Chapter 18
Economic Analysis

18.1 Introduction

The future of any energy resource depends on the state of the art of the technology to harvest, convert, and transport it and hence on economic and political factors. The political factors include rules and regulations. The relationships among factors have been studied and characterized during the past century in the context of power plant engineering and regulated utilities. Between energy engineering and economics there is obviously a trade-off because a design achieving high energy generation efficiency is costly and this leads to a high price per unit of energy. On the other extreme, a low-cost design features low efficiency, and hence the cost of energy is high because one needs to spend large amounts of primary energy resources. Somewhere in between a technical–economical optimum of the design can be found.

One of the roles of engineering economics is to establish technical–economical criteria for design optimization. For example, such criteria can be minimum life-cycle cost, maximum life-cycle savings (LCS), minimum levelized energy cost, and so on. Even though these concepts are well developed in the context of classic power plant engineering (Drbal et al. 1996), there are only a few texts that discuss and give instructive examples of the technical–economical peculiarities of recently established sustainable energy systems.

The key factor to be considered here is the additional costs involved in clean emission enforcement. These costs may include the CO_2 separation and sequestration system, the carbon tax, tax deductions on renewable energy development and associated power generation, incentives and bonds issued by governments to help initial investments in renewable energy generation, and others. These factors as such can change the economic picture in general and accelerate the march of societies toward a globally spread sustainable energy practice.

Apart from their use in system design and optimization, engineering economics establishes the criteria for choosing among options. For example, life-cycle cost can be used to decide which of two or more alternative energy systems attaining the same purpose is preferable. These systems can be based on fossil fuel or on renewable sources or a combination of sources.

İ. Dinçer and C. Zamfirescu, *Sustainable Energy Systems and Applications*,
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If several equivalent energy systems are studied during the same period of time (or if the systems have a similar lifetime), normally the system with the lowest life-cycle cost is to be preferred. If the studied alternatives each have a different lifetime, the system featuring the lowest levelized energy cost should be selected.

Economics is crucial in guiding the engineering decisions in the implementation of various sustainable energy systems and technologies. The goal is to make such systems and technologies more cost-effective and hence more economical.

Politics, influences the economic decisions about renewable energy. Boyle (2004) summarized the main political factors through which governments may influence the promotion of sustainable energy technologies. These are related first to legislation and regulations that specify standards and codes for renewable energy. For example, in Greece and Israel there are requirements that new buildings have solar collectors for water heating. Most countries rely, however, on various financial incentives that modify the life-cycle cost or savings so that sustainable energy sources are promoted by making them economically attractive. Some examples are given below:

- Exemption from taxes
- Capital grants
- Auction to supply contracts for renewable energy
- Renewable obligations (electricity suppliers must purchase a specific proportion of renewable energy)
- Feed-in tariffs (fixed premium prices for electricity from renewables)

The U.S. Energy Policy Act of EPACT (2008) states that the Department of Energy shall seek, to the extent that is economically feasible and technically practicable, to increase the total amount of renewable energy that the federal government consumes during the following fiscal years:

(a) Not less than 3% in fiscal years 2007 through 2009
(b) Not less than 5% in fiscal years 2010 through 2012
(c) Not less than 7.5% in fiscal year 2013 and each fiscal year thereafter

The U.S. implements this policy by offering Renewable Energy Certificates (RECs) to eligible economic actors and agencies that generate, buy, or sell any form of renewable energy. An REC represents an allowance given in equivalent of 1 MWh unit, especially to new projects to reduce the initial costs and hence to promote the development of renewable energy trade. The European Union proceeds somewhat similarly, but its target is to achieve a 12% share for renewable energy of the total energy consumption by 2010 (EC 2001).

Other books discuss the topic of sustainable energy systems and include chapters on economic analysis and optimization. Rabl (1985) discusses solar concentrators. Rubin and Davidson (2001) discuss the fundamentals of engineering economics and its applications for life-cycle cost analysis and compare technology options for environment control and policy. Boyle (2004) and Tiwari and Ghosal (2007) discuss renewable energy. Tester et al. (2005) discuss sustainable energy economics (including nuclear).

In contrast, this chapter discusses finance issues such as the rate of discounting the future, worth analysis, loan payments and taxation, the current prediction of fuel price escalation and consumer price index (CPI) evolution up to 2050, life-cycle cost analysis and optimization for renewable energy sources, homeowner or non-utility energy generators and utility electrical energy generators, and cogeneration and district energy systems.

The work by Fuller and Petersen (1995), which describes the life-cycle cost methodology and criteria established by the U.S. Federal Energy Management Program (FEMP) for economic evaluation of (renewable) energy and water conservation projects, has been consulted for updated information on fuel price and electrical energy escalation rates. Their report is accompanied by a yearly supplement that offers price indexes and discount factors for life-cycle cost analysis. The last issue of the supplement is by Rushing and Lippiatt (2008) and includes fossil fuel and electrical energy escalation prices, as predicted up to 2038.

Another important reference is ASHRAE (2007), which presents a chapter on owning and operating costs that includes information about the life-cycle cost of heating, ventilating, air conditioning and refrigeration systems, and district energy systems. The costs are categorized as incidental (initial cost, replacement cost, salvage value) or periodic (e.g., loan, insurance, tax, etc.). The operating costs are differentiated into fuel, utility and water costs and in-house labor, materials, maintenance services, and other maintenance allowances. This source offers valuable tabulated data of the life-cycle costs of residential, commercial, and industrial energy conversion systems.

This chapter discusses some fundamental aspects of engineering economic analysis and its applications to various practical cases, where the role of economics is critical. Several problems are presented to explain and illustrate the concepts and definitions. The criteria that can be used for life-cycle cost analysis, design selection, and optimization are also explained.

18.2 Elements of Financing and Engineering Economics

This section introduces some relevant financing and economics concepts in, such as discount rate, inflation, present and future worth of capital, levelizing, financing through loans, taxation, depreciation, and salvage. These concepts constitute the fundamental building blocks of life-cycle cost analysis and technical–economical system optimization.

18.2.1 Rate of Discounting the Future

The most basic concept in economics is *capital*, which refers to items of extensive value. Even though the term has several other meanings, we refer here only to *financial capital*, which represents a value owned by legal entities that can be saved, traded, and useful when retrieved.

When traded, financial capital can be liquidated as *money* because by its nature money is used as a medium of exchange. It is important to note that the market value of capital is not based on the historical accumulation of money invested but on the perception by the market of its expected revenues and of the risk entailed. The revenue may come from the investment of financial capital in the form of money. Since money can be invested, it augments the capital, and thus the future worth of money always increases. Said another way, the present worth of money (or of a capital measured by money) is always smaller than the future worth. In economics, one says that the present worth is discounted with respect to the future worth.

By definition, the *rate of discounting the future* (or the discount rate) represents the incremental growth of worth during a period of time. If one denotes the discount rate with r, the future worth with F, and the present worth with P, then the incremental growth of worth, $1 + r$, is $1 + r = F/P$, and therefore the discount rate for one time period is

$$r = \frac{F}{P - 1}. \tag{18.1}$$

In general, the unit of time period in economics is 1 year. However, it is common that the discount rate stays constant along several time intervals n; hence, $r = F_k/P_k - 1, k = 1 \ldots n$. In this situation, the present worth in the second period, P_2, is the same as the future worth after the first period, F_1. Moreover, the present worth in the third period, P_3, is equal to the future worth after the second period, F_2, and, in general one can write $P_k = F_{k-1}$, $k = 2 \ldots n$. Taking the product of (F_k/P_k) for $k = 1 \ldots N$ and reducing any P_k with F_{k-1}, one eventually obtains $(1 + r)^N = F_N/P_1$; hence,

$$r = \left(\frac{F_N}{P_1}\right)^{1/N} - 1 \tag{18.2}$$

represents the discount rate that models the present worth P_1 growth after n times intervals.

Application of the discount rate for more than one period is known as *compounding*. Through compounding one obtains the ratio between the future and present worth, which is an equivalent form of Eq. (18.2), such as

$$\frac{F_N}{P_1} = (1 + r)^N, \tag{18.3}$$

which is called *compound amount factor* and denoted with the consecrated notation $(F/P, r, N)$, where N is the number of periods (e.g., years), F the future worth after N periods, P is the present worth, and r is the discount rate (see Fraser et al. 2006).

