they will be offsetting as shown by the straight line labeled $D=0$, $E=0$ and $D=0.10$, $E=0.10$.

⁵See Dixit Avinash and Pindyck (1994), which is considered the “bible” of real options, and Copeland Antikarov (2001), which offers more practical spreadsheet methods.

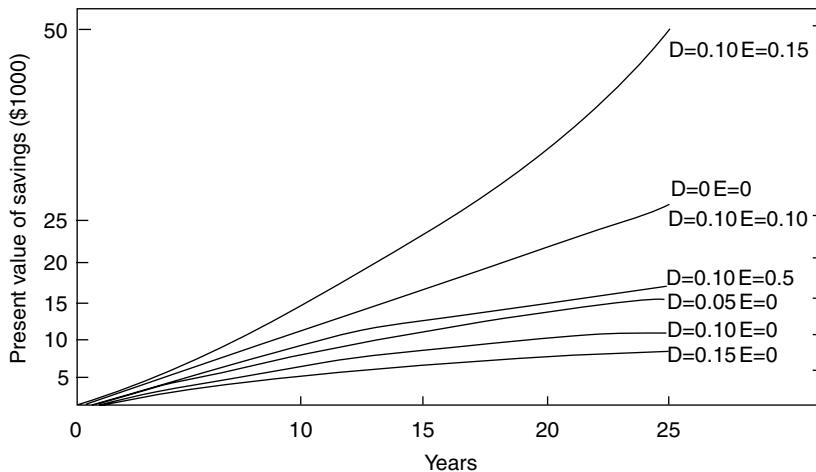


FIGURE 3.7 Sensitivity of present value energy savings to time horizons, discount rates, and energy price escalation rates.

3.5 Building Blocks of Evaluation

Beyond the formula for the basic evaluation methods and risk assessment techniques, the practitioner needs to know some of the “nuts-and-bolts” of carrying out an economic analysis. He or she needs to know how to structure the evaluation process; how to choose a method of evaluation; how to estimate dollar costs and benefits; how to perform discounting operations; how to select an analysis period; how to choose a discount rate; how to adjust for inflation; how to take into account taxes and financing; how to treat residual values; and how to reflect assumptions and constraints, among other things. This section provides brief guidelines for these topics.

3.5.1 Structuring the Evaluation Process and Selecting a Method of Evaluation

A good starting point for the evaluation process is to define the problem and the objective. Identify any constraints to the solution and possible alternatives. Consider if the best solution is obvious, or if economic analysis and risk assessment are needed to help make the decision. Select an appropriate method of evaluation and a risk assessment technique. Compile the necessary data and determine what assumptions are to be made. Apply the appropriate formula(s) to compute a measure of economic performance under risk. Compare alternatives and make the decision, taking into account any incommensurable effects that are not included in the dollar benefits and costs. Take into account the risk attitude of the decision maker, if it is relevant.

Although the six evaluation methods given earlier are similar, they are also sufficiently different in that they are not always equally suitable for evaluating all types of energy investment decisions. For some types of decisions, the choice of method is more critical than for others. Figure 3.8 categorizes different investment types and the most suitable evaluation methods for each. If only a single investment is being considered, the “accept–reject” decision can often be made by any one of several techniques, provided the correct criterion is used.

The accept/reject criteria are as follows:

- LCC technique: LCC must be lower as a result of the energy efficiency or renewable energy investment than without it.
- NPV (NB) technique: NPV must be positive as a result of the investment.

