4 Economic Analysis of Energy Investments

In this chapter, we will focus on investments made by firms and governments in the energy sector, and on learning tools and methods that we can apply to evaluate investments in the energy and climate sectors, that is, that can help us to understand whether it is economically sound to make an investment, or not. Of course, these tools can also be applied to analyse investments undertaken by households. However, in this case, the benefits do not easily translate into 'revenues', because households usually do not produce and sell electricity or other services on a market. Nonetheless, a household can compute the lifetime cost of a project and compare it to the subjective economic value of the energy services produced by it. Furthermore, in situations in which a household has to decide between several technologies, for example, between heating systems that provide the same quantity and quality of heating services, the choice can be based on comparing their respective 'lifetime costs', an idea that will be discussed in more detail in Chapter 5.

The first part of this chapter will explain some important concepts for conducting a private investment analysis, that is, one in which economic agents do not factor in any potential social impact of their investment decisions at the time when they make the decision. This discussion will primarily focus on energy-sector investments performed by firms. We will then discuss the levelised cost of energy (LCoE), which is often used to evaluate returns from investments made in the energy sector. Next, we will briefly elaborate on the commonly observed notion of declining unit costs of production in the energy sector, applying the concept of learning curves that are useful in illustrating trends in investment costs. These can be used to define the amount of initial investments in the energy sector. Last, we will introduce social cost-benefit analysis, the notion of undertaking investment analysis from a broader perspective (factoring in the social costs and benefits of each decision). This approach can be applied to evaluate a hydropower project from a societal point of view, analyse the impact of the implementation of a policy measure to mitigate the long-term effects of climate change, and judge the economic effects of preventative adaptation investments.

4.1 Energy–Sector Investments and the Role of Discounting

An energy investment involves making a purchase of durable goods that are used in the energy sector. Different kinds of investments can be made by economic agents; for example, an individual may choose to purchase a new heating system or a new electrical appliance. Similarly, a firm may invest in a new power plant or in new production machinery. Governments may also invest in large-scale energy projects, such as electricity transmission lines or in adaptation projects, such as flood protection.

In doing an investment analysis, one compares the costs and benefits of a project over the lifetime of the investment. This comparison helps economic agents to decide whether to implement an energy project or not. For a firm, the benefits are mainly the revenues from selling a product or a service related to the realisation of a project. For a household, the benefits are the economic value of the energy services generated, for example, the heating services provided by a new heating system. From a government's perspective, on the other hand, the benefit from an energy project is the economic value of the services produced by the investment to society, for example, the protection services provided by a new flood wall that mitigates flooding risks.

Note that the discussion in this chapter will mainly focus on investments in the power sector; however, the same issues and methods of evaluating investments can be applied to other investments in the energy sector performed by firms such as in oil and gas, as well as in energy-intensive sectors such as the cement industry, or by households.

4.1.1 Characteristics of Energy–Sector Investments

Investments can be made by firms into any of the different functions in which energy is the final output. As Figure 4.1 illustrates, some investments may be made in the production of energy (such as in the extraction of oil or gas or in the production of renewable energy), others may be made in transport (such as in the processing of oil, gas, and electricity for the transport sector), and last, investments may also be made in the distribution of energy (for instance, in the setting up of a distribution network for gas or electricity). Note that while the transmission or transport of electricity entails the large-scale movement of electricity from a power plant to a substation, the distribution of electricity involves the transformation of high-voltage electricity at substations to lower-voltage electricity that can then be used by customers. These categories correspond to different types of functions or stages in the provision of energy.

Projects in the energy sector owned by firms and governments have some essential features that can make investments and their evaluation in this sector particularly challenging. These are:

- **Capital intensity:** Energy-sector projects are characterised by high initial investment costs.

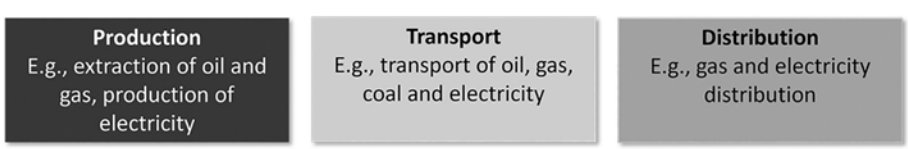


Figure 4.1 Investments in different energy functions

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

- **Capital specificity:** The physical capital in the energy sector tends to have a high degree of specificity, which means that it is difficult to find alternative uses for this type of capital.
- **Long lifespan of assets:** Most energy-sector investments have a long lifespan. For instance, a gas-fired plant can easily operate for 25–30 years, while a hydropower plant is able to produce electricity for up to 80–100 years. This implies that to perform a thorough investment analysis, one would need to collect information on both revenues and costs incurred over a relatively long duration.

Note that at least two of these features, that is, capital intensity and long lifespan, are also valid for investments performed by households. Asset specificity is more relevant for investments made by firms and the government. For instance, it is difficult to find alternative uses for drilling rigs used in oil extraction industries or for flood protection walls.

4.1.2 Investment and Net Cash Flow of a Typical Energy–Sector Project

A typical project in the energy sector realised by a firm (like most infrastructure-based projects) involves large outlays made at the outset when costs are incurred for setting up a power plant or a transmission line. During this period, revenues are most likely zero or negligible, as the plant is not yet operational. Figure 4.2 denotes the typical annual net cash flows, that is, the revenues minus operating costs, for a project from the date when the decision is made to set it up (denoted by time = 0 on the horizontal axis). The first three bars denote these initial (negative) cash flows due to the costs of setting up the project. In the following years, the project starts to yield revenues and the cash flows become positive, which is depicted by the remaining bars in the figure, and these may last over the lifetime of the project. Positive cash flows denote that the project

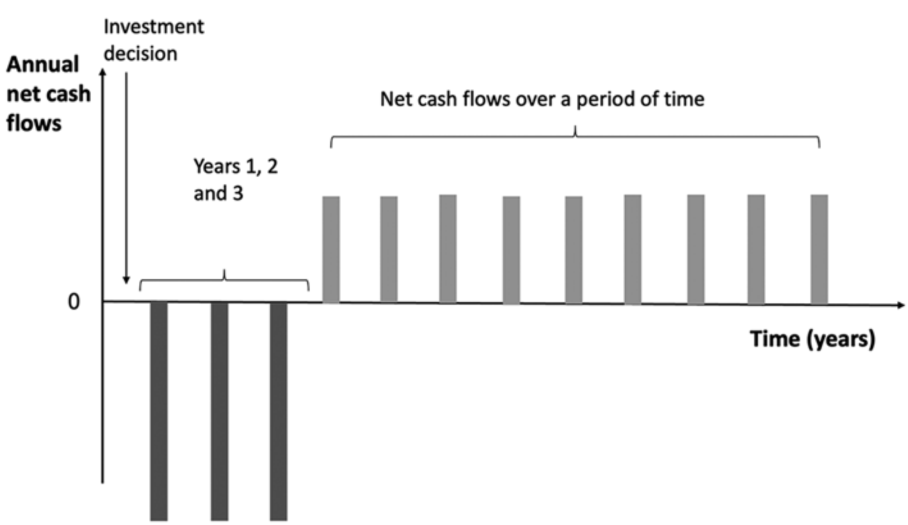


Figure 4.2 The life cycle net cash flows of an investment

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

yields revenues that are higher than the operating costs that are incurred. Of course, during the lifetime of a project, the cash flows can also be negative in some years.

Investment analysis first involves converting these cash flows made over different time periods to present-day values, that is, ‘bringing’ these cash flows to the present period (t = 0), when the investment decision is made. The conversion of future cash flows (negative or positive) to present-day monetary values is achieved by multiplying the value of the cash flow in time period t with the discount factor (w_t) for that time period, which is equivalent to weighting these cash flows. Closely associated with the discount factor is the notion of the discount rate (r). The discount factor used to discount cash flows of period t is defined as in Equation 4.1.

$$w_t = \frac{1}{(1+r)^t} \tag{4.1}$$

The economic arguments for discounting future benefits and costs are twofold.

- **The time preference argument** reasons that individuals generally prefer to spend today rather than later, that is, they give more value to a dollar today than a dollar in 10 years. As consumers, we tend to be impatient; there is always a risk of falling ill, dying, or not being able to enjoy one’s material wealth that nudges us to favour spending money today rather than tomorrow. This means that we should discount (i.e., downsize) any payment that we receive or make in the future when we convert it to present-day terms.
- **The capital productivity argument** put forth by economists suggests that since capital is inherently productive, one can invest his or her resources in one option today, at the cost of investing in an alternative option, to obtain some possible gains. The forgone financial gain when one invests in one alternative, but not in another one, is called the opportunity cost of the alternative. It is the value of the next best option, or of what is given up. These opportunity costs are another reason to discount future payments or revenues; by making an investment in the most profitable option today, investors forego the possible future gains from investing in other viable options.