The converse of Eq. (18.3) is known as the *present worth factor* and it facilitates the calculation of the present worth, which is a value gain after a number N of time periods during which the present value is incrementally augmented. Hence, the present worth factor, denoted (P/F, r, N), is

$$\frac{P_1}{F_N} = (1+r)^{-N}. \tag{18.4}$$

The present and future worth are general notions because they refer to values. For example, they apply to money that increases its present value due to the productivity of capital, but as well these concepts apply to any commodity (e.g., oil). It is interesting to note that taxes that increase in time at a constant rate can be modeled on the same equation Eq. (18.2), as can be seen in the next example.

Example 18.1

An industry consumes oil at a constant rate per day for heating purposes. The period under consideration is from 2010 to 2050. It is known that about 0.3 tonne of CO_2 is produced per GJ of combusted oil. Estimate the total tax paid for CO_2 emission in constant dollars in 2008. Calculate the rate of increase in the CO_2 tax if one assumes that between 2010 and 2050 this rate is constant. The following equation gives the tax on CO_2 emission in 2008 dollars of constant currency (amended for inflation) per tonne for any year between 2007 and 2050:

$$t_{CO_2} = (3.2y - 6,422.4)\frac{\text{US\$}_{2008}}{\text{tonneCO}_2},$$

where y is the year and US$2008 represent the U.S. dollars at their 2008 value.

Solution

- The tax on CO_2 per GJ of energy produced from oil combustion is $t_{CO_2} = (3.2y - 6,422.4)\,(\text{US\$}_{2008}/\text{tonneCO}_2)\ \times 0.3\,(\text{tonneCO}_2/\text{GJ})$.
- The above equation becomes $t_{CO_2} = 0.96y - 1,926.72\,(\text{US\$}\ _{2008}/\text{GJ})$.
- The total tax on CO_2 emission paid per GJ of combusted oil between 2007 and the year y is then $t_{CO_2,2007}(y) = \int_{2007}^{y}(0.96y - 1,926.72)\mathrm{d}y$, which solves to

$$t_{CO_2,2007}(y) = 0.48y^2 - 1,926.72y + 1,933,463\frac{\text{US\$}_{2008}}{\text{GJ}}.$$

- Thus, the total tax paid between 2010 and 2050 is

$$t_{CO_2,\text{tot}} = t_{CO_2,2007}(2050) - t_{CO_2,2007}(2010) = 883\frac{\text{US\$}_{2008}}{\text{GJ}}.$$

- The tax in 2010 is, according to above equation, $t_{CO_2,2010} = \text{US\$}13.8/\text{GJ}$; if one assumes a constant rate of tax increase, the future value in year N is $F_N = (1+r)^N t_{CO_2,2010}$; therefore, for a fixed rate of emission during 2010 and 2050 the total tax paid is the summation

$$t_{CO_2,\text{tot}} = \sum_{k=1}^{N} F_k = t_{CO_2,2010}\sum_{k=1}^{N}(1+r)^k,$$

which is a geometric progression with ratio $a = 1 + r$ and has the known sum of

$$\sum_{k=1}^{N} a^k = a\left(\frac{1 - a^N}{1 - a}\right),$$

where $N = 40$ years; therefore, one equates

$$13.8a\left(\frac{1 - a^{40}}{1 - a}\right) = 883$$

and solves it for a; the result is $a = 1.022$ or $r = 2.2\%$.

- Written according to Eq. (18.3) the tax in year N is given with respect to the present tax in 2008 by $F_N = 1.022^N t_{CO_2,2008}$.
- Note that in the constant rate of increase approach, the tax in the year 2050 is $t_{CO_2,2050} = F_{40} = 1.022^{40} \times 13.8 = \text{US}_{2008}\$33/\text{GJ}$, which is different from that predicted by the equation given in the problem statement, $t_{CO_2,2050} = \text{US}\$_{2008}138/\text{GJ}$.

Example 18.2

What is the value after 5 years of a deposit of \$1,000 in a bank savings account with 6% compounding yearly?

Solution

- The interest rate of 6% is in fact the rate of discounting the future; hence $r = 0.06$.
- The present worth is $P_1 = \$1{,}000$ and the number of compounding periods $N = 5$.
- The compound amount factor calculated with Eq. (18.3) is $(F/P, 0.06, 5) = 1.06^5 = 1.338$.
- Therefore, the future worth of the deposit is $F_5 = (F/P, 0.06, 5)P_1 = 1.338 \times \$1{,}000 = \$1{,}338$.

Example 18.3

A homeowner assumes that his water heater needs to be replaced after 15 years at a cost of \$2,000. What amount must he deposit today with 4% interest so that he can buy the replacement boiler after 15 years? How much should the interest rate be if he deposits \$1,000?

Solution

- The future value $F_{15} = \$2{,}000$ is discounted by the rate $r = 0.04$ for $N = 15$ years.
- The present worth factor is, according to Eq. (18.4), $(P/F, 0.04, 15) = 1.04^{-15} = 0.555$.
- The homeowner has to deposit $P_1 = (P/F, 0.04, 15)F_{15} = 0.555 \times 2{,}000 = \$1{,}110$.
- If the homeowner deposits $P_1 = \$1{,}000$, then the discount rate for 15 compounding periods is given by Eq. (18.2), $r = (F_{15}/P_1)^{1/15} - 1 = 2^{1/15} - 1 = 4.73\%$; thus the interest rate must be 4.73%.

In the examples given above, we used the term *interest rate* without defining it since it is assumed that the reader is familiar with it (this term is commonly used for bank-related business). The important aspect here is to observe that the rate of discounting the future is a consequence of the productivity of capital, and therefore, for the case of bank savings, the discount rate is the same as the interest rate. However, the discount rate is a more general concept, as can be deduced from Example 18.1, where the discount rate is taken to be the same as the growth rate of the carbon tax.

It is clear that the higher the discount rate, the lower the present worth. However, the choice of the discount rate is not clear because different investments yield different returns. Similarly, regulators have the dilemma of determining what taxation rate to impose (which, as exemplified above, acts similarly to a discount rate) because imposing a high tax or too low a tax may lead to unwanted economic consequences. It is useful here to discuss some examples of how to choose a discount rate for some relevant situations.

First, consider a homeowner who has enough money in his savings account to purchase a solar water heater. Instead of buying the water heater, he could leave the money in his savings account. If he does buy the water heater, he forgoes the interest that he could otherwise earn from the savings account. Hence, his discount rate is the interest rate of his savings account. If he had no savings, he would have to borrow money for the water heater. In that case, his discount rate would be the interest of his loan. Loan interest rates are generally higher than the rates for savings account.

The situation is more complex if there are several investment alternatives. For example, a homeowner might invest his money in real estate, stocks, or bonds, each with a different rate of return and a different risk. Industrial and commercial investors usually have a range of investment opportunities. In such cases, the appropriate discount rate for the analysis of a sustainable energy investment is the rate of return for investments of comparable risk that would be made if the money were not spent on a sustainable energy system.

When a project is examined from the point of view of society, the discount rate should be based on the rate of return for society as whole. This rate is called the social discount rate. It is the subject of much controversy, entailing as it does delicate problems such as intergenerational equity. A high discount rate de-emphasizes the importance of future costs or benefits; in other words, it favors the present generation over future generations.

18.2.2 Inflation Rate

Another factor regarding the discount rate is the volatile value of money, which can inflate or deflate. Inflation refers to increase over time in the average *price* of goods and services. The term *price* refers to the assignment of a monetary value to a good or service. Any price is given in a specific currency that represents a unit of trade, which is a measure of money.

