3 Investment and Profitability Calculation

Capital budgeting and profitability accounting are necessary for assessing the economic viability of energy investments. Although the methodology for energy investments does not differ fundamentally from other applications, there are unique problems associated with it due to some particularities of investment in energy technologies. Long planning, construction, and operation periods make the result of an investment decision strongly dependent on the discounting of future cash flows.

These facts motivate consideration of the following issues:

– What is the meaning of (net) present value of a flow of revenues (expenditures, respectively)?
– Why is the interest rate especially important in investment projects relating to energy and what determines this rate of interest?
– How can one account for future inflation (deflation, respectively)?
– Would it be preferable to abstain from discounting altogether, in the interest of sustainability?
– What insights can be gleaned from recent developments in the theory of finance?

The variables used in this chapter are:

av	Individual risk aversion
Cap	Rated capacity of power plants and other energy technologies
C_{var}	Total variable cost (incl. fuel cost)
c_{var}	Variable cost per output unit
E_t	Annual energy production
Inv	Investment expenditure (incl. financing cost)
i	Interest rate, discount rate
ic	User cost of capital per output unit
ν	Capacity factor
NPV	Net present value
Π	Total profit
p	Price per output unit

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DOI 10.1007/978-3-662-53022-1_3

p_E	Price of energy
p_F	Price of a (energy) future
Q	Total output (quantity)
q_{market}	Market expectations regarding return on investment
q_s	Savers' time preference
PVF	Present value factor
ROI	Return on investment
σ_E	Standard deviation (volatility)
T	Assumed lifetime of the investment
w	Probability

3.1 Basics

Financial appraisal techniques require a forecast of future flows of costs and revenues over the lifetime of the investment. In this regard, only those costs and revenues that are directly linked to the planned investments are to be considered. For example, in the decision process of retrofitting a power plant, the initial construction cost of the plant is irrelevant; only the additional costs and revenues caused by the upgrade should be taken into account. Likewise, in a short-term production decision ("Should the existing power plant increase its rate of production?"), only the associated additional costs affect its outcome. The most important cost components are:

– Additional costs for fuel and emission rights, depending, among other things, on output-related fuel efficiency;
– Accelerated degradation of the installation due to thermal stress resulting from temperature change in boilers and pipes;
– Fuel losses during start-up and shut-off periods.

The sum of these costs divided by the additional production is the marginal unit cost that describes the economic impact on the plant operator if production is to increase or decrease by one unit. The investment outlay and other expenditures that are not affected by the production decision, such as personnel and administration, are irrelevant for the evaluation of short-term production decisions.

For the evaluation of a long-term investment decision, again only those economic variables that might be affected by it have to be considered. If a company plans for an incremental expansion of capacity, the cost of management should be excluded, for example. However, the additional expected sales revenues per period generated by the investment are relevant. They depend on:

– The capacity *Cap* to be installed (measured for example in tons of output per day or in megawatt of electricity);

– The capacity factor ν, specifying the average expected percentage of annual full-load operation[1];
– The average expected price of energy sales p_E.

With power plant capacity denoted by Cap (measured in MW), annual output and corresponding annual sales revenues are calculated as follows,

$$Q = Cap \cdot \nu \cdot 8760 \quad (3.1)$$

$$p_E \cdot Q = p_E \cdot (Cap \cdot \nu \cdot 8760) \quad (3.2)$$

The financial counterpart of annual sales revenues are the expected future annual costs, which can be divided into a variable and a fixed cost component. Variable cost C_{var} includes the cost of intermediate inputs such as annual expenses for raw materials, fuels, emission rights, waste disposal, and to some extent also wages (given flexible employment contracts). When dividing expected variable cost by expected output Q, one obtains variable cost per unit output $c_{var}= C_{var}/Q$. The fixed cost amounts to the annualized investment outlay. The ratio, fixed cost/variable cost is an indicator of the capital intensity of an investment project. The contribution margin is defined as the difference between annual revenue and annual variable cost.

For investment decisions, investment outlay Inv including the cost of financing must be compared to the annual expected cash flows or contribution margins, respectively, during the project's lifetime. In a simplified analysis, one assumes the investment outlay to take place in period t_0, leading to a negative cash flow Inv_0 in this period. In the following years, the cash flows are given by $(p_{Et} - c_{var,t}) \cdot Q_t$. They should predominantly be positive in order to make the project economically viable. The time horizon is the end of the project's economic life T.

A time series of annual cash flows can only be meaningfully evaluated if their individual values are referenced to the period in which the investment is undertaken ($t = 0$). The resulting quantity is called Net Present Value (NPV). It is given by

$$NPV = -Inv_0 + \sum_{t=1}^{T} \frac{\left(p_{E,t} - c_{var,t}\right) \cdot Q_t}{(1+i)^t} \quad . \quad (3.3)$$

The (real, inflation-adjusted) interest rate i discounts all future cash flows; it is therefore called discount rate. The term $(1+i)^{-t}$ is referred to as the discount factor.