In the case of firms, the capital productivity argument is usually more relevant, whereas for households, both arguments may be valid.

4.2 Investment Criteria: Net Present Value and Internal Rate of Return

4.2.1 Net Present Value and Internal Rate of Return

Let us look at Figure 4.2 again: when we are provided with information on the net cash flows of an investment over multiple periods, we should discount them to bring them to present value terms. Given the discounted net cash flows, we should then apply an investment criterion to evaluate each investment. The two most used criteria are the net present value (NPV) of a project and the internal rate of return (IRR) of a project.

The NPV is equal to the present value of the sum of the net cash flows (revenues minus costs) over all time periods during the life of the project, including those incurred in the present day (i.e., at t = 0). These cash flows are discounted by multiplying them with the respective discount factor for that time period. The following formula is used to compute the NPV:

$$NPV = \overbrace{\sum_{t=0}^{T} \frac{CF_t}{(1+r)^t}}^{\text{Sum of the net cash flows}} \tag{4.2}$$

where:
NPV: Net present value
CF_t: Net cash flow (revenue minus cost) in year t
r: Discount rate
T: Lifetime of the investment

We can interpret r as the firm's opportunity cost of capital, that is, the rate of return for the firm from investing in the best alternative project having similar risk. The NPV criterion for project evaluation suggests that any project that has a positive or zero NPV, that is, whose revenues are greater than or equal to the costs over the life of the project, is interesting from an economic point of view. If the NPV equals zero, there is no gain or loss from the project. If the NPV is negative, the project should not be considered for investment. In situations with similar projects, the project with the highest NPV should be chosen.

An alternative to the NPV as a criterion to take an investment decision is the IRR. The IRR is the value of the discount rate that sets the NPV of a specific project equal to zero. Mathematically, this can be written as:

$$0 = NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+IRR)^t} \tag{4.3}$$

In order to obtain the IRR of a project, it is necessary to solve Equation 4.3. The IRR criterion for project evaluation is that any project that has an IRR larger than or equal to the cost of capital is worth investing in. In other words, if the rate of return on the project is higher than what one could get from investing money at the prevailing interest rate (or the cost of capital), then it is interesting to invest in the project from an economic point of view.

NPV and IRR are interrelated decision criteria because the IRR of an investment is defined as the discount rate required to make its NPV equal to zero. One of the advantages of the IRR is the possibility to compare investment projects having different lifetimes, based on their estimated rate of return. However, the IRR tends to be sensitive to the size of the project. In situations in which we are comparing two projects, one with a much lower initial capital outlay than the other, the IRR criterion tends to under evaluate the larger project. For instance, in the energy sector, we could imagine comparing an investment in a small hydropower plant with a large one, both of which have similar lifetimes. The smaller plant requires a lower initial capital outlay to be made in comparison to the larger plant. On applying the IRR criterion, it is likely that the larger project may not be realised. This is due to the fact that the IRR is derived by comparing the value of cash flows relative to the initial capital outlay of the project, and it tends to relatively 'undervalue' the higher potential cash flows of larger projects (in absolute terms) that are likely to also lead to higher profits.

Note that in performing an investment analysis using the NPV or the IRR criteria, one of the most challenging parts is to estimate the value of the cash flows, partially due to the long lifespan of these projects, and the difficulty in estimating future revenues and costs.

Finally, the NPV and IRR calculations should be done using either real values accounting for inflation in both cash flows as well as in the discount rates, or nominal values for both. This implies that if we use the nominal values of the cash flows, we should use the nominal value of the discount rate as well (i.e., the discount rate unadjusted for inflation), and *vice versa*.

As we will discuss later in the book, some energy and climate policy instruments can be designed to promote investments in renewable energy sources by increasing the NPV of such investments, for instance. One type of policy instrument that is often used is a subsidy to reduce the initial investment costs. These types of subsidies would increase the net cash flows from the project at the beginning (by reducing costs) and thus increase its NPV. In practice, these subsidies have been implemented in several countries, such as Switzerland, where the government subsidises investment costs for solar panels by up to 30 per cent.

4.2.2 Cost of Capital

In using the criteria discussed above, a certain cost of capital has been considered in the form of the discount rate. Here we provide a brief explanation of this important concept.

To realise energy-sector projects, firms need to collect financial resources that can be drawn from different sources. On the one hand, capital can be raised by using debt as an instrument, and on the other hand, the firm can also issue equity. Based on the use of these two sources, it is possible to calculate the discount rate using the so-called 'weighted average cost of capital (WACC)'.

The WACC is the weighted average of the cost of equity r_e weighted by the factor (E/V) and the cost of debt r_d weighted by the factor (D/V) (where the weights are the respective shares of financing through equity and debt). It can be represented as shown below:

$$r_{WACC} = WACC = \frac{E}{V} r_e + \frac{D}{V} r_d \tag{4.4}$$

Where:

r_{WACC}: Weighted average cost of capital (WACC)
r_e: Cost of equity (i.e., what shareholders expect as a return)
r_d: Cost of debt (i.e., the interest rate to be paid to the lenders)
V: Total market value of equity and debt

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

E/V: Proportion of equity financing
D/V: Proportion of debt financing

The cost of equity for a firm is influenced by factors such as the dividends paid per share issued by the firm, the current market value of the firm, as well as the dividend growth rate. The cost of debt is affected by prevailing interest rates as well as tax rates and tax regulations. Both of these factors are influenced by general market and economic conditions, risk of the investment, monetary and fiscal policy, corporate governance as well as financial stability.

An example of an energy and climate policy instrument to incentivise the adoption of renewable technologies by firms could be a reduction in their capital costs, for example, with a discount on the interest rate paid on debt. This would manifest as a reduction in the r_{WACC} and would increase the NPV of the investment.

Estimating the cost of capital for renewable energy projects

In a study, Steffen (2020) [71] empirically computed estimates of the cost of capital across forty-six countries over the period of 2009–2017. The author discussed the importance of the input data on the cost of capital and discount rates, and how it varied across different countries and technologies significantly, especially in the case of renewable technologies. The order of costs across different technologies was found to be consistent across countries, with offshore wind having the highest capital costs, followed by onshore wind and solar PV. Also, the cost of capital was significantly lower in industrialised countries, when compared to developing countries, and variations were also found within these two broad groups of countries, based on the level of economic development of the countries. This study seeks to highlight the large heterogeneity in the WACC across markets, which should be considered for cost-effective deployment of renewables and to mitigate financial barriers towards renewable energy investment.

4.2.3 Importance of Discount Rates in Investment Decisions

To illustrate the centrality of the discount rate in investment decisions, Table 4.1 includes values of the NPV of USD 100 calculated assuming different time periods and discount rates. For instance, USD 100 in 40 years would be worth USD 67.20 in today's money at a discount rate of 1 per cent, whereas it would be worth USD 0.10 in today's money at a discount rate of 20 per cent. This demonstrates the important role of discount rates in all investment analyses, including those in the energy sector. As investments in the energy sector are characterised by long life cycles, the discount rate chosen in any model, such as in a forecasting model, can decisively change the outcome of the prediction.