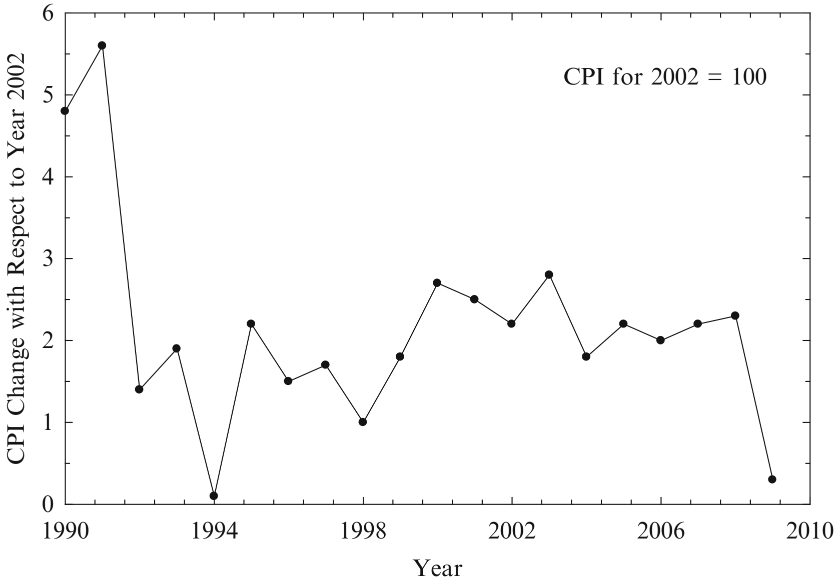

Fig. 18.1 Variation of the Canadian CPI in the period 2004–2008 [data from StatCan (2010)]

Deflation is the opposite of inflation, representing a decrease over time in the average purchasing power of money. Inflation and deflation phenomena come in succession; that is, after a period of inflation may come a period of deflation, depending on the march of the economy as a whole. These phenomena can be quantified by accounting for the relative variation of currency.

The rate of discount of any kind of business is affected by inflation and deflation because they modify the cash flows associated with any economic (and engineering) project conducted over a period of time. It is important therefore to quantify these effects and their impact on the discount rate.

Inflation and deflation can be quantified through the CPI that represents the average price of a basket of goods in a given period, divided by the price of the same basket in a base period. Since it refers to price, the CPI is always given with respect to a specific currency. In Canada, for example, the year 2002 is taken as the reference year for CPI estimation (the CPI value is set to 100 for year 2002). In Fig. 18.1, the variation of the CPI in Canada for the period 1990–2008 is shown. One can clearly observe how a period of inflation (CPI growth) is followed by a period of deflation (CPI decrease).

The CPI provides a means to differentiate between the real worth and the nominal worth of a currency. The *real worth of a currency* (RW) represents the worth of that currency in the reference period taken by convention for computing the CPI. The *nominal worth of currency* (NW) refers to the actual worth at the current date or at any other specified period different from the reference period for the CPI. The CPI is therefore defined by

$$\mathrm{CPI}_N = \frac{\mathrm{NW}_N}{\mathrm{RW}}, \tag{18.5}$$

where the subscript N indicates that the CPI and the nominal worth correspond to the year N after (or before) the reference period. On the other hand, the nominal worth can be viewed as a future worth of currency in the reference period that inflated (or deflated) with the discount rate i; therefore, the equation becomes

$$\mathrm{NW}_N = \mathrm{RW}\left(\frac{F}{P}, i, N\right), \tag{18.6}$$

which introduces the *inflation rate* that represents the discount rate i of nominal currency with respect to real currency. Solving simultaneously Eq. (18.5) and Eq. (18.6) for CPI_N, one obtains

$$\mathrm{CPI}_N = \left(\frac{F}{P}, i, N\right), \tag{18.7}$$

an equation that can be further solved for the inflation rate i to get

$$i = \mathrm{CPI}_N^{1/N} - 1. \tag{18.8}$$

Observe from Eq. (18.8) that if a deflation occurs with respect to reference period for CPI, that is, if CPI is subunitary, and then the inflation rate is negative, indicating thus a deflation period. Hence, the inflation rate is a universal indicator that models both the periods of inflation (positive i) and deflation (negative i).

The U.S. Department of Energy predicts that the implied long-term (up to year 2040) average inflation that may be included in economic analysis of energy projects is 1.8% (see Rushing and Lippiatt 2008). The predicted yearly variation of the U.S. dollar inflation rate up to 2018 is presented in Fig. 18.2, with reference to year 2007.

18.2.3 Real Rate

It is important to account for inflation when adopting a discount rate in any engineering project that extends over a predictable period in future. Assume that for a given period of time the inflation rate is i and the discount rate is r. Then, due to the productivity of capital, the future worth increases by $(1 + r)$ times, while due to inflation it decreases by $(1 + i)$ times. Hence, the future worth F of a present worth P is

$$F = \frac{1 + r}{1 + i} P. \tag{18.9}$$

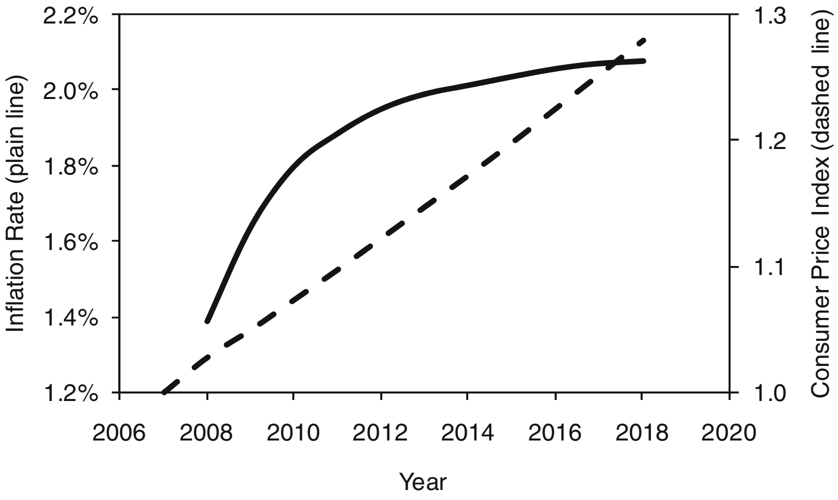

Fig. 18.2 Predicted inflation rate and CPI of the U.S. currency with respect to reference year 2007 [data from Sahr (2008)]

Equations (18.1) and (18.9) introduce the *real rate* of discount, namely,

$$r_{\mathrm{r}} = \frac{1+r}{1+i} - 1, \tag{18.10}$$

where one has to distinguish the term r as the *market discount rate*, that is, a discount rate given in nominal currency, which does not account for inflation.

In engineering economics, it is recommended to pursue the analysis in *constant currency* (or real currency) that represents the currency amended for the inflation. Therefore, in calculation of the present worth and compound amount factors and other economic indicators, the real discount rate must be used and not the market discount rate. This is illustrated in the following example.

Example 18.4

A loan of \$1,000 is made at an interest rate of 15% when the inflation rate is 12%, and it is repaid in one installment after 2 years. Calculate the amount repaid. What is the difference between this result and the result obtained if inflation is ignored?

Solution

- The real rate is given by Eq. (18.10), $r_{\mathrm{r}} = 1.15/1.12 - 1 = 2.67\%$.
- The compound amount factor is $(F/P, r, N) = (1 + r_{\mathrm{r}})^2 = 1.054$.
- The amount paid after 2 years is $F_2 = 1.054 \times 1,000 = \$1,054$.
- If inflation is ignored, the compound amount factor is $(F/P, r, N) = (1 + r)^2 = 1.322$.
- Therefore, the future worth is $F_{2i} = 1.322 \times 1,000 = \$1,322$.
- Hence, due to the effect of inflation, one pays $F_{2i} - F_2 = 1,322 - 1,054 = \$268$ less.

One important comment regarding the real rate is that it may be considered as relatively constant over a long period of time. For example, as mentioned in Rabl (1985), the real rate was 2.2% for 25 years, from 1955 to 1980, despite large fluctuations in the inflation rate. However, the inflation rate must be accounted for if tax deduction and depreciation claims are to be taken. This factor which is relevant when dealing with long-term loans, is analyzed later.

18.2.4 Price Escalation

The inflation rate is calculated based on the average price of a basket of goods and services. However, some commodities, such as fuel and electricity, display a real growth so that their price escalates more than the average price represented by inflation. Observe in Fig. 18.1 the major impact that the energy market (and implicitly fuels) has on inflation. As a consequence, for a more accurate economic analysis, the price escalation of fossil fuels and electrical energy must be accounted for. This analysis is similar to the one presented above for inflation.