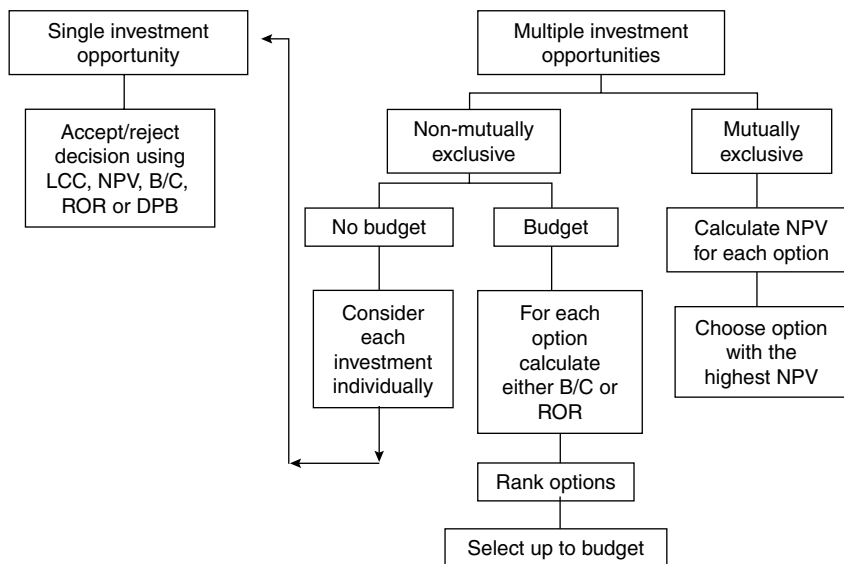


FIGURE 3.8 Investment decisions and evaluation methods.

- B/C (SIR) technique: B/C (SIR) must be greater than one.
- IRR technique: the IRR must be greater than the investor's minimum acceptable rate of return.
- DPB technique: the number of years to achieve DPB must be less than the project life or the investor's time horizon, and there are no cash flows after payback is achieved that would reverse payback.

If multiple investment opportunities are available, but only one investment can be made (i.e., they are mutually exclusive), any of the methods (except DPB) will usually work, provided they are used correctly. However, the NPV method is usually recommended for this purpose, because it is less likely to be misapplied. The NPV of each investment is calculated and the investment with the highest present value is the most economic. This is true even if the investments require significantly different initial investments, have significantly different times at which the returns occur, or have different useful lifetimes. Examples of mutually exclusive investments include different system sizes (e.g., three different photovoltaic array sizes are being considered for a single rooftop), different system configurations (e.g., different turbines are being considered for the same wind farm), and so forth.

If the investments are not mutually exclusive, then (as shown in Figure 3.8), one must consider whether there is an overall budget limitation that would restrict the number of economic investments that might be undertaken. If there is no budget (i.e., no limitation on the investment funds available), then there is really no comparison to be performed and the investor simply makes an accept–reject decision for each investment individually as described above.

If funds are not available to undertake all of the investments (i.e., there is a budget), then the easiest approach is to rank the alternatives, with the best having the highest BCR or rate of return. (The investment with the highest NPV will not necessarily be the one with the highest rank, because present value does not show return per unit investment). Once ranked, those investments at the top of the priority list are selected until the budget is exhausted.

In the case where a fast turnaround on investment funds is required, DPB is recommended. The other methods, although more comprehensive and accurate for measuring an investment's lifetime profitability, do not indicate the time required for recouping the investment funds.

3.5.2 Discounting

Some or all investment costs in energy efficiency or renewable energy systems are incurred near the beginning of the project and are treated as “first costs.” The benefits, on the other hand, typically accrue over the life span of the project in the form of yearly energy saved or produced. To compare benefits and costs that accrue at different points in time, it is necessary to put all cash flows on a time-equivalent basis. The method for converting cash flows to a time-equivalent basis is often called *discounting*.

The value of money is time-dependent for two reasons: First, inflation or deflation can change the buying power of the dollar. Second, money can be invested over time to yield a return over and above inflation. For these two reasons, a given dollar amount today will be worth more than that same dollar amount a year later. For example, suppose a person were able to earn a maximum of 10% interest per annum risk-free. He or she would require \$1.10 a year from now to be willing to forego having \$1 today. If the person were indifferent between \$1 today and \$1.10 a year from now, then the 10% rate of interest would indicate that person’s time preference for money. The higher the time preference, the higher the rate of interest required to make future cash flows equal to a given value today. The rate of interest for which an investor feels adequately compensated for trading money now for money in the future is the appropriate rate to use for converting present sums to future equivalent sums and future sums to present equivalent sums (i.e., the rate for discounting cash flows for that particular investor). This rate is often called the *discount rate*.