4.2.4 Example of Investment Analysis for a Power Plant

In Table 4.2, we present the information on revenue, cost, and net cash flows as well as the NPV of a hypothetical investment in a new power plant. The project spans a period

Table 4.1 NPV and the power of discounting

	Time horizon in years			
Discount rate	5 years	10 years	20 years	40 years
1%	95.1	90.5	82.0	67.2
2.5%	88.4	78.1	61.0	37.2
5%	78.4	61.4	37.7	14.2
10%	62.1	38.6	14.9	2.2
20%	40.2	16.2	2.6	0.1

Table 4.2 Investment analysis

Year	Cost (million USD)	Revenue (million USD)	Net cash flow (million USD)	Net discounted cash flow using discount rate of 5% (million USD)	Net discounted cash flow using discount rate of 1% (million USD)
0	700.00				
1	60.00	100.00	40.00	38.10	39.60
2	60.00	100.00	40.00	36.28	39.21
3	60.00	100.00	40.00	34.55	38.82
4	60.00	100.00	40.00	32.91	38.44
5	60.00	100.00	40.00	31.34	38.06
6	60.00	100.00	40.00	29.85	37.68
7	60.00	100.00	40.00	28.43	37.31
8	60.00	100.00	40.00	27.07	36.94
9	60.00	100.00	40.00	25.78	36.57
10	60.00	100.00	40.00	24.56	36.21
11	60.00	100.00	40.00	23.39	35.85
12	60.00	100.00	40.00	22.27	35.50
13	60.00	100.00	40.00	21.21	35.15
14	60.00	100.00	40.00	20.20	34.80
15	60.00	100.00	40.00	19.24	34.45
16	60.00	100.00	40.00	18.32	34.11
17	60.00	100.00	40.00	17.45	33.78
18	60.00	100.00	40.00	16.62	33.44
19	60.00	100.00	40.00	15.83	33.11
20	60.00	100.00	40.00	15.08	32.78
			NPV (million USD)	−201.51	21.82

of 20 years and has an initial outlay of USD 700 million. The total costs of the power plant include this initial investment cost, along with a yearly operating cost of USD 60 million over the entire life of the project. This cost generally includes expenditure for labour, maintenance, materials, and energy use (such as coal or gas). We have made the assumption that after the first year, the plant starts generating revenue of USD 100

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

million per year until the end of its lifetime. For the purpose of the investment analysis exercise, we calculate the NPV of the project assuming two different discount rates of 5 per cent and 1 per cent, respectively. We find that the NPV of the project is negative on using a discount rate of 5 per cent, that is, the project incurs a net loss of USD 201.51 million over the period of 20 years. Thus, the given investment is not worth making, economically speaking. On the other hand, we find that using a discount rate of 1 per cent generates a positive net cash flow for the project, and its NPV in this case equals USD 21.82 million. Using this discount rate, the project seems worth investing in. This example also shows us the importance of the choice of discount rates in NPV calculations.

4.2.5 Types of Risks Associated with Investments in the Energy Sector

Due to the high initial outlay, the long life cycle of a plant, and competition in the markets where the goods are sold (at least for some projects), realising an investment in the energy sector implies substantial risk and uncertainty.

From an economic point of view, we can use the term ‘risk’ when we can assign an objective probability to the likelihood of an event taking place. The use of the term ‘uncertainty’ is more prevalent in situations in which the probability itself is unknown. Therefore, in these situations, firms and individuals tend to use subjective probabilities or a qualitative assessment of the level of uncertainty of an outcome.

The four main types of uncertainties or risks that investments in the energy sector face are as follows:

1. **Construction risks:** for example, due to delays, technical problems, and cost overruns in the construction of a project.
2. **Cost risks:** for example, due to the introduction of new safety measures, changes in fuel prices, capital costs, or decommissioning costs.
3. **Market risks:** for example, risks arising due to competition from other technologies, or due to changes in consumer preferences or in demand.
4. **Policy risks:** for example, due to the change in regulations such as the introduction of subsidies for certain energy types.

In some cases, it may be possible for economists to form expectations based on past events or forecasts about the nature and severity of these uncertainties and, therefore, to assign a probability to an event. In other cases, it is more difficult to obtain information on the probability of an event occurring. Cost uncertainties, for one, are not always predictable when performing an investment analysis. After the Fukushima Daiichi nuclear disaster in Japan in 2011, for example, governments all over the world introduced more stringent safety measures on nuclear power plants, which increased production costs for nuclear energy. Developments such as this one cannot be foreseen at the point when an investment decision is made.

Generally, energy projects have different levels of risk across energy types. For instance, the construction of a nuclear power plant faces higher risks than the construction of a wind power plant, along the four dimensions discussed above.

4.2.6 Measures of Risk

In performing an investment analysis, the level of risk of an energy investment can be accounted for by using different approaches. In this chapter, we will briefly discuss two of them, that is, the risk-adjusted discount rate and the expected return/standard deviation approach.

A standard method is to use the risk-adjusted discount rate, that is, a discount rate which reflects or captures the risk associated with the cash flows of an investment. The risk-adjusted discount rate for a project is the sum of the risk-free rate of return (e.g., the rate of return on government bonds) and the risk premium associated with a project. The latter accounts for the risk of a project over and above what one may have received if they would have invested at the risk-free rate. The risk premium indicates the risk that characterises the investment and is generally calculated using the so-called Capital Asset Pricing Model (CAPM) developed in financial economics. Therefore, the risk-adjusted discount rate can be expressed as:

$$r = RFR + RP \tag{4.5}$$

where:
r: Risk-adjusted discount rate
RFR: Risk-free return
RP: Risk premium

The risk premium associated with a project compensates investors for 'systematic risks' that cannot be eliminated by risk diversification approaches, such as market risks and policy risks described above.

The second approach to take into account the level of risk of an investment is to measure risk using the expected value and the standard deviation over the NPVs of cash flows, which are computed using a risk-unadjusted discount rate. In this case, based on some information, a probability distribution is assumed for the different NPVs that can arise from a project. Using this distribution, it is then possible to calculate two measures that can be used for decision-making under the conditions of risk, that is, the expected value of these NPVs and the standard deviation.

The expression for the computation of the expected value of the NPVs is the following:

$$\bar{R} = \sum_{i=1}^{n} R_i p_i \tag{4.6}$$

where:
$\bar{R}$: Expected value of the NPVs
R_i: NPV in case i
p_i: Probability of case i
n: Number of possible outcomes

The standard deviation of the NPVs can be computed as follows:

$$\sigma = \sqrt{\sum_{i=1}^{n} (R_i - \bar{R})^2 p_i} \tag{4.7}$$

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

where:
σ: Standard deviation of the NPVs
$\bar{R}$: Expected value of the NPVs
R_i: NPV in case i
p_i: Probability of case i
n: Number of possible outcomes

The expected value of the NPVs and their standard deviations are measures that capture the various types of risks described above. For instance, construction, cost, market, and policy risks can influence the probability distribution of the NPVs, and thus have an impact on influencing both of these measures.

To show how to apply these concepts to investments in the energy sector, we provide the following example. Consider making a choice between investing in one of two projects: project A or project B. Due to the types of risks described above, the NPV of each project is determined with a certain probability distribution. These NPVs are given in column (1) for project A and column (7) for project B in Table 4.3. The corresponding probabilities are listed in columns (2) and (8), respectively. We present the products of each NPV with the corresponding probabilities in columns (3) and (9), respectively. On summing these values listed in columns (3) and (9), we find that the expected value of each project (denoted by $\bar{R}$) is equal to USD 4,100. In calculating this value, we have used Equation 4.6 mentioned earlier.

In columns (4) to (6), we present the values of the other elements that are needed to compute the standard deviation of project A (the corresponding values for project B are mentioned in columns (10)–(12)). For both projects, we use a value of $\bar{R}$ equal to USD 4,100. We can then compute the standard deviation of the projects using Equation 4.7 mentioned above, which is the square root of $\sum_{i=1}^{n}(R_i - \bar{R})^2 p_i$; this term equals 1,890,000 for project A and 29,306,000 for project B, thus yielding a standard deviation of USD 1374.44 for project A and USD 5413.50 for project B.

We can see that the expected values of the net cash flows are identical for the two projects. In this case, the choice between both projects can be made on the basis of the values of the standard deviations of these cash flows. The second investment has a standard deviation that is much higher than the first one (as can be seen from Table 4.3), therefore, it is riskier. For this reason, given that investors are generally averse to risk, the first investment will be preferable.