If one denotes the market price escalation rate of a commodity with r_{pe}, then the real escalation rate r_{per} accounting for inflation is calculated with Eq. (18.10), which is equivalent with

$$r_{per} = \frac{r_{pe} - i}{1 + i}. \tag{18.11}$$

Now, assume that an economic activity runs at a real discount rate r_r consuming a commodity with a real price escalation rate r_{per}. The future worth is therefore

$$F = \frac{1 + r_r}{1 + r_{per}} P. \tag{18.12}$$

Consequently, the real equivalent discount rate accounting for price escalation is

$$r_e = \frac{r_r - r_{per}}{1 + r_{per}}. \tag{18.13}$$

Example 18.5

From Example 18.1, calculate the total cost spent per GJ of combusted oil between 2010 and 2050. If the fuel consumption is 10 MWh per day, what are the total costs in 2008 dollars? What is the ratio between the CO_2 tax and the oil price? Calculate the rate of oil price increase in the assumption that this rate is constant. It is given that the cost of oil by 2010 is \$6/GJ; it increases quasi-linearly to ~\$8/GJ by 2015, and one can approximate a further linear increase to \$18/GJ by 2050. What is the market growth rate of the oil price taxed for CO_2 emission if the average inflation rate is 1.5%? If the real discount rate is 10%, calculate the equivalent discount rate that accounts for the oil price escalation.

Solution

- We assume that the oil price escalation occurs in two linear steps, from 2010 to 2015 and from 2015 to 2050. Thus, the cost of oil per GJ is obtained by linear interpolation

$$c_{\text{oil}} = \begin{cases} \frac{2}{5}y - 798, & y \in [2010, 2015] \\ \frac{2}{7}y - 567.7, & y \in [2016,\ 2050] \end{cases},$$

  where y is the year.
- By integrating the above expression from year 2010 until year y one obtains the total cost of GJ in the following form:

$$C_{\text{oil},2010}(y) = \begin{cases} \frac{1}{5}y^2 - 798y + 795,960, & y \in [2010,\ 2015] \\ \frac{1}{3}y^2 - 567.714y + 563,946, & y \in [2016,\ 2050] \end{cases}.$$

- The total cost of GJ on oil consumed up to 2050 is therefore $c_{\text{tot}} = \$490$. Since the associated CO_2 emission tax in the same period is \$883, the total cost of 1 GJ of oil combusted at a constant rate in the period 2010 to 2050 is \$1,373.
- At 10 MWh per day, the amount for a period of 40 years is

$$C_{\text{tot}} = 40 \times 365 \times 10\text{MWh} \times 36\left(\frac{\text{GJ}}{\text{MWh}}\right) \times 1,373\left(\frac{\text{US\$}_{2008}}{\text{GJ}}\right)$$
$$= \text{US\$}\ _{2008}7,216,488,000.$$

- The amount paid for the CO_2 tax in this period is

$$t_{CO_2} = 40 \times 365 \times 10\,\text{MWh} \times 36\left(\frac{\text{GJ}}{\text{MWh}}\right) \times 883\left(\frac{\text{US\$}_{2008}}{\text{GJ}}\right)$$
$$= \text{US\$}\ _{2008}4,641,048,000.$$

- Note that in the scenario proposed by the present example, the amount paid on the CO_2 tax is larger than the real cost of oil; from the total cost of combusted oil 883/1,373 = 64% represents the carbon tax.
- For calculating the rate of oil price increase r_o, one proceeds similarly as in the previous example. The total cost spent on oil is therefore

$$c_{\text{tot}} = c_{\text{oil}(2010)} \sum_{k=1}^{N} (1 + r_o)^k,$$

  where $C_{\text{oil}(2010)} = \$20,086/\text{GJ}$.

- With the notation $a_0 = 1 + r_0$ and for $c_{tot} = \mathrm{US\$}_{2008}490/\mathrm{GJ}$,

$$490 = 6a_0 \left(\frac{1 - a_0^{40}}{1 - a_0} \right),$$

  which gives $a_0 = 1.032$ and $r_o = 3.2\%$.
- Note that for a fixed oil increase rate the predicted oil price by 2050 comes to $c_{oil(2050)} = F_{2050} = (1 + r_o)^{40} c_{oil(2010)} = \mathrm{US\$}_{2008}21.1/\mathrm{GJ}$, which is slightly higher than the value of $\mathrm{US\$}_{2008}18/\mathrm{GJ}$ predicted with the equation given in the problem statement.
- The price growth rate of oil taxed for emission is given by solving $1,373 = 6a_0(1 - a_0{}^{40})/(1 - a_0)$ for a_0, which results in the price growth rate of oil, including carbon tax $r_{ot} = 7.26\%$.
- Conversely, one can estimate the total cost of GJ for oil plus tax in 2050 based on 2010 present value that is $2/5 \times 2010 - 768 = \mathrm{US\$}_{2008}36$ for oil plus $0.96 \times 2010 - 1,926.72 = \mathrm{US\$}_{2008}2.88$ for the carbon tax. In total, the present value in 2010 for oil is $36 + 2.88 = 38.88\mathrm{US\$}_{2008}/\mathrm{GJ}$.
- The future worth for 2050 is therefore $38.88 \times (1 + r_{ot})^{40} = 642\mathrm{US\$}_{2008}/\mathrm{GJ}$.
- With an average inflation rate $i = 1.5\%$, the market rate of taxed oil price escalation results from Eq. (18.10), which is solved for r knowing that $r_r = r_{ot} = 7.26\%$.
- Hence, $r = (1 + r_{ot})(1 + i) - 1 = 1.0726 \times 1.015 - 1 = 23.3\%$.
- With a real rate $r_r = 10\%$, the equivalent discount rate, including fuel price escalation, is given by Eq. (18.13), where $r_{per} = r_{ot} = 7.26\%$, thus $r_e = 2.55\%$.
- Note that in the assumed scenario, businesses must have high real discount rate (over 7.5%) so that the equivalent discount rate, including inflation, is positive. In the negative discount rate case, the future worth of money decreases, thus the business does not make sense.

Figure 18.3 gives the price range of biofuels in GJ equivalent for two cases: the average price of 2006 and the predicted price for 2030.

For example, if an investor makes an equity investment in an oil field by 2010, he or she would like to seal it and exploit it some decades later, let's say by 2050. If he sells the oil in 2010, the estimated real value is \$6/GJ, while if he sells it by 2050 the oil price estimate reaches \$18/GJ in real terms (see Fig. 18.2). Thus, the discount rate for 40 years is $r = (18/6)^{1/40} - 1 = 2.8\%$.

Due to the predicted oil price escalation, businesses that consume oil have to support a substantial increase of expenses in future years. This is why conversion to nonconventional energy might be an attractive alternative. If biofuels are used instead of oil, the fuel expense reduces in relative terms according to the estimation presented in Fig. 18.3. Moreover, because biofuels are a renewable energy source, no tax on CO_2 emission has to be paid.

For example, based on bioethanol data from Fig. 18.3, the fuel reduces its value—one says that it *discounts*—from \$20.5 in 2006 to \$13.4 in 2030. Viewed from a consumer's point of view, the discount rate for 24 years is in this case $r = (20.5/13.4)^{1/24} - 1 = 1.8\%$. From the same figure, in the case of biodiesel, the

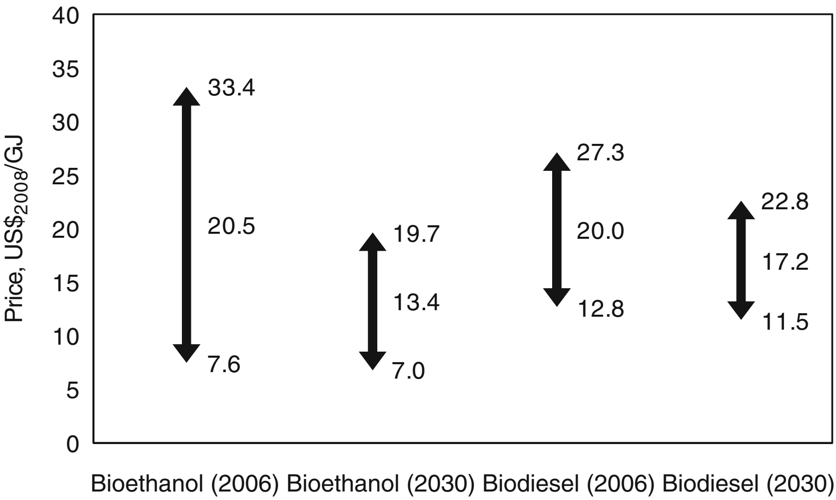

Fig. 18.3 Recent (averaged) and future (2030 predicted) price of biofuels [data from IEA (2006)]

discount rate is $r = (20/17.2)^{1/24} - 1 = 0.6\%$. This figure suggests that those who base their fuel dependence on bioethanol will benefit with a three times higher discount rate than for businesses using biodiesel.