To evaluate correctly the economic efficiency of an energy efficiency or renewable energy investment, it is necessary to convert the various expenditures and savings that accrue over time to a lump-sum, time-equivalent value in some base year (usually the present), or to annual values. The remainder of this section illustrates how to discount various types of cash flows.

Discounting is illustrated by [Figure 3.9](#) in a problem of installing, maintaining, and operating a heat pump, as compared to an alternative heating/cooling system. The LCC calculations are shown for two reference times. The first is the present, and it is therefore called a *present value*. The second is based on a yearly time scale and is called an *annual value*. These two reference points are the most common in economic-evaluations of investments. When the evaluation methods are derived properly, each time basis will give the same relative ranking of investment priorities.

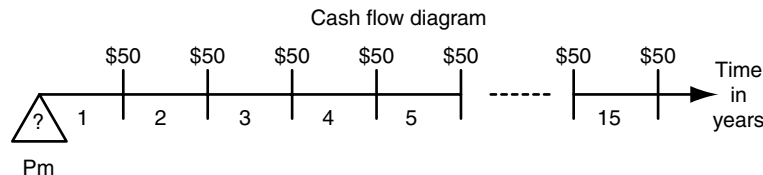
The assumptions for the heat pump problem—which are given only for the sake of illustration and not to suggest actual prices—are as follows:

1. The residential heat pump (not including the ducting) costs \$1,500 to purchase and install.
2. The heat pump has a useful life of 15 years.
3. The system has annual maintenance costs of \$50 every year during its useful life, fixed by contractual agreement.
4. A compressor replacement is required in the eighth year at a cost of \$400.
5. The yearly electricity cost for heating and cooling is \$425, evaluated at the outset, and increased at a rate of 7% per annum due to rising electricity prices.
6. The discount rate (a nominal rate that includes an inflation adjustment) is 10%.
7. No salvage value is expected at the end of 15 years.

The LCCs in the sample problem are derived only for the heat pump and not for alternative heating/cooling systems. Hence, no attempt is made to compare alternative systems in this discounting example. To do so would require similar calculations of LCCs for other types of heating/cooling systems. Total costs of a heat pump system include costs of purchase and installation, maintenance, replacements, and electricity for operation. Using the present as the base-time reference point, one needs to convert each of these costs to the present before summing them. Assuming that the purchase and installation costs occur at the base reference point (the present), the \$1,500 is already in present value terms.

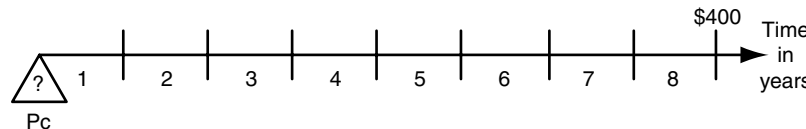
Figure 3.9 illustrates how to convert the other cash flows to present values. The first task is to convert the stream of annual maintenance costs to present value. The maintenance costs, as shown in the cash flow diagram of Figure 3.9, are \$50 per year, measured in current dollars (i.e., dollars of the years in which

Task description^a
 (Find P, given A)
 Find the present value (P_m) of the \$50 annual maintenance cost (A_m) over 15 yr



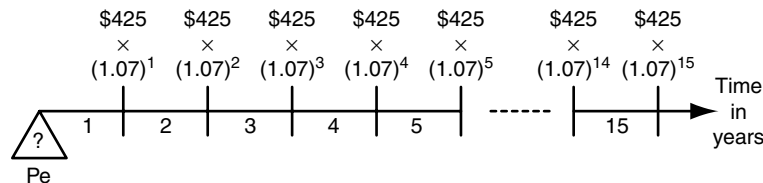
Discounting operation^b
 $P_m = A_m + UPW$
 $P_m = \$50 (UPW, 10\%, 15 \text{ yr})$
 $P_m = \$50 (7.606) = \380