In case the expected values of the net cash flows are not identical, then the standard deviation can be a misleading measure of risk by itself, and we need to use another risk measure, that is, the coefficient of variation. This coefficient of variation is defined as the standard deviation of the NPVs divided by the expected value, such as:

$$CV = \sigma / \bar{R} \tag{4.8}$$

where:
σ: Standard Deviation of the NPVs
$\bar{R}$: Expected value of the NPVs

Let us assume now that Project B doesn't have an expected value of USD 4,100, but instead has a much higher expected value such as USD 20,000. The standard

Table 4.3 Calculating expected NPVs and standard deviations of projects A and B

Project	Project A						Project B					
Column	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Parameter	R_i	p_i	$p_i{*}R_i$	$(R_i\text{-}\bar{R})$	$(R_i\text{-}\bar{R})^2$	$(R_i\text{-}\bar{R})^2\ p_i$	R_i	p_i	$p_i{*}R_i$	$(R_i\text{-}\bar{R})$	$(R_i\text{-}\bar{R})^2$	$(R_i\text{-}\bar{R})^2 p_i$
	2,000	0.2	400	−2,100	4,410,000	882,000	1,000	0.4	400	−1,500	2,250,000	900,000
	4,000	0.3	1,200	−100	10,000	3,000	3,000	0.1	300	500	250,000	25,000
	3,000	0.1	300	−1,100	1,210,000	121,000	20,000	0.1	2,000	15,900	252,810,000	25,281,000
	5,000	0.2	1,000	900	810,000	162,000	2,000	0.3	600	−500	250,000	75,000
	6,000	0.2	1,200	1,900	3,610,000	722,000	8,000	0.1	800	5,500	30,250,000	3,025,000
Sum			$\bar{R} = \sum_{i=1}^{n} R_i p_i = 4{,}100$			$\sum_{i=1}^{n}(R_i - \bar{R})^2 p_i$ =1,890,000			$\bar{R} = \sum_{i=1}^{n} R_i p_i = 4{,}100$			$\sum_{i=1}^{n}(R_i - \bar{R})^2 p_i$ =29,306,000
Standard deviation						1374.44						5413.50

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

deviations of the two projects are the same as before, that is, USD 1374.44 for Project A and USD 5413.50 for Project B. In this case, if we compute the coefficients of variation (CV) for the two projects using Equation 4.8, we will get $CV_A = 0.34$ and $CV_B = 0.27$. Thus, Project B is more interesting than Project A from an investment perspective, given that it has a lower coefficient of variation, that is, a lower risk relative to its expected value.

Note that this second approach, based on the expected value of the net cash flows and on the standard deviation, can be refined by using simulation-based techniques that consider different probability distributions of all elements of the formula used in calculating the NPV of the cash flows, for example, the discount rate, revenues, and costs. Based on these different distributions, it is possible to obtain several hundreds or thousands of distributions of net cash flows, and thus calculate the expected NPV of the cash flows, the standard deviation, and the coefficient of variation. The decision-making process will still remain the same, as described above.

In case we don't have any information on the probability distributions of the cash flows, we are in a situation of uncertainty. Under these conditions, doing an investment analysis is more difficult, and one solution is to get an idea of the level of uncertainty of the investment, and thereby estimate a range of feasible benefits and costs, using sensitivity analysis. Given that uncertainty involves the decision-maker being unsure about the likelihood of different outcomes occurring, it may be possible only to make qualitative statements about the range of outcomes.

4.3 The Levelised Cost of Energy

The NPV approach is useful to evaluate different types of investment projects in the energy sector, such as in power plants, electricity transmission lines, or gas pipelines. For the evaluation of investments in new power plants, another approach that can be used is based on the calculation of the LCoE. The LCoE is a special case of the NPV calculation because it is the average price that yields a zero NPV. If the expected average price of electricity is greater than or equal to the LCoE, then it makes sense to invest in this technology.

The LCoE can also be defined as the price at which energy produced by a given technology should be sold, such that the revenues equal the costs over the entire lifetime of the technology.

The idea of the LCoE was conceptualised in the field of electricity economics to better compare the production costs of electricity using different technologies, even if these technologies may have different scales or lifespans. It is calculated by equating the present value of the sum of discounted revenues with the present value of the sum of discounted costs. It is important to note that the methodology of the LCoE was developed at a time when electricity markets were regulated, which meant that the price of electricity was assumed to be constant over time. With electricity market regulation, this was a justifiable assumption to make.

Consider the mathematical expression in Equation 4.9. On the left-hand side of this expression, we have the sum of the discounted revenues from the sale of energy/electricity (price per unit of energy P_{MWh} multiplied by the total amount produced in year i, MWh_i, summed over all time periods and discounted at the rate r) whereas, on the right-hand side, we present the sum of total discounted costs. These costs include the initial costs of investment I_i (which are most likely only incurred in the early time periods), the operating and maintenance costs O_i, fuel costs F_i as well as decommissioning and waste management costs D_i. We now set the total discounted sum of revenues equal to the total discounted sum of costs.

$$\sum_{i=0}^{T} \frac{P_{MWh} \cdot MWh_i}{(1+r)^i} = \sum_{i=0}^{T} \frac{I_i + O_i + F_i + D_i}{(1+r)^i} \tag{4.9}$$

P: Price
I_i: Investment costs in year i
O_i: Operating and maintenance costs in year i
F_i: Fuel costs in year i
D_i: Decommissioning and waste management costs in year i
r: WACC
T: Lifetime of the project

As previously defined, the LCoE is the price per unit of energy (P_{MWh}) that solves this expression. To be able to solve this expression for the LCoE, the implicit assumption is that price levels are constant, which is in line with the notion of regulated markets. Then, we can solve the expression as:

$$LCOE = P_{MWh} = \frac{\sum_{i=0}^{N} \frac{I_i+O_i+F_i+D_i}{(1+r)^i}}{\sum_{i=0}^{N} \frac{MWh_i}{(1+r)^i}} = \frac{\textit{Total life cycle cost}}{\textit{Total lifetime energy production}} \tag{4.10}$$

In Table 4.4, we present an example of computing the LCoE for new power plants using different technologies (for example, a residential-scale solar PV plant and a gas peaking plant), for an industrialised country. The rows of this table show the values used for the computation (and also the assumptions made), and the last two rows list the LCoE values with and without considering the external costs. Note that this is an illustrative example introduced for pedagogical reasons, and is based on some assumptions. A change in these assumptions, for instance, in the level of the investment per kW, in the degree of utilisation, or in the discount rate, can change the level of the LCoE significantly. In this simple example, we see that the production costs for the solar PV plant are lower than those of the gas-peaking plant.

Although the LCoE is interesting as an economic concept and quite useful, it has the following limitations:

- **Problem 1:** 1 kilowatt-hour of electricity produced during peak hours has more economic value than 1 kilowatt-hour produced during off-peak hours when electricity demand is low. In assuming a constant price, this variation is not captured by the LCoE.

Table 4.4 LCoE comparison across different power plants

	Photovoltaic	Gas
Initial investment [USD/kW]	1100	450
Installed capacity [MW]	0.50	1,000
Degree of utilisation	0.10	0.55
Discount rate	0.05	0.05
CO_2 price (USD/t CO_2)		30
External costs [USD/kWh]	0.0033	0.005
Lifetime [years]	30	30
LCoE without external cost [USD]	141.1	185.2
LCoE with external cost [USD]	144.4	190.2

- **Problem 2:** due to the inherent variability in renewable electricity generation, backup power and/or storage are often needed. This is an additional capital cost not accounted for in the LCoE calculation for renewable technologies such as solar or wind.
- **Problem 3:** comparing the LCoE of renewables to the LCoE of fossil fuel-based technologies is a meaningless comparison if negative externalities to the environment from the use of fossil fuels are not considered in the comparison. Generally, LCoE estimates do not include all the social costs of using individual technologies. For example, the LCoE of operating a coal-fired power plant includes the cost of CO_2 emissions (in terms of the cost of emissions based on charges, if any are imposed), but generally does not include the social costs that arise due to local pollution. To note that for some technologies, there is no general agreement in the scientific community regarding the exact value of these social costs. Some values of external costs for different technologies are presented in Figure 4.3. These values are important to keep in mind for a complete evaluation of investments in these technologies, since in the future, governments may introduce additional environmental taxes to systematically internalise the social costs of all technologies.
- **Problem 4:** the LCoE does not account for risks adequately (such as fuel supply risks, volatility of oil and gas pricing, and regulatory risks).

4.3.1 Example of LCoE Calculation for Different Technologies at an International Level

Every year, several studies and reports are published containing estimates of the LCoE for different countries. Some of these reports are published by national agencies, whereas others are published by international institutions such as the International Energy Agency. In this section, we present and discuss the values of LCoE estimated for the entire world, published by the International Energy Agency.