Example 18.6

In Example 18.5, calculate the present worth of savings if the bank average interest rate on long-term deposits is 8% per annum and the respective industry makes oil provisions for 5-year periods.

Solution

- The amount of oil stored for 5 years in energy units is

$$E_{5\text{years}} = 5 \times 365 \times 10\,\text{MWh} \times 36\left(\frac{\text{GJ}}{\text{MWh}}\right) = 657{,}000\,\text{GJ}.$$

- The total cost of oil paid eight times during the 40-year period is

$$C_{\text{oil,tot}} = E_{5\text{years}} \sum_{y=1}^{8} c_{\text{oil}\,(2005+5y)} = \text{US\$}\ _{2008}60{,}445{,}126.$$

- According to Example 18.5, the tax paid on continuous CO_2 emission during the whole period is 883 US$$_{2008}$/GJ of combusted oil, which makes US $$_{2008}$4,641,048,000.
- The total cost in the present situation is then $F_{40} = \text{US\$}_{2008}4{,}701{,}493{,}126$.
- From Example 18.5 the former cost is $F_{40,\text{ex5}} = \text{US\$}_{2008}7{,}216{,}488{,}000$.

- Hence, the savings after 40 years is $S_{40} = F_{40,\text{ex5}} - F_{40} =$ US $\$_{2008}$2,514,994,874.
- Thus, according to Eq. (18.4), for 40 years the present worth factor is (P/F, 0.08, 40) = 0.046.
- The present worth is $S_{40} \times$ (P/F, 0.08, 40) = US$\$_{2008}$2,514,994,874 × 0.046 = US$\$_{2008}$115,689,764.

Example 18.7

An old heat engine–driven electrical generator runs with oil fuel with 10% efficiency. Calculate the discount rate that is obtained if the generator is replaced with a bioethanol fuel cell with 65% efficiency. One assumes that the capital is available as equity investment. The reference period is 2010–2030.

Solution

- Assuming a constant oil consumption rate, one estimates the pay on the carbon tax between 2010 and 2030 according to Example 18.1; the result is $0.48 \times (2030^2 - 2010^2) - 1{,}926.72 \times (2030 - 2010) =$ US$\$_{2008}$249.6 per GJ oil combusted.
- Since the efficiency is 10%, one has to pay \$249.6/0.1 = \$2,496 per GJ.
- From Fig. 18.3 the average cost of the GJ of bioethanol is \$20.5 in 2006 and \$13.4 in 2030. Based on these readings, we approximate the cost variation linearly with $c(y) = 614.3 - 0.296y$ US$\$_{2008}$/GJ.
- Integrating the bioethanol costs between 2006 and year y, the cost per GJ equivalent of fuel $C(y) = 641.3y - 0.148y^2 - 690{,}890.5$.
- The expenses on bioethanol fuel between 2010 and 2030 are therefore $C_{tot} = C(2030) - C(2010) =$ US$\$_{2008}$867.6/GJ.
- Since efficiency of the fuel cell is 65%, \$20,081,335 has to be paid per GJ.
- The savings after 20 years of operation are $S_{20} = 2{,}496 - 1{,}335 =$ US $\$_{2008}$1,161/GJ.
- In the present worth with a 6% discount, the savings are (P/F, 0.06, 20) × 1,161 = US$\$_{2008}$362.
- The actual fuel cell cost is ~ US$\$_{2008}$4,000/kW and for 20 years this produces 630 GJ; this is the cost of US$\$_{2008}$7/GJ; in conclusion, the initial investment in fuel cells can be largely paid from savings.

18.2.5 Levelizing

It is customary in economics to express costs and revenues that occur once or at irregular intervals as equivalent equal payments at regular intervals. This is beneficial in many situations: comparing the levelized cost of economic activities that extend over different period, establishing the rate on energy or electricity, computing loan rates, and so on.

This practice is known as *levelizing*. To introduce this notion, let us consider the example of a natural gas provider. Due to shortage, the natural gas cost increases at the rate r every year. If A is the levelized annual payment (which is the same every year in future worth), the corresponding present value in the kth year, according to Eq. (18.4), is $P_k = A(1 + r)^{-k}$. Therefore, the total payment over the N years expressed in the present worth is

$$P = \sum_{k=1}^{N} A(1+r)^{-k}. \tag{18.14a}$$

This is a geometric progression for which the formula is known as

$$P = \frac{A[1-(1+r)^{-N}]}{r}. \tag{18.14b}$$

The ratio P/A derived from Eq. (18.14b) is known in economics as the *present worth factor*, denoted with

$$\left(\frac{P}{A}, r, N\right) = \frac{1-(1+r)^{-N}}{r} \tag{18.15}$$

and its inverse A/P is called the *capital recovery factor:*

$$\left(\frac{A}{P}, r, N\right) = \frac{r}{1-(1+r)^{-N}}. \tag{18.16}$$

In Eq. (18.16), when $r \to 0$, the capital recovery factor tends to $1/N$.

Example 18.8

It is given that the electrical energy cost increases at a rate of 1% yearly. A capital C is invested at present in a field of solar panels that produce electricity that is sold at an annually levelized cost A. What is the levelized cost per unit of invested capital so that the capital is recovered after $N = 20$ years?

Solution

- We consider the rate of electricity cost increase as a discount rate r, and the invested capital C as the present worth.
- Thus, the levelized electricity cost (LEC) calculated with $r = 1\%$ is

$$\text{LEC} = \left(\frac{A}{P}, r, N\right) C \to \frac{\text{LEC}}{C} = 0.055.$$

- Note: at a 1% discount rate, the yearly levelized cost for 20 years is 5.5% from the invested capital.

Example 18.9

A geothermal energy system that produces constant revenue at a rate r needs an overhaul after the kth year of operation with cost C. The lifetime of the system is $N > k$. The value of the cost to be paid in year k is saved from the annual revenue in levelized tranches during the lifetime of the system. What is the levelized cost of the overhaul?

Solution

- The present worth of the overhaul is $P = (P/F, r, k)C$.
- This present worth is levelized over the lifetime of the system using the capital recovery factor; thus the levelized cost is $A = (A/P, r, N)P$.
- Using the formula for P, one then obtains $A = (A/P, r, N)(P/F, r, k)C$.
- Therefore, the levelized cost A over N years of a future payment C made in year $k < N$ is given by the formula

$$A = \frac{r(1+r)^{-k}C}{1-(1+r)^{-N}}. \tag{18.17}$$

Example 18.10

A renewable energy system saves the amount S at the end of its lifetime of N years. The equity invested capital (meaning that no loan is made for initial investment) is C, and the discount rate is r. What is the levelized benefit from the produced energy?

Solution

- The present worth of the savings S obtained at rate r after the lifetime N is $P = (P/F, r, N)S$.
- The levelized savings is then $A_s = (A/P, r, N)P$, which is given by Eq. (18.17) if one replaces C with S and k with N.
- The levelized capital cost for the same discount rate is $A_c = (A/P, r, N)C$.
- Therefore, the levelized benefit is $A_b = A_s - A_c$

$$A_b = \frac{r(1+r)^{-N}S}{1-(1+r)^{-N}} - \frac{rC}{1-(1+r)^{-N}}.$$

Example 18.11

A company runs a business having the present worth of its financial capital of \$1 million. The real rate of discount $r_r = 4\%$, which means that the present worth is discounted with respect to the future worth after 1 year such that $P = (1 + r_r)^{-1}F$. Due to the electricity price escalation, the future worth of the capital is diminished with respect to the present worth at an annual rate of $r_{per} = 2\%$. Calculate the present worth after $N = 10$ years. What is the benefit obtained after N years?

Solution

- According to the problem statement, if there is no electricity price escalation, after 1 year, due to the discount rate, the worth is $(1 + r_r)P$.
- However, this amount is reduced due to escalating expenses on electricity. Therefore, the future worth after 1 year is $F = [(1 + r_r)/(1 + r_{per})]P$.