(Find P, given F)
 Find the present value (P_c) of the \$400 future cost of replacing compressor (F_c) at end of 8 yr



$P_m = F_c + SPW$
 $P_m = \$400 (SPW, 10\%, 8 \text{ yr})$
 $P_m = \$400 (0.4665) = \187

(Find P, given A with escalation)
 Find the present value (P_e) of the annual electricity costs (A_e) over 15 yr, beginning with a first year's cost of \$425 and electricity cost escalation of 7%/yr



$P_e = A_e + UPW^+$
 $P_e = \$425 (UPW^+, 10\%, 15 \text{ yr}, 7\% \text{ escalation})$
 $P_e = \$425 (12.1092) = \$5,146$

Find the total present value of the heat pump (P_h)

$P_h = \text{purchase and installation cost} + P_m + P_c + P_e$
 $P_h = \$1,500 + \$380 + \$187 + \$5,146$
 $P_h = \$7,213$

Note: ^a P = Present value, A = Annual value, F = Future value.
^b UPW = Uniform present worth factor, SPW = Single present worth factor, UPW⁺ = Uniform present worth factor with energy escalation.
 Purchase and installation costs are \$1,500 incurred initially.

FIGURE 3.9 Discounting for present value: a heat pump example. (From Marshall, H. E. and Ruegg, R. T., in *Simplified Energy Design Economics*, F. Wilson, ed., National Bureau of Standards, Washington, DC, 1980.)

TABLE 3.4 Discount Formulas

Standard Nomenclature	Use When	Standard Notation	Algebraic Form
Single compound amount	Given P ; to find F	(SCA, $d\%$, N)	$F = P(1 + d)^N$
Single present worth	Given F ; to find P	(SPW, $d\%$, N)	$P = F \frac{1}{(1+d)^N}$
Uniform compound amount	Given A ; to find F	(UCA, $d\%$, N)	$F = A \frac{(1+d)^N - 1}{d}$
Uniform sinking fund	Given F ; to find A	(USE, $d\%$, N)	$A = F \frac{d}{(1+d)^N - 1}$
Uniform capital recovery	Given P ; to find A	(UCR, $d\%$, N)	$A = P \frac{d(1+d)^N}{(1+d)^N - 1}$
Uniform present worth	Given A ; to find P	(UPW, $d\%$, N)	$P = A \frac{(1+d)^N - 1}{d(1+d)^N}$
Uniform present worth modified	Given A escalating at a rate e ; to find P	(UPW*, $d\%$, e , N)	$P = A \frac{(1+e) \left[1 - \left(\frac{1+e}{1+d} \right)^N \right]}{(d-e)}$

P , a present sum of money; F , a future sum of money, equivalent to P at the end of N periods of time at a discount rate of d ; N , number of interest periods; A , an end-of-period payment (or receipt) in a uniform series of payments (or receipts) over N periods at discount rate d , usually annually; e , a rate of escalation in A in each of N periods.

they occur). The triangle indicates the value to be found. The practice of compounding interest at the end of each year is followed here. The present refers to the beginning of year one.

The discounting operation for calculating the present value of maintenance costs (last column of Figure 3.9) is to multiply the annual maintenance costs times the uniform present worth (UPW) factor. The UPW is a multiplicative factor computed from the formula given in Table 3.4, or taken from a look-up table of factors that have been published in many economics textbooks. UPW factors make it easy to calculate the present values of a uniform series of annual values. For a discount rate of 10% and a time period of 15 years, the UPW factor is 7.606. Multiplying this factor by \$50 gives a present value maintenance cost equal to \$380. Note that the \$380 present value of \$50 per year incurred in each of 15 years is much less than simply adding \$50 for 15 years (i.e., \$750). Discounting is required to achieve correct statements of costs and benefits over time.

The second step is to convert the one-time future cost of compressor replacement, \$400, to its present value. The operation for calculating the present value of compressor replacement is to multiply the future value of the compressor replacement times the single-payment present worth factor (SPW) that can be calculated from the formula in Table 3.4, or taken from a discount factor look-up table. For a discount rate of 10% and a time period of 15 years, the SPW factor is 0.4665. Multiplying this factor by \$400 gives a present-value cost of the compressor replacement of \$187, as shown in the last column of Figure 3.9. Again, note that discounting makes a significant difference in the measure of costs. Failing to discount the \$400 would result in an overestimate of cost in this case of \$213.