Figure 4.4 plots the LCoE for different technologies (renewable as well as non-renewable) based on information from twenty-four countries in 2020. These average values have been obtained by computing the NPV of each technology using a

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

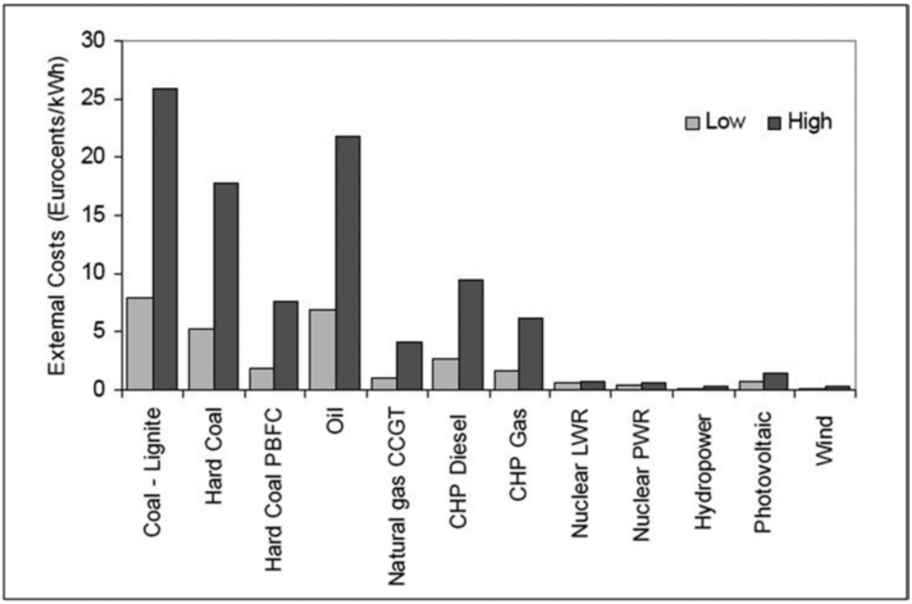
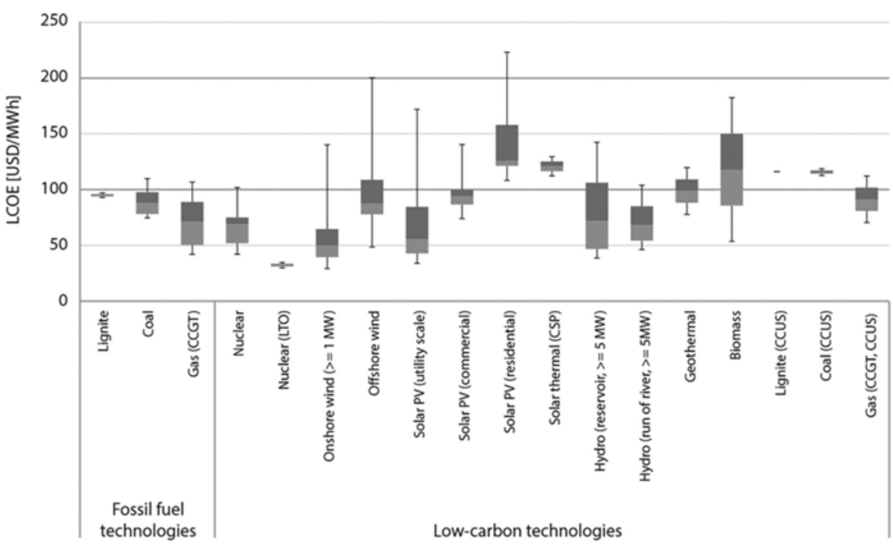


Figure 4.3 Estimated average external costs for different technologies in the EU [72]



Note: Values at 7% discount rate. Box plots indicate maximum, median and minimum values. The boxes indicate the central 50% of values, i.e. the second and the third quartile.

Figure 4.4 Levelised cost of energy (LCoE) by technology aggregated over twenty-four countries [73]

discount rate of 7 per cent which is commonly assumed to be the case for industrialised countries and large developing countries (such as China). The information presented in this figure takes into account the specific investments needed to be made for each technology, within a range. The x-axis presents the different energy source types. We see, again, that there is significant heterogeneity in these values across technologies.

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

Solar PV (utility-scale) and onshore wind have reached LCoE levels comparable to fossil fuel-based technologies such as gas or coal. On the other hand, solar PV (residential), solar thermal, and geothermal technologies still remain relatively more expensive.

It is important to note that the calculation of the LCoE is based on making some assumptions such as on the level of the discount rate, the initial investment cost per kW, fuel prices, carbon price, and the lifetime of a plant. A change in the values assumed in the calculation can change the value of the LCoE significantly. Further, the values of the LCoE are also strongly influenced by national and local conditions. For instance, more or less favourable production sites for renewable energy generation, varying regulations and safety standards, heterogeneous fuel costs, and different levels of technical knowledge can lead to large regional and national differences in production costs.

In general, some renewable energy sources are competitive, while others remain relatively expensive as also shown in Figure 4.4. However, as we will discuss in further detail in the next section, generally the production costs of renewable technologies tend to decrease over time because of technical progress. On the other hand, the current competitiveness of coal power plants is relatively low compared to onshore wind and solar PV (utility scale). Furthermore, the introduction of new environmental taxes in the future, such as a pollution tax, will further affect the competitiveness of fossil fuel-based power plants.

By the same yardstick, some plants seem to have a low LCoE, such as nuclear power plants. However, we must keep in mind that these LCoE estimates are often theoretical, and based on making assumptions that may be unrealistic, and for which there is not always agreement in the scientific community. For example, sometimes the assumptions on construction time and on the average construction cost per kw (total overnight capital cost) tend to be optimistic.

4.4 The Learning Curve

We have seen in previous sections that the investment costs per kW are an important component of investment analysis. The value of this component can vary over time. Therefore, for investment analysis, it is important to have information on the evolution of these values over time. The learning curve can be a useful tool for this purpose.

The development of the production costs over time depends on two main factors, that is, technical progress and cost declines due to experience in the production of the technology. The learning curve provides policymakers and firms with important information on these kinds of developments over time and on the expectations of future costs of technologies.

4.4.1 The Learning Curve in the Energy Sector

The learning curve is a graphical representation of the trend in production costs as a function of the cumulative production volume of technology. It is thus a function

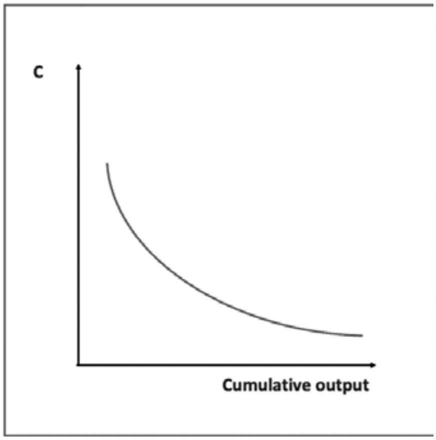


Figure 4.5 A typical learning curve

that describes the impact of learning and of experience acquired with an increase in the production volume on the costs. It can also be mathematically represented and estimated by empirical methods.

As an illustration, Figure 4.5 denotes the production costs (C) needed to produce one unit of output using a certain technology on the y-axis and the cumulative output of that technology on the x-axis. The illustrative curve shows the extent to which the production costs fall as the cumulative output increases. For instance, we could plot the cumulative number of solar panels produced by a firm against the average production cost per solar panel.

Theoretically, these cost reductions may be driven by two economic processes:

- **Learning-by-doing:** the learning effect operational at existing facilities and plants results in benefits from an increase in the efficiency and productivity of using equipment over time.
- **Learning-by-researching:** the benefits derived from investments in research and development may lead to the production of new knowledge as well as innovations.

Learning curves can be obtained empirically by plotting the cumulative output on the horizontal axis, and cost per output on the vertical axis or by using more sophisticated approaches based on econometric methods. Figure 4.6 provides stylised learning curves based on some data by International Renewable Energy Agency (IRENA) for different renewable energy technologies for the period 2010–2020, with the cumulative deployment plotted on the x-axis and the LCoE values plotted on the y-axis. The LCoE values are obtained by collecting information on global cost averages for electricity generated using solar PV as well as onshore wind energy. While costs have declined across both technologies, the decline has been steeper in the case of solar PV, which also had the highest levels of deployment. In fact, as can be seen from the figure, during the period from 2010 to 2020, the global weighted average LCoE of utility-scale solar PV projects declined by more than 80 per cent, whereas the decline was lower for onshore wind [74].