- Then, the levelized worth obtained in year k can be related to the present worth with the expression $A = [(1 + r_r)/(1 + r_{per})]^k P_k$.
- Therefore, the present worth after N years of benefit is the summation of the present worth for each year:

$$P = \sum_{k=1}^{N} P_k = A \sum_{k=1}^{N} \left(\frac{1 + r_{per}}{1 + r_r} \right)^k. \quad (18.18)$$

- This is a geometric progression with ratio $a = (1 + r_{per})/(1 + r_r) = 0.981$ having the sum

$$\frac{P}{A} = \frac{a(1 - a^N)}{1 - a} = 9.01.$$

- For the present worth of \$1 million, the levelized return is $A =$ \$0.111 million/year for 10 years.
- Therefore, the future worth after 10 years is $F = NA =$ \$1.11 million and the benefit is \$0.11 million.

Note that if in Eq. (18.15) one uses the real escalation rate r_e defined by Eq. (18.13), then the levelized amount can be expressed with the help of the present worth factor using r_e as the real rate:

$$P = \left(\frac{P}{A}, r_e, N \right) A. \quad (18.19)$$

The total present worth P can be levelized also in amounts A_r based on the business discount rate r_r over the same number of years:

$$P = \left(\frac{P}{A}, r_d, N \right) A_d. \quad (18.20)$$

Solving simultaneously Eqs. (18.19) and (18.20) for A_d/A one obtains

$$\frac{A_d}{A} = \frac{(P/A, r_e, N)}{(P/A, r_r, N)}. \quad (18.21)$$

The factor A_d/A represents the *levelizing factor* (LF) and can be expressed also using the capital recovery factors for rate r_e and r_r:

$$\text{LF} = \frac{(A/P, r_r, N)}{(A/P, r_e, N)}. \quad (18.22)$$

The factor given by Eq. (18.20) is useful for calculating the levelized amounts at the business real discount rate r_r for the case when due to reasons such as escalating prices the returns (or expenses) come at another rate r_e.

Example 18.12

Owing to the fact that fuel price increases at the real rate of $r_{per} = 4\%$ per year, a business decides to replace the gas cooker with a solar cooker with the capital cost C that is 7.44 times higher than the total costs paid on fuel for the first year. The real discount rate is $r_r = 10\%$ per annum. Calculate in how many years the benefit returns if the capital is recovered in equal yearly payments.

Solution

- If one denotes the fuel cost in the first year with C_{f1}, then, according to the problem statement we have $C_{f1} = C/7.44$.
- If the oil cooker would be used, from Eq. (18.15) where A is replaced with the fuel cost for the first year (C_{f1}), then the present worth of fuel value after N years is $P_{oil} = (P/A, r', N)C_{f1}$.
- The equivalent discount rate r_e is calculated with Eq. (18.13), $r_e = 5.77\%$.
- If the solar heater is used, the capital invested has to be balanced by the present worth of the oil consumed in the case when the oil cooker would be in operation, thus $C = P_{oil}$.
- Therefore, one has $C = (P/A, r_e, N)C_{f1} = (P/A, r_e, N)C/7.44$, which becomes $(P/A, r_e, N) = 7.44$ with $r_e = 5.77\%$.
- Using Eq. (18.15), $1 - (1 + 1.0577^{-N}) = 7.44 \times 0.0577$, which solves for $N = 10$.

Example 18.13

It is given that the main providers sell electricity with a discount rate $r_{d1} = 1\%$ while the price escalates with a real rate $r_{per} = 4\%$ for the next $N = 20$ years, due to a fossil fuel shortage. In this context, a competing company analyzes the opportunity of investment in wind energy. To be economically attractive, the company intends to sell electrical energy with a levelized price lower with $f = 10\%$ with respect to conventional energy providers and a discount rate of $r_{d2} = 6\%$ in the same time interval of 20 years. What is the ratio between invested capital C in wind energy and the electricity price in the first year p_1?

- The *LEC* practiced by the main providers during the specified period is $\text{LEC}_1 = \text{LF}_1 p_1$ where the levelizing factor is calculated using Eq. (18.22) for $r_d = r_{d1} = 1\%$ and r_e is calculated according to Eq. (18.13) for $r_{per} = 4\%$ and $r_r = r_{d1} = 1\%$. The result is $\text{LF}_1 = 1.529$.
- The invested capital C is to be discounted with the real rate $r_{d2} = 6\%$ in $N = 20$ years, thus the levelized capital discount rate is $A = (A/P, r_{d2}, N) C = 0.0872C$.
- The capital is recovered by selling electricity at the levelized cost LEC_2 that balances the rate for discounting the capital, $\text{LEC}_2 = A = 0.0872C$.
- According to the problem statement (above), $\text{LEC}_2 = (1 - f/100)\text{LEC}_1$.
- Therefore, $0.0872C = (1 - f/100)\text{LF}_1 p_1$; thus,

$$\frac{C}{p_1} = \left(1 - \frac{10}{100}\right)\frac{1.529}{0.0872} = 15.78.$$

- Consequently, if one succeeds in reducing the capital investment such that it is less than 16 times the conventional electricity price for the first year, the business becomes competitive.

18.2.6 Taxation

The picture of economic analysis of any energy project is affected by the laws regarding taxation. In any society (or economic context), taxation is practiced for purposes such as (1) infrastructure works, education, health services, army, justice, and other basic social services administered by governments, (2) redistribution of revenue toward undeveloped regions or industrial/social sectors, and (3) reprising certain activities, such as carbon emissions. This section presents the general means to compute taxes as a part of the life-cycle cost of any energy system.

Income tax: In order to introduce the general taxation method, assume that at the end of the fiscal year an entity reports the total obtained as the taxable income I_t during that year. The income tax required by the law is a fraction t of the taxable income. Therefore, the considered entity has to pay the amount $T = I_t \times t$, where t is the tax rate. In order to determine the taxable income, a deduction D can be subtracted from the total income I, therefore $I_t = I - D$. Relevant to life-cycle analysis is the fact that some of the expenses (e.g., loans interest) are tax deductible. Assume that the amount C_t is tax deductible from the inventory of a project's life-cycle cost. Then, the amount $D_t = t \times C_t$ represents the tax deduction and can be extracted from the life-cycle cost.

Tax credit: If the economic entity deploys a certain category of business (e.g., generates energy from renewable sources), it might be eligible for a tax credit. In this case, the income tax that the entity has to pay is reduced with an amount proportional to the investment in the tax credit activity. Let us note with C the investment in a tax creditable activity. Then, the deduction received due to the tax credit is $D_{cred} = t_{cred} \times C$, where t_{cred} is the tax on the credit. In some countries, the tax credit on renewable energy can go up to 40% (see Rabl 1985). The amount D_{cred} should be extracted from the initial cost of the project.

Property tax: Assume that a property is owned by an economic entity such as a business, a society, or an individual. In this case, a tax on the property (denoted here with t_{prop}) has to be paid to the regulating authority. However, this tax is deductible from the income tax. If C_{prop} is the capital value of the property and t the income tax, then the tax paid on the property is

$$T_{prop} = C_{prop} \times t_{prop} \times (1 - t). \qquad (18.23)$$

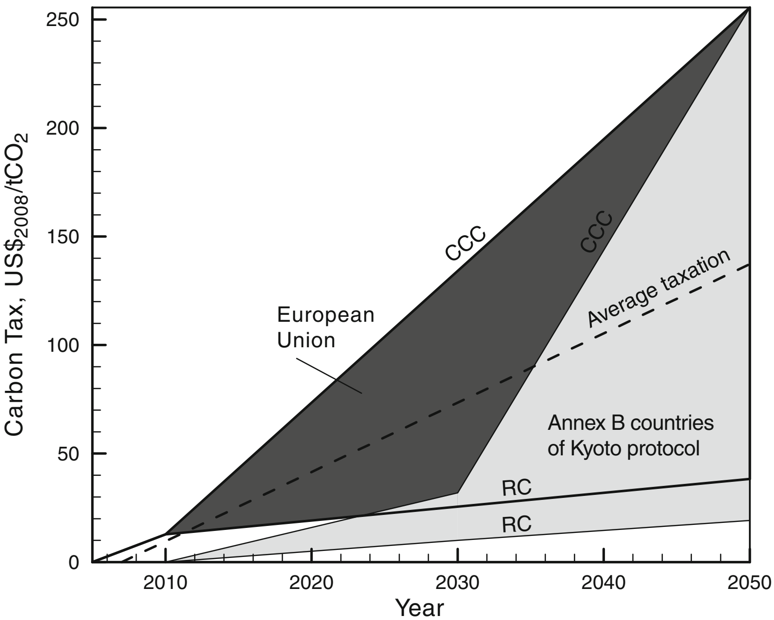

Fig. 18.4 Estimated tax on CO_2 emission in 2008 US$ for the European Union and Kyoto protocol countries

Carbon tax: It is certain that most governments will impose (some already do) a tax on CO_2 emission so that the investment and consumption decisions of the economic agents could be modified for the benefit of a better environment. For example, in the European Union (EU 2006) a carbon value of €10/tCO_2 is assumed in 2010 that increases, according to the predictions, to €110/tCO_2 by 2050. In this report, the geopolitical context, CO_2 emission profile, oil, gas, and coal production profiles, H_2-technology development, population growth, predicted energy demand, and other factors are accounted to propose for three scenarios for energy technology development up to 2050.