The third step is to convert the annual electricity costs for heating and cooling to present value. A year's electricity costs, evaluated at the time of installation of the heat pump, are assumed to be \$425. Electricity prices, for purposes of illustration, are assumed to increase at a rate of 7% per annum. This is reflected in Table 3.4 by multiplying \$425 times $(1.07)^t$ where $t=1,2,\dots,15$. The electricity cost at the end of the fourth year, for example, is $\$425(1.07)^4 = \557 .

The discounting operation for finding the present value of all electricity costs (shown in Figure 3.9) is to multiply the initial, yearly electricity costs times the appropriate UPW* factor. (An asterisk following UPW denotes that a term for price escalation is included.) The UPW or UPW* discount formulas in Table 3.4 can also be used to obtain present values from annual costs or multiplicative discount factors from look-up tables can be used. For a period of 15 years, a discount rate of 10%, and an escalation rate of 7%, the UPW* factor is 12.1092. Multiplying the factor by \$425 gives a present value of electricity costs of \$5,146. Note, once again, that failing to discount (i.e., simply adding annual electricity expenses in current prices) would overestimate costs by \$1,229 (\$6,376 – \$5,146). Discounting with a UPW factor that does not incorporate energy price escalation would underestimate costs by \$1,913 (\$5,146 – \$3,233).

The final operation described in [Figure 3.9](#) is to sum purchase and installation cost and the present values of maintenance, compressor replacement, and electricity costs. Total LCCs of the heat pump in present value terms are \$7,213. This is one of the amounts that a designer would need for comparing the cost-effectiveness of heat pumps to alternative heating/cooling systems.

Only one discounting operation is required for converting the present-value costs of the heat pump to annual value terms. The total present-value amount is converted to the total annual value simply by multiplying it by the uniform capital recovery factor (UCR)—in this case the UCR for 10% and 15 years. The UCR factor, calculated with the UCR formula found in [Table 3.4](#), is 0.13147. Multiplying this factor by the total present value of \$7,213 gives the cost of the heat pump as \$948 in annual value terms. The two figures—\$7,213 and \$948 per year—are time-equivalent values, made consistent through the discounting.

[Figure 3.9](#) provides a model for the designer who must calculate present values from all kinds of benefit or cost streams. Most distributions of values occurring in future years can be handled with the SPW, the UPW, or the UPW* factors.

3.5.3 Discount Rate

Of the various factors affecting the NB of energy efficiency and renewable energy investments, the discount rate is one of the most dramatic. A project that appears economic at one discount rate will often appear uneconomic at another rate. For example, a project that yields net savings at a 6% discount rate might yield net losses if evaluated with a 7% rate.

As the discount rate is increased, the present value of any future stream of costs or benefits is going to become smaller. High discount rates tend to favor projects with quick payoffs over projects with benefits deferred further in the future.

The discount rate should be set equal to the rate of return available on the next-best investment opportunity of similar risk to the project in question, i.e., it should indicate the opportunity cost of the investor.

The discount rate may be formulated as a “real rate” exclusive of general price inflation or as a “nominal rate” inclusive of inflation. The former should be used to discount cash flows that are stated in constant dollars. The latter should be used to discount cash flows stated in current dollars.

3.5.4 Inflation

Inflation is a rise in the general price level. Because future price changes are unknown, it is frequently assumed that prices will increase at the rate of inflation. Under this assumption, it is generally easier to conduct all economic-evaluations in constant dollars and to discount those values using “real” discount rates. For example, converting the constant dollar annual maintenance costs in [Figure 3.9](#) to a present value can be easily done by multiplying by a uniform present-worth factor because the maintenance costs do not change over time. However some cash flows are more easily expressed in current dollars, e.g., equal loan payments, tax depreciation. These can be converted to present values using a nominal discount rate.