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

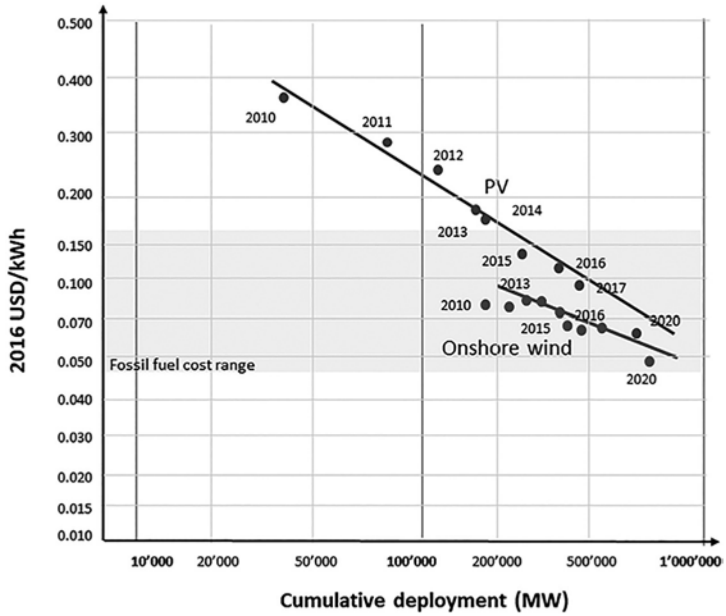


Figure 4.6 Learning curves for renewable energy technologies: adapted from IRENA [74]

From an econometric point of view, there are two types of learning curves that can be estimated, depending on whether we only consider learning-by-doing as a driving factor for cost reductions, or if we consider both learning-by-doing and learning-by-researching.

A one-factor learning curve illustrates the relationship between the unit cost of production of a technology and accumulated learning (normally captured by cumulative output/production). The underlying assumption behind this curve is the existence of only one kind of learning, namely learning by doing. The simplest and most common form of the one-factor learning curve can be written in mathematical form:

$$C_t = C_0 CP_t^a \tag{4.11}$$

C_t: Cost of unit production at time t
C_0: Average unit production cost at $t = 0$
CP_t: Cumulative output produced up to time period t
a: Elasticity of learning

The elasticity of learning a in the equation represents the percentage change in unit costs for a 1 per cent increase in the cumulative output produced up to the time period t, and is the parameter of interest derived from a learning curve. If one takes the logarithm of both sides of this equation, we obtain:

$$\ln C_t = \ln C_0 + a \ln CP_t + \epsilon \tag{4.12}$$

In this form, the equation can be easily estimated empirically, using identification strategies such as the OLS methodology. The term ϵ refers to the idiosyncratic error

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

term, which captures unobservable variables not considered in the model. Such methods allow us to estimate the elasticity of learning. Once we have derived this estimate, we can also use it to calculate the learning-by-doing rate (LR), which is defined as:

$$LR_D = 1 - 2^a \tag{4.13}$$

The learning-by-doing rate is the fractional decrease in costs associated with a doubling of cumulative capacity or production.

Unlike the one-factor learning curve, the two-factor learning curve encapsulates both learning-by-doing and learning-by-researching. Learning-by-researching describes the association of per-unit production costs and the accumulated knowledge stock determined by research and development activities. A simple equation for the two-factor learning curve looks similar to the one-factor learning curve:

$$C_t = C_0 CP_t^a R_t^b \tag{4.14}$$

C_t: Cost of unit production at time t
C_0: Average unit production cost at $t = 0$
CP_t: Cumulative output produced up to time period t
a: Elasticity of learning
R_t: Knowledge stock up to time t
b: Elasticity of learning-by-researching

One can notice that the only difference in the mathematical expression of the two-factor learning curve from that of the one-factor learning curve is the inclusion of the term capturing accumulated knowledge stock and the elasticity of learning-by-researching. Taking the logarithm on both sides of this equation, we obtain:

$$\ln C_t = \ln C_0 + a \ln CP_t + b \ln R_t + \epsilon \tag{4.15}$$

As before, we can estimate this model empirically, using the OLS methodology, for instance. This will yield estimates for the elasticity terms a and b. As with the one-factor curve, we can then use these estimates to derive both the learning-by-doing rate, as well as the learning-by-researching rate, where the learning-by-doing rate is defined as previously, and the learning-by-researching rate is defined as:

$$LR_R = 1 - 2^b \tag{4.16}$$

As an example, in the economic literature, the average learning-by-doing rate computed for solar PV is about 20–25 per cent using a one-factor model. Using two-factor models, in general, the learning-by-doing rate tends to be high for solar PV among all energy types, and the learning-by-researching rate tends to be high for onshore wind [75].

4.5 Social Cost–Benefit Analysis

The construction of a power plant, such as a large run-of-river hydropower plant, yields revenues and costs for the firm that realises this project, but also generates benefits as

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

well as costs for society. For instance, the construction of a large dam could reduce the risk of flooding along the river by regulating the flow of water and, therefore, creating benefits for the population living downstream from the dam. On the other hand, the construction of this dam may also create disamenities due to the reduced flow that may impede the ability of households living downstream to enjoy outdoor activities related to the use of the river. Therefore, if investment projects have the potential to generate significant costs and benefits for society, it is essential, from an economic point of view, to consider these effects when performing an investment analysis. These social aspects of investment projects are not considered in the typical private investment analysis approach that we presented earlier in the chapter. Therefore, to also incorporate the social effects of projects, we can perform a social cost–benefit analysis. This analysis is a form of investment analysis, usually performed by governments that considers both private costs and benefits of a project (which could be either direct or indirect), as well as its social costs and benefits (which include intangible costs and benefits) over the lifetime of a project. This is a useful tool that can be employed to evaluate the most important projects in the energy and climate sectors (such as building a new power plant or a gas pipeline or constructing embankments to prevent coastal flooding or flood protection walls near a river for a community). The main objective of using this methodology is to identify projects that can improve the overall welfare of a society. This method can be put to use either for evaluating the social value of a single project or to rank alternative projects to understand which one is most beneficial.

4.5.1 Steps of Doing a Social Cost–Benefit Analysis

There are typically three steps in doing a social cost–benefit analysis. The first step is to select the projects to evaluate or compare. The next step is to expound on the different types of costs and benefits that are needed to do a social cost–benefit analysis. Following the identification and monetary evaluation of these components, the sum of the benefits and costs for all projects can be compared. Collecting information on the indirect and external or intangible costs and benefits is the most challenging part of this analysis. Frequently, the information on the external costs and benefits is unavailable and, therefore, has to be estimated in separate studies.

The different steps in doing a social cost–benefit analysis are described in Figure 4.7.

After the first step of selecting the projects to be evaluated, as can be seen in Figure 4.7, the second step includes the evaluation of different types of costs and benefits, namely primary, secondary, and intangible, that we explain below. The third step is to compute the sum of the discounted benefits and costs for all projects and compare them by choosing an appropriate discount rate. We will discuss this in more detail in the next subsection.

Primary Benefits and Costs

- **Primary benefits:** these equal the value of the goods and services produced if the project is implemented (such as the electricity produced by a power plant). Primary benefits can be measured by summing up the total revenue and the consumer

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

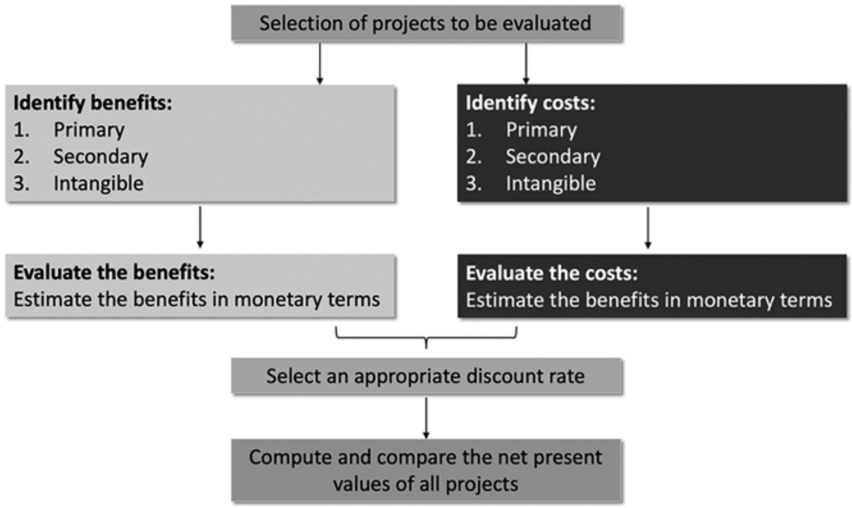


Figure 4.7 Steps in doing a social cost–benefit analysis

surplus. In case the value of the consumer surplus is unknown, the value of primary benefits from a project can be approximated by the total revenue generated. However, this simplified approach underestimates the benefits and therefore may introduce imprecision in the analysis.