In the reference case (RC) scenario, a minimum degree of political initiative is assumed in all countries toward sustainable development. In the second scenario, the carbon constraint case (CCC), severe political limits in CO_2 emissions are assumed up to 2050. In the third scenario, the H_2-case, it is assumed that a firm political decision is made in most countries to develop a hydrogen economy, and therefore major breakthroughs are possible.

There are two predicted limits of taxation: the upper limit corresponds to CCC and the lower to RC as indicated in Fig. 18.4. The European Union promises the highest tax on CO_2 emissions in the years to come. By the end of 2050, in the CCC the tax reaches $250/t$CO_2$ in 2008 currency, while for the reference case scenario this tax is estimated to be $38/t$CO_2$. For the non–Annex B countries of the Kyoto protocol (United Nations 1998), the tax policy is expected to be in rapport with the European Union. These countries start imposing carbon tax by ~2010, which will increase up to \$19/tCO_2 by 2050 in the RC. For the CCC scenario, the increase suggested in (EU 2006) can be approximated by two slopes, namely from zero to \$32 per tonne of CO_2 emission from 2010 until 2030, and a further increase to \$255/tCO_2 by 2050.

Thus, in the CCC scenario, all country signatories of the Kyoto protocol may reach the amount of \$255 per tonne of CO_2 emitted. For the estimation presented in Fig. 18.4, we indicate the average taxation with a dashed line. This curve can be approximated by

$$t_{\mathrm{CO_2}} = 3.2y - 6,422.4\left(\frac{\mathrm{US\$_{2008}}}{\mathrm{tonneCO_2}}\right), \tag{18.24}$$

where y is the year between 2007 and 2050.

Depreciation is a tax deduction due to the fact that, according to law, the worth of some categories of goods depreciates over time. Say that a good has a capital value C_{i} at time zero; after a period of time, its worth depreciates by the amount C_{Dep}; then the current worth becomes $C_{\mathrm{i}} - C_{\mathrm{Dep}}$. Since from the point of view of depreciation the capital is a property and its worth diminishes over time, then for each year a tax deduction can be claimed for depreciation. Depending on the law in place, the depreciation can be assessed based on a “straight line” schedule:

$$D_{\mathrm{Dep}} = \frac{t(P/A, r, N)C}{N} \tag{18.25}$$

or based on the so-called sum-of-the-yearly-digits schedule:

$$D_{\mathrm{Dep}} = \frac{2t[N - (P/A, r, N)]}{rN(N+1)}, \tag{18.26}$$

where one takes the years of depreciation equal to the lifetime of the system, N, and r as the real discount rate. In the above two formulas, the present worth factors were used in order to assess the deduction on depreciation D_{Dep}.

Tax on salvage: At the end of the lifetime, the system has a depreciated value known in economics as the *salvage value*. The tax perceived by the government when salvage is valorized, t_{salv}, is in general different from the income tax. Therefore, the factor $(1 - t_{\mathrm{salv}})$ represents the amount of money that the business earns after tax, the amount that discounts the capital investment. Hence, the deduction on the salvage value is proportional to the invested capital and given by

$$D_{\mathrm{salv}} = f_{\mathrm{salv}}\left(\frac{P}{F}, r, N\right)C(1 - t_{\mathrm{salv}}), \tag{18.27}$$

where r is the real discount rate.

18.2.7 Loans

Loans are paid in regular installments over a period of time N_{Loan} and with a real interest rate r_{Loan}, defined by the loan agreement. The cost of the loan is discounted by the business rate real discount rate r_{r}; therefore, using the capital recovery factor the cost of loan whose present value is C, is

$$C_{\text{Loan}} = \frac{(A/P, r_{\text{Loan}}, N_{\text{Loan}})}{(A/P, r_{\text{r}}, N_{\text{Loan}})} C, \tag{18.28}$$

where N is the period over which the business runs (it can be the lifetime of an energy system).

Loan payments are composed of two parts: the principal, which represents the part of the loan that pays for reducing the loan balance, and the interest, which is the other part (the revenue obtained by the bank). In any year k, $i_k + p_k = A$, where A represents the annual payment while i and p are the interest and principal. The interest in year $k + 1$ is smaller than the interest in year k because less loan is left to be paid; the difference is given by the interest rate, $r_{\text{Loan}} = (i_k - i_{k+1})/p_k$, where $p_k = A - i_k$. Thus, $i_{k+1} = (1 + r_{\text{Loan}})i_k - r_{\text{Loan}}A$, a recursion that has the following solution, as can be demonstrated by mathematical induction:

$$\frac{i_k}{A} = 1 - (1 + r_{\text{Loan}})^{k-1-N}. \tag{18.29}$$

The interest can be expressed in the present worth such that the total amount of the tax deduction on the loan interest can be determined. The final expression for the tax deduction on loans is given as given below (see Rabl 1985):

$$D_{\text{Loan}} = t\left[\frac{(A/P, r_{\text{Loan}}, N_{\text{Loan}})}{(A/P, r, N_{\text{Loan}})} - \frac{(A/P, r_{\text{Loan}}, N_{\text{Loan}}) - r_{\text{Loan}}}{(1 + r_{\text{Loan}})(A/P, r'_{\text{Loan}}, N_{\text{Loan}})}\right] C, \tag{18.30}$$

where $r'_{\text{Loan}} = (r - r_{\text{Loan}})/(1 + r_{\text{Loan}})$ is the effective loan interest rate, and t is the income tax.

18.3 Technical and Economic Criteria for Sustainable Energy Systems

The basis of financing and economics presented in the above section allows for defining a number of criteria that can be used for technical and economic evaluation of a sustainable energy system. Furthermore, through these criteria, it is possible to perform system design optimization, or one may use them for system selection among various options. We introduce the following criteria: life-cycle cost, life-cycle savings, internal rate of return, cost of saved energy, and payback period.

Life-cycle cost: This represents the total cost of the system and it is divided into two parts: initial cost and periodic costs. The initial costs are mainly owing (or capital costs), while the periodic costs include operating and maintenance costs. We show here how to calculate the life-cycle cost of an energy system, in general. The calculation goes as follows:

1. Estimate the total capital cost C (or initial costs) by inventorying all materials, manufacturing, works, permissions, etc.
2. Negotiate a loan: establish how much is the down payment and how much is the loan (denote with f_{Loan}), the portion of the capital that is paid with a loan. Agree on the number of years for the loan N_{Loan} and the real interest rate. The down payment is

$$C_{\mathrm{Down}} = (1 - f_{\mathrm{Loan}})C.$$

3. Determine the real discount rate r_{r} of the energy business. Then, the cost of the loan in the present worth is

$$C_{\mathrm{Loan}} = \frac{(A/P, r_{\mathrm{Loan}}, N_{\mathrm{Loan}})}{(A/P, r, N_{\mathrm{Loan}})} \times f_{\mathrm{Loan}} \times C.$$