3.5.5 Analysis Period

The analysis period is the length of time over which costs and benefits are considered in an economic-evaluation. The analysis period need not be the same as either the “useful life” or the “economic life,” two common concepts of investment life. The useful life is the period over which the investment has some value; i.e., the investment continues to conserve or provide energy during this period. Economic life is the period during which the investment in question is the least-cost way of meeting the requirement. Often economic life is shorter than useful life.

The selection of an analysis period will depend on the objectives and perspective of the decision maker. A speculative investor who plans to develop a project for immediate sale, for example, may view the relevant time horizon as that short period of ownership from planning and acquisition of property to the first sale of the project. Although the useful life of a solar domestic hot water heating system, for example, might be 20 years, a speculative home builder might operate on the basis of a two-year time horizon, if the property is expected to change hands within that period. Only if the speculator expects to gain the benefit of those energy savings through a higher selling price for the building will the higher first cost of the solar energy investment likely be economic.

If an analyst is performing an economic analysis for a particular client, that client's time horizon should serve as the analysis period. If an analyst is performing an analysis in support of public investment or a policy decision, the life of the system or building is typically the appropriate analysis period.

When considering multiple investment options, it is best with some evaluation methods (such as LCC, IRR, and ORR) to use the same analysis period. With others like NPV and BCR, different analysis periods can be used. If an investment's useful life is shorter than the analysis period, it may be necessary to consider reinvesting in that option at the end its useful life. If an investment's useful life is longer than the analysis period, a salvage value may need to be estimated.

3.5.6 Taxes and Subsidies

Taxes and subsidies should be taken into account in economic-evaluations because they may affect the economic viability of an investment, the return to the investor, and the optimal size of the investment. Taxes, which may have positive and negative effects, include—but are not limited to—income taxes, sales taxes, property taxes, excise taxes, capital gain taxes, depreciation recapture taxes, tax deductions, and tax credits.

Subsidies are inducements for a particular type of behavior or action. They include grants—cash subsidies of specified amounts; government cost sharing; loan-interest reductions, and tax-related subsidies. Income tax credits for efficiency or renewable energy expenditures provide a subsidy by allowing specific deductions from the investor's tax liability. Property tax exemptions eliminate the property taxes that would otherwise add to annual costs. Income tax deductions for energy efficiency or renewable energy expenses reduce annual tax costs. The imposition of higher taxes on nonrenewable energy sources raises their prices and encourages efficiency and renewable energy investments.

It is important to distinguish between a before-tax cash flow and an after-tax cash flow. For example, fuel costs are a before-tax cash flow (they can be expensed), whereas a production tax credit for electricity from wind is an after-tax cash flow.

3.5.7 Financing

Financing of an energy investment can alter the economic viability of that investment. This is especially true for energy efficiency and renewable energy investments that generally have large initial investment costs with returns spread out over time. Ignoring financing costs when comparing these investments against conventional sources of energy can bias the evaluation against the energy efficiency and renewable energy investments.

Financing is generally described in terms of the amount financed, the loan period, and the interest rate. Unless specified otherwise, a uniform payment schedule is usually assumed. Generally, financing improves the economic effectiveness of an investment if the after-tax nominal interest rate is less than the investor's nominal discount rate.

Financing essentially reduces the initial outlay in favor of additional future outlays over time—usually equal payments for a fixed number of years. These cash flows can be treated like any other: The equity portion of the capital cost occurs at the start of the first year, and the loan payments occur monthly or annually. The only other major consideration is the tax deductibility of the interest portion of the loan payments.

3.5.8 Residual Values

Residual values may arise from salvage (net of disposal costs) at the end of the life of systems and components, from reuse values when the purpose is changed, and from remaining value when assets are sold prior to the end of their lives. The present value of residuals can generally be expected to decrease, other things equal, as (1) the discount rate rises, (2) the equipment or building deteriorates, and (3) the time horizon lengthens.