- **Primary costs:** primary costs comprise input costs of the project, such as capital, labour, and energy, as well as operational and maintenance costs. These should be evaluated using the notion of opportunity costs, that is, if there is no alternative use of input, then its opportunity cost is said to be zero. For example, the opportunity cost of unemployed people is zero, whereas for employed people, it is the highest wage they could get in the next best job that they could find in a labour market.

Secondary Benefits and Costs

- **Secondary benefits:** it is important to account for indirect benefits that may manifest during the project, such as reduced flooding damages due to the construction of a dam. These types of benefits are called secondary benefits.
- **Secondary costs:** like secondary benefits, secondary costs might also arise in the form of indirect costs of a project. For example, building a dam along a river may decrease the flow of water downstream, and this could increase the production costs of a commercial fishing farm.

Intangible Benefits and Costs

- **Intangibles:** one of the most difficult aspects of conducting a social cost–benefit analysis is the evaluation of intangibles. Intangibles are goods and services whose economic value is not revealed in prices because they lack a market; thus, assigning a price to them is impossible. These are also called non-market goods. This also means that it is not possible to observe the revealed demand for these goods or their quality. For instance, it is quite difficult to evaluate the social cost of

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

air pollution due to the construction and operation of a coal-fired power plant or the loss of biodiversity due to the construction of a hydropower plant. Furthermore, it is difficult to assign an economic value to the protection offered to villages from reduced flood risk due to the construction of a dam along a river that regulates the flow of water.

Another example of adaptation projects is flood protection on the sea shore. This type of investment aims to protect the local community from the increased risk of damage caused by flooding. These are large-scale public investments that entail the construction of dams, embankments, dikes, and so on. These are fairly common in the Netherlands; for instance, the storm surge barrier at the Hollandse IJssel, an economically important region below sea level near Rotterdam, protects the area from floods. For these types of investments, the government performed a social cost–benefit analysis that considered, apart from the large initial construction costs, benefits such as increased safety and reduced damage to infrastructure and buildings, and the mitigated negative impact on agricultural yields. Intangible costs and benefits are extremely difficult to measure, making a social cost–benefit analysis relatively non–trivial compared to a private cost–benefit analysis.

In economic literature, several methods have been developed to evaluate the value of non-market goods. We can distinguish between methods based on stated choice and revealed choice. One of the most commonly used stated choice methodologies is contingent valuation, which normally involves doing a survey to infer the willingness to pay for a non-market good or an improvement in its quality in a hypothetical situation. For instance, we can use this method to elicit the willingness to pay for the possible improvement in air quality in urban areas that is likely from a hypothetical project. Another method based on the stated choices of individuals is the choice experiment, which differs from contingent valuation methods in that individuals are not directly required to express their willingness to pay, but end up doing so indirectly, by making choices between different hypothetical goods having different attributes (such as its environmental impact). Using information on these choices, and differences in the attributes across the goods, it is possible to estimate the value of an environmental attribute to individuals.

An example of a revealed preference method is the hedonic pricing method. This method is based on the theory that the price or value of a good depends on different characteristics, including its environmental attributes. The effect of changes in these attributes on the price can be assessed using regression-based methodologies. Another method usually used for revealed preference analysis is the travel cost method. In this case, the demand for a non-market good, for instance for preserving an alpine valley that is likely to be submerged due to the construction of a hydropower plant, is inferred by observing the visit frequencies to this valley and calculating the cost incurred by the visitors to get there. This cost includes not only the transport costs but also the opportunity cost of time. With information on travel costs and frequency, it is possible to estimate a demand function for non-market goods using econometric methods, and thus it is possible to have an estimate of the willingness to pay to protect this environment.

Incremental benefits of air quality improvements

Several cities around the world are affected by severe local air pollution. One possible solution to decrease the level of air pollution, at least partially, is to substitute old inefficient diesel buses with new electric buses using electricity produced from renewable energy sources. Figure 4.8 presents the marginal social benefit (MSB) function for improved air quality that can be used to identify the incremental benefits of introducing electric buses. This project is said to improve air quality because of the reduction in the number of fossil fuels burned, which will also reduce the number of local pollutants such as PM_{10} emitted. On the x-axis, we plot the quantity of PM_{10} abated, whereas on the vertical axis, we plot the MSBs from reducing the emissions of PM_{10}.

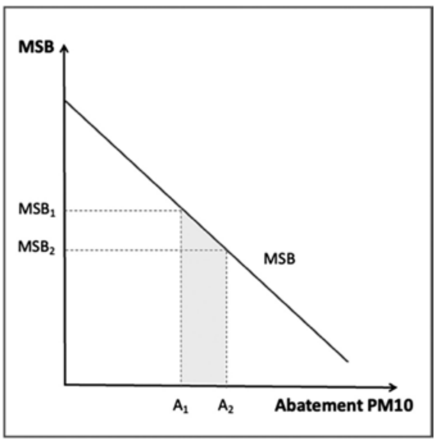


Figure 4.8 Incremental social benefits for air quality

The marginal social benefits function represents society's willingness to pay for the benefits obtained from a reduction of PM_{10} emissions, in terms of the improvement in air quality. The shaded area represents the incremental benefits from a decrease in PM_{10} emissions from A_1 to A_2. Of course, in Figure 4.8, we are assuming that we can observe the demand for pollution abatement. However, we know that there are no explicit markets for several environmental goods, and, therefore, it is not easy to estimate the incremental benefits. In these cases, as discussed previously, economists have suggested several approaches to derive the benefits from improvements in environmental quality, or more generally, the benefits of using goods and services not traded on a market.

The local socioeconomic impacts of large hydropower plant development in a developing country

In a study on Brazil, de Faria et al. (2017) [76] evaluated the local socioeconomic effects of sixty-six hydropower plants built from 1991 to 2010 across various counties in Brazil. They used econometric methods to evaluate their impact while considering counties in which hydropower projects were planned, but not yet built as the control group. The authors found that while the establishment of hydropower projects led to an economic boom in the short term (within 15 years of construction), these effects did not persist beyond that time. Also, they did not find a significant effect of hydropower projects on average incomes, life expectancy, as well as on other socioeconomic indicators. The findings of this paper lend support for taking a deeper look at costs and benefits over varying time horizons before constructing energy–sector projects, especially in developing countries, where capital costs may tend to be high.

4.5.2 Net Present Value Criterion

The concept of the NPV also applies as a decision criterion for doing a social cost–benefit analysis. From a mathematical perspective, this is done by rewriting the cash flows in the formula of NPV as the difference between societal benefits and costs, substituting the discount rate with a social discount rate, and subtracting the initial investment, as shown:

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1 + r_s)^t} - I \tag{4.17}$$

where:
NPV: Net Present Value
I: Initial investment cost
B_t: Societal benefits in period t
C_t: Societal costs in period t
r_s: Social discount rate

Note that values of I, C, B, and r should either all be measured in real terms, with an adjustment for the inflation rate, or all be measured in nominal terms.

The NPV criterion for social project evaluation suggests that any project that has a positive NPV, that is, benefits that exceed costs over the life of the project, is interesting from both economic and social perspectives. This criterion is based on the Kaldor–Hicks Criterion which states that if a project makes some individuals better off, and others worse off, then the project will increase social welfare if the winners, at least hypothetically, can compensate the losers while maintaining higher welfare. Moreover, this criterion implies that between similar projects, the project with the highest NPV should be chosen.

We must note that in general, evaluating the income and wealth-based distributional effects of a project is quite important, however, it is generally not considered when doing a social cost–benefit analysis.

Nevertheless, one could think of assigning weights to the benefits as well as costs, depending on the number of economic agents that experience these due to a project. For example, in a developing country, the construction of a hydropower plant will

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press

benefit households belonging to the middle and upper classes who consume electricity more than households that do not own appliances and perhaps have to leave their homes so that the plant can be built. In this case, one could consider giving less weight to the benefits and more weight to the costs of displacing poor households, especially in an economic equity-oriented society.

4.5.3 The Social Discount Rate

In Section 4.1, we discussed the rationale for discounting when doing an investment analysis. The social discount rate reflects the rate of substitution of society between present and future consumption. Two arguments were put forth: the time preference argument and the capital productivity argument. These arguments are equally valid in the case of discounting while doing a social cost–benefit analysis. An additional rationale for discounting also arises in this case, namely economic growth and decreasing marginal utility of income – today's investments and technical change are likely to give rise to economic growth, which implies that future generations are likely to be richer than present generations. Thus, their marginal utility from each unit of income will be lower, that is, each unit of currency will be worth less in the future when everyone enjoys higher incomes than it is today. Therefore, discounting is an important way to consider this decline in the marginal utility of income.