4. The associated tax deduction on loan payments is calculated according to Eq. (18.30).
5. Calculate the tax credit, $D_{\mathrm{cred}} = t_{\mathrm{cred}} \times C$.
6. Calculate the depreciation $D_{\mathrm{Dep}} = t(P/A, r, N)C/N$; in the case of a homeowner, the law does not accept depreciation.
7. Calculate the salvage value $D_{\mathrm{salv}} = f_{\mathrm{salv}}(P/F, r, N)C(1 - t_{\mathrm{salv}})$; in the case of homeowner, the tax on salvage is zero.
8. To calculate the tax on property, one has to determine first the value of the property, that is a fraction f_{prop} of the initial cost $C_{\mathrm{prop}} = f_{\mathrm{prop}} \times C \times t_{\mathrm{prop}} \times (1 - t)$.
9. The cost of operation and maintenance is tax deductible (except for homeowners); the operation and maintenance costs are a fraction of the capital cost; hence, $C_{\mathrm{o\&m}} = f_{\mathrm{o\&m}} \times C \times (P/A, r_{\mathrm{r}}, N) \times (1 - t)$.
10. The cost of fuel $C_{\mathrm{f}} = (P_{\mathrm{e1}}/\eta) \times (P/A, r_{\mathrm{e}}, N) \times (1 - t)$, where P_{e1} represents the amount spent on fuel in the first year, r_{e} represents the real discount rate, including the fuel price escalation rate, η represents the conversion efficiency of the fuel consuming energy system (this augments the fuel consumption and therefore operating costs). Note that the cost of fuel is not deductible for homeowners. If the system does not consume fuel (e.g., solar heaters, etc.), then the cost of fuel is not part of the life-cycle cost. However, one may want to add the equivalent fuel cost that a system based on fossil fuels needs to achieve

the same useful output as a renewable energy system under study. As shown later this is a way to compare and select among options.

The life-cycle cost is therefore the sum of the individual cost minus the sum of deductions:

$$\begin{aligned}\text{LCC} = &\left(C_{\text{Down}} + C_{\text{Loan}} + C_{\text{prop}} + C_{\text{o\&m}} + C_{\text{f}}\right)\\ &- \left(D_{\text{cred}} + D_{\text{Dep}} + D_{\text{salv}}\right).\end{aligned} \tag{18.31}$$

The life-cycle cost can be levelized over the lifetime using the capital recovery factor, so that investments having different lifetimes can be compared. The levelized life-cycle cost is therefore

$$\overline{\text{LCC}} = \text{LCC} \times \left(\frac{A}{P}, r_{\text{r}}, N\right). \tag{18.32}$$

Life-cycle savings (LCS): The LCS is defined as the difference between the cost savings on conventional fuel and the capital cost of the renewable energy system that is supposed to replace (or compete with) the energy system based on fossil fuel.

To derive an expression for the LCS, let us consider that the quantity of energy produced by the renewable energy system, whatever its form (work, heat, electricity, chemical energy), is denoted with E. The fossil fuel system generates the same amount of energy over the same period with a given efficiency η. If the price of the fuel per unit of energy content in the first year is p_1, and it escalates with a fixed rate such that the equivalent discount rate is r_{e} during the life-cycle of N years, and if the discount rate that defines the future worth of money is r, then the levelized cost spent on fuel each year is $A = p_1 E/h$. This means that the LCS is

$$\left(\frac{P}{A}, r_{\text{e}}, N\right)\frac{p_1 E}{\eta} - C. \tag{18.33}$$

The *internal rate of return* represents that rate of return for which the LCS is zero. Hence, in Eq. (18.33) one sets LCS $= 0$ and solves for r_{e}. Further, assuming that the real price escalation of fuel r_{per} is known, Eq. (18.13) is solved for the real rate of the business, r_{r}. The internal rate of return is useful for comparing investments when the discount rate cannot be evaluated. If the real internal rate of return is higher than the average real rate of return on similar investments, then the business is profitable.

Cost of saved energy: Assume a renewable energy system that has the life-cycle cost C_{Life} and produces the amount of energy E every year. The same energy can be obtained by converting fuel with a conversion efficiency η. Then, the cost of fuel in the first year is

$$p_1 = \left(\frac{A}{P}, r_{\text{r}}, N\right) \times C_{\text{Life}} \times \frac{\eta}{E}. \tag{18.34}$$

One can compare this cost with the price of fuel in that year to determine if the renewable energy system is beneficial or not.

Payback period: The last criterion discussed here is the payback period defined as the ratio of capital cost over annual savings. In other words, the investment in the system is paid by the savings, at the end of the payback period.

$$\mathrm{NP} = \frac{C}{E \times p_1/\eta}, \tag{18.35}$$

where C is the invested capital, E is the energy produced per year, p_1 is the price of energy in the first year, and η is the conversion efficiency. The payback period may be misleading because it does not account for price escalation, discount rate, and tax deduction. However, it is easy to compute the criterion that can be used for first-hand evaluation.

18.4 Concluding Remarks

In this chapter we discussed the main economic and financing elements relevant to life-cycle cost analysis of energy systems as well as its engineering economics. Several example problems were presented to explain and illustrate the concepts and definitions for analysis. The criteria that can be used for life-cycle cost analysis, design selection, and optimization were also explained.

Nomenclature

A	Levelized annual payment
A/P	Capital recovery factor
c	Specific cost, currency per unit of product
C	Cost, currency
CPI	Consumer price index
D	Depreciation
E	Energy, MJ
F	Future worth
i	Inflation rate
N	Number of years
NP	Payback period, years
NW	Nominal worth of currency
LCC	Life-cycle cost
LCS	Life-cycle savings
LEC	Levelized electricity cost

LF	Levelizing factor
p	Cost of saved energy, currency
P	Present worth, currency
r	Rate of discounting the future
RW	Real worth of currency, currency
t	Taxation, currency per unit of product
T	Tax, currency
y	Year

Greek Letter

η	Energy efficiency

Subscripts

cred	Credit
Dep	Depreciation
Down	Down payment
e	Equivalent
k	Index
N	Number of time periods
pe	Price escalation
per	Real price escalation
prop	Property
r	Real
salv	Salvation
tot	Total

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Study Questions/Problems

18.1 Why is economic analysis important in sustainable energy engineering?

18.2 Define the rate for discounting the future and comment on its usefulness.

18.3 An industry consumes oil at a constant rate per day for heating purposes. The period under consideration is from 2000 to 2020. It is known that about 0.4 tonne of CO_2 is produced per GJ for combusted oil. Estimate the total tax paid for CO_2 emission in constant dollars for 2010. Calculate the rate of increase in the CO_2 tax if one assumes that between 2000 and 2020 this rate is constant. The following equation gives the tax on CO_2 emission in US $2010 constant currency (amended for inflation) per tonne for any year between 2000 and 2020: $t_{CO_2} = (3y - 6,420)\mathrm{US\$}_{2010}/\mathrm{tonneCO_2}$.

18.4 What is the value after 5 years of a deposit of $10,000 in a bank savings account with 7% interest compounded yearly?

18.5 A water heater needs to be replaced after 20 years of operation at a cost of $1,000. What amount must be deposited today with 1% interest so that one can buy the replacement boiler after 20 years? How much should the interest rate be on a deposit of $500?

18.6 Define the inflation rate and its relation to the consumer price index.

18.7 A loan of \$2,000 is made at an interest rate of 7% when the inflation rate is 10% and paid in one installment after 1 year. Calculate the amount paid. What is the difference between this result and the result obtained if the inflation is ignored?

18.8 Explain the importance of price escalation in economic analysis.

18.9 What is cost levelizing and what is its importance?

18.10 Electrical energy costs increase at a rate of 0.5% yearly. An amount of capital C is invested today in a field of solar panels that produce electricity that is sold at an annually levelized cost A. What is the levelized cost per unit of invested capital so that the capital is recovered after $N = 10$ years?

18.11 Fuel price increases at the real rate of $r_{\mathrm{per}} = 1\%$ per year. In these conditions a gas cooker is replaced with a solar cooker with the capital cost C that is ten times larger than the total cost paid on fuel for the first year. The real discount rate is $r_{\mathrm{r}} = 7\%$ per annum. Calculate in how many years the benefit returns if the capital is recovered in equal yearly payments.

18.12 What is depreciation and what is its impact in economic calculations?

18.13 Define the life-cycle cost and explain how life-cycle cost analysis is performed.

18.14 What is life-cycle savings and what is the difference between life-cycle cost and life-cycle savings with regard to the manner in which the economic analysis is performed?