To estimate the residual value of energy efficiency or renewable energy systems and components, it is helpful to consider the amount that can be added to the selling price of a project or building because of those systems. It might be assumed that a building buyer will be willing to pay an additional amount equal to the capitalized value of energy savings over the remaining life of the efficiency or renewable investment. If the analysis period is the same as the useful life, there will be no residual value.

3.6 Summary

There are multiple methods of economic performance and multiple techniques of risk analysis that can be selected and combined to improve decisions in energy efficiency and renewable energy investments. Economic performance can be stated in a variety of ways, depending on the problem and preferences of the decision maker: as NPV, as LCCs, as the cost of energy, as a rate of return, as years to payback, or as a ratio. To reflect the reality that most decisions are made under conditions of uncertainty, risk assessment techniques can be used to reflect the risk exposure of the project and the risk attitude of the decision maker. Rather than expressing results in single, deterministic terms, they can be expressed in probabilistic terms, thereby revealing the likelihood that the outcome will differ from the best-guess answer. These methods and techniques can be used to decide whether or not to invest in a given energy efficiency or renewable energy system; to determine which system design or size is economically efficient; to find the combination of components and systems that are expected to be cost-effective; to estimate how long before a project will break even; and to decide which energy-related investments are likely to provide the highest rate of return to the investor. The methods support the goal of achieving economic efficiency—which may differ from technical efficiency.

Glossary

Analysis period: Length of time over which costs and benefits are considered in an economic-evaluation.

Benefit/cost (B/C) or saving-to-investment (SIR) ratio: A method of measuring the economic performance of alternatives by dividing present value benefits (savings) by present value costs.

Constant dollars: Values expressed in terms of the general purchasing power of the dollar in a base year. Constant dollars do not reflect price inflation or deflation.

Cost-effective investment: The least-cost alternative for achieving a given level of performance.

Current dollars: Values expressed in terms of actual prices of each year (i.e., current dollars reflect price inflation or deflation).

Discount rate: Based on the opportunity cost of capital, this minimum acceptable rate of return is used to convert benefits and costs occurring at different times to their equivalent values at a common time.

Discounted payback period: The time required for the discounted annual NB derived from an investment to pay back the initial investment.

Discounting: A technique for converting cash flows that occur over time to equivalent amounts at a common point in time using the opportunity cost for capital.

Economic efficiency optimization: Maximizing NB or minimizing costs for a given level of benefits (i.e., “getting the most for your money”).

Economic life: That period of time over which an investment is considered to be the least-cost alternative for meeting a particular objective.

Future value (worth): The value of a dollar amount at some point in the future, taking into account the opportunity cost of capital.

Internal rate of return: The discount rate that equates total discounted benefits with total discounted costs.

Investment costs: The sum of the planning, design, and construction costs necessary to obtain or develop an asset.

Levelized cost of energy: The before-tax revenue required per unit of energy to cover all costs plus a profit/return on investment equal to the discount rate used to levelize the costs.

Life-cycle cost: The present-value total of all relevant costs associated with an asset or project over the analysis period.

Net benefits: Benefits minus costs.

Present value (worth): Past, present, or future cash flows all expressed as a lump sum amount as of the present time, taking into account the time value of money.

Real options analysis: Method used to analyze investment decisions in which the decision maker has one or more options regarding the timing or sequencing of investment.

Risk assessment: As applied to economic decisions, the body of theory and practice that helps decision makers assess their risk exposures and risk attitudes to increase the probability that they will make economic choices that are best for them.

Risk attitude: The willingness of decision makers to take chances on investments with uncertain outcomes. Risk attitudes may be classified as *risk averse*, *risk neutral*, and *risk taking*.

Risk exposure: The probability that a project's economic outcome will be less favorable than what is considered economically desirable.

Sensitivity analysis: A non-probability-based technique for reflecting uncertainty that entails testing the outcome of an investment by altering one or more system parameters from the initially assumed values.

Time value of money: The amount that people are willing to pay for having money today rather than some time in the future.

Uncertainty: As used in the context of this chapter, a lack of knowledge about the values of inputs required for an economic analysis.

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