The definition of the social discount rate is critical and always creates much discussion since the value of NPV is strongly influenced by this rate. A high social discount rate corresponds to a high social value of consumption today relative to consumption in the future, or a high social value of the costs today relative to costs in the future. In other words, it implies that the consumption and costs of future generations are valued less than current consumption and costs. The extent of the impact of the discount factor on estimations is best explained using an example. Consider a social discount rate $r_s = 4$ per cent. If the discounted period is 50 years, such a discount rate would result in a discount factor (w) of 0.14. This implies that a gain or loss in 50 years would be valued at only 14 per cent of its initial value now ($w_{50} = 1/(1.04)^{50} = 0.14$). This is an extremely low value, which illustrates the potential sensitivity of the NPV calculation to the choice of the social discount rate. It is important to keep in mind that in the energy and climate sectors, we typically have projects with long lifespans. For instance, a hydropower plant can have a lifetime of up to 80–100 years. The benefits of adaptation projects can also last up to 100–150 years.

In all these cases, the choice of discount rate profoundly influences the evaluations. A high discount rate will dramatically reduce the value of the future benefits of reducing the damages of climate change, that is, the benefits for future generations. Likewise, a high discount rate implies that the long-term costs associated with the treatment and storage of nuclear waste are meagre. However, future generations will need to pay these costs, giving more weight to the costs than the one assumed in doing the cost–benefit analysis. Therefore, by choosing a high discount rate, current generations are not fully taking into account the benefits and costs of these investments for future generations.

4.6 Issues in Developing Countries

As we learnt in this chapter, investment analysis in the energy sector can have important repercussions on the energy transition towards renewables. We will now discuss three issues that we think are relevant for investment analysis in developing countries, namely the growth of decentralised energy systems and the role of renewable energy technologies in developing countries and the importance of social discount rates.

In many developing countries, given the abundance of resources such as sunlight, water, and wind, and the decline in renewable energy production costs, the transformation to cleaner sources of energy is inevitable, even though fossil fuels may still remain dominant in some settings. One apparent (and already underway) outcome of this transition is the growth of decentralised energy systems: we will first discuss these systems in this section, which have paved the way for affordable and clean energy access for millions in the developing world. We will then discuss the role of policy in facilitating the transition to renewables in developing countries. Last, given that investments in public projects entail knowledge of the social discount rates, we will discuss relatively high social discount rates in developing countries, underlining the method of computation and how it can have an impact on the values of this parameter.

4.6.1 Application of Investment Analysis: Growth of Decentralised Energy Systems

There are vast differences in terms of access to electricity across the world; however, many parts of the developing world, particularly in Africa, are far from achieving universal access to electricity. Furthermore, the quality of electricity supply is poor in many countries, and this implies frequent blackouts and load-shedding events, which can have serious consequences on the benefits of electrification.

While designing policy instruments to promote electrification in developing regions, policymakers face several challenges. Some of these are high electricity connection charges (especially to extend grid electricity to remote rural areas), high operating costs, low population density in rural areas, difficult terrain, unreliability in supply, as well as a lack of finance for adequate investment in infrastructure.

Moreover, extending electricity access is not the panacea for all problems related to electricity. Ensuring the reliability of electricity supply and power quality (with minimal interruptions, blackouts, and voltage fluctuations) remains an enormous technical and financial challenge in many developing countries.

Decentralised systems such as solar home systems as well as micro/mini-grids offer households living in rural, remote areas the possibility to easily connect to electricity by 'leap-frogging' centralised systems. The benefits of these decentralised systems that rely almost exclusively on renewable technologies are that they provide an affordable means to acquire reliable access to electricity (even though the cost per kWh of some of these options may be higher than that of grid connections) and are relatively cheaper and cleaner than using diesel generators. One of the disadvantages is that the smaller systems make it impossible to use multiple or high-power appliances.

Thus, from the policymaker's perspective, performing a cost–benefit analysis is important to understand whether it is worth extending the electricity grid to the rural areas, possibly at a high cost, or whether to emphasise subsidising or promoting the use of decentralised systems, which can serve to extend access to energy to these households. Given that these are relatively small-scale systems, policymakers may choose to ramp up investments in building or extending grid infrastructure over time, prioritising the adoption of these systems in the short run.

An investment analysis from a private point of view is also interesting in this regard. Consider a situation where households living in remote areas are looking to acquire access to electricity and have two possibilities: either connecting to the grid (if it is available nearby) or investing in an off-grid system (such as a solar home system). In the first case, the initial investment costs for a grid connection may, in many cases (especially in low-income countries), be very high, and the theoretical benefits may also be relatively large (compared to the off-grid system). On the other hand, several challenges related to supply, such as poor reliability and quality of electricity and transmission and distribution losses, may make these benefits less likely to materialise. In the case of the off-grid system, while households may pay less upfront, the magnitude of benefits realised also generally tends to be smaller (given the smaller scale of these systems). However, with low or no transmission losses and a relatively stable electricity supply, households are better assured of receiving these benefits. The choice between the two forms of electricity will depend on how high the grid connection costs are and the magnitude of discounted benefits. Households can then undertake an investment analysis and compare the two options (in terms of their NPV) to decide which one they prefer.

4.6.2 Levelised Cost of Energy in Developing Countries

The primary challenge for the larger deployment of renewable energy, not just in developing countries, but also in developed countries, is their somewhat higher cost of installation, and in the case of solar and wind, their short-term variable character.

The opportunities offered by renewable energy technologies in developing countries are paramount: for instance, most parts of the developing world are well endowed with sunlight and wind. The LCoE for renewable energy technologies has declined in many developing countries in recent times due to a combination of factors: technological progress, a decline in operating costs (due to declining labour costs with technical progress, as well as economies of scale), and a decline in investment costs (which is a result of both technological improvements and policy). These trends are also likely to continue, which suggests that economic policy must be supportive of renewable deployment in developing countries, and policymakers could prioritise this as a short-term energy policy goal to facilitate decarbonisation.

The inherent intermittence and variability of renewable power production implies that developing countries must invest in backup systems as well as storage, and improve forecasting to benefit from their use. Greater research and development (R&D) efforts are needed to advance technical knowledge, increase efficiency, and reduce the costs of storage and backup technologies. Even though installation costs have fallen over time for these technologies even in developing countries, it remains important to increase capital investments in reducing variability, which should be supported by innovation-based policies. Furthermore, investments also need to be made in the grid infrastructure, such as in extending the network and in digitalisation. These investments are important for extending the grid to remote areas and ensuring that clean electricity is used by households and businesses.

Role of policy for promoting investments in solar energy in developing countries

Ondraczek et al. (2015) [77] discussed the importance of financing costs in determining the LCoE for solar PV. They argued that in developing countries, the WACC was generally higher than in developed countries (due to higher costs of capital) and that this difference between both sets of countries contributed more to variations in LCoE across countries than differences in solar potential. They highlighted that policymakers in developing countries should emphasise de-risking renewable sector investments and promoting access to cheap finance, to reduce the cost of borrowing, as has also been argued in other studies cited in this chapter.

4.6.3 Social Discount Rates

As we saw in Section 4.5, the choice of social discount rate is an important determinant of the evaluation of the social costs and benefits of a public project. In many developing countries, the market interest rate (or rate of return on private sector investments) is used as the social discount rate in cost–benefit analysis, and this typically tends to be high (in the range of 10–12 per cent). The use of such high discount rates may discourage projects having relatively high upfront costs, with benefits spanning several time periods (such as investments in renewable power projects).

An alternative to calculate social discount rates, in such settings, may be to use the real interest rate at which these countries can borrow. Some economists argue that this measure correlates better with the cost of borrowing for governments, who are most likely to be funding these projects. This would imply a real discount rate of about 5 per cent, which is lower than the current social discount rate used in many countries. This is also the approach used in many industrialised countries. Of course, if sovereign debt yields were to increase due to changes in macroeconomic conditions in the country, the real interest rates may increase, and then the social discount rate should reflect these changes.

4.6.4 Review Questions and Problems

The online question bank contains review questions and problems for this chapter, including solutions (see https://wp-prd.let.ethz.ch/exercisesfortextbookeep/).

https://doi.org/10.1017/9781009471831.005 Published online by Cambridge University Press