Discounting reflects the fact that a cash flow that occurs later in time has a reduced value. If funds are received early, they can be re-invested to generate additional revenue. Assuming a common interest rate i for borrowing and lending, the re-invested funds increase by $(1+i)$ within 1 year.[2] Conversely, the present value

[1] A year has $24 \cdot 365 = 8760$ h (8784 h in a leap year). Thus a capacity factor of $\nu = 20\%$ equals $0.2 \cdot 8760 = 1752$ full load operation hours.

[2] The assumption that borrowing and lending occur at the same rate is equivalent to the assumption of perfect capital markets. Another important proposition is that all transactions are free of costs Sect. 3.2.

of one monetary unit received (or paid, respectively) 1 year from now amounts to $1/(1+i)$. At an interest rate of 5% e.g., this is 0.952 monetary units because $0.952 \cdot 1.05 = 1$. By analogy, funds received 2 years hence have a present value of $1/(1+i)^2$.

If annual cash flows remain constant over the entire life of the project, Eq. (3.3) can be rewritten to become

$$NPV \quad = \quad -Inv_0 + (p_E - c_{var}) \cdot Q \cdot \sum_{t=1}^{T} \frac{1}{(1+i)^t}. \tag{3.4}$$

The sum on the right-hand side is called present value factor *PVF* of an annuity,

$$PVF_{i,T} \quad = \sum_{t=1}^{T} \frac{1}{(1+i)^t} = \frac{1}{i} - \frac{1}{i \cdot (1+i)^T}. \tag{3.5}$$

It defines the net present value of an annual cash flow consisting of one monetary unit paid T times, at a given discount rate i. Table 3.1 shows the *PVF* for different investment periods T and discount rates i. For example, at an interest rate of 8%, 1 EUR paid ten times has a present value of only 6.7101 EUR rather than 10 EUR because most of the payments come in with a delay. At an interest rate of 10%, the present value drops to 6.1446 EUR. The effect of discounting is even more marked for longer time horizons; 1 EUR paid 20 times is 'worth' only 8.5136 EUR today at 10%—with no inflation whatsoever.

The reciprocal of the *PVF* is the capital recovery factor *CRF*,

$$CRF_{i,T} = \frac{1}{PVF_{i,T}} \quad = \frac{i \cdot (1+i)^T}{(1+i)^T - 1}. \tag{3.6}$$

It defines the constant annual amount necessary to repay a loan of one monetary unit within a time T and at a given discount rate i. Using the capital recovery factor, the cost of an initial investment outlay Inv_0 can be rewritten as a sequence of negative cash flows over T time periods. This yields so-called annual capital user cost,

$$ic = Inv_0 \frac{1}{PVF_{i,T}} \quad = \quad Inv_0 \frac{i \cdot (1+i)^T}{(1+i)^T - 1}. \tag{3.7}$$

According to Eq. (3.4) the *NPV* of an investment depends on several variables, in particular the discount rate i, the expected sales price p_E, and the lifetime T of the project. When setting $NPV = 0$, Eq. (3.3) or (3.4) can be solved with respect to each of these variables. This generates three different evaluation indicators:

– Solving with respect to the discount rate i yields the so-called internal rate of return *IRR*, an indicator of return on investment (ROI). *IRR* is calculated by

Table 3.1 Sample present value factors (*PVF*) of an annuity of 1 paid *T* times

	Interest rate *i*							
Years *T*	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10
1	0.9709	0.9615	0.9524	0.9434	0.9346	0.9259	0.9174	0.9091
5	4.5797	4.4518	4.3295	4.2124	4.1002	3.9927	3.8897	3.7908
10	8.5302	8.1109	7.7217	7.3601	7.0236	6.7101	6.4177	6.1446
15	11.9379	11.1184	10.3797	9.7122	9.1079	8.5595	8.0607	7.6061
20	14.8775	13.5903	12.4622	11.4699	10.5940	9.8181	9.1285	8.5136
25	17.4131	15.6221	14.0939	12.7834	11.6536	10.6748	9.8226	9.0770
30	19.6004	17.2920	15.3725	13.7648	12.4090	11.2578	10.2737	9.4269
40	23.1148	19.7928	17.1591	15.0463	13.3317	11.9246	10.7574	9.7791
50	25.7298	21.4822	18.2559	15.7619	13.8007	12.2335	10.9617	9.9148

simulating Eq. (3.3) or (3.4) under varying interest rates until the net present value becomes zero. Figure 3.1 shows a fictitious example resulting in $IRR = 11.5\%$.

– By solving Eq. (3.4) for the energy price p_E, one obtains the break-even price required to recover investment outlay Inv_0 and unit variable cost c_{var}. It is often referred to as unit production cost or the levelized cost of energy,

$$p_E = \frac{Inv_0}{Q \cdot PVF_{i,T}} + c_{var}. \tag{3.8}$$

Figure 3.2 shows how this break-even price depends on project life T and the discount rate i. The figure assumes costs that are typical of an investment in onshore wind power. As long as break-even price pE exceeds the wholesale price of power, the investment is not competitive. However, the government may mandate electrical grid operators to purchase e.g. wind power at a fixed feed-in tariff. In this case, wind power installations become virtually economic if their break-even prices are below the fixed feed-in tariff. Other support schemes such as market premiums[3] and investment subsidies may have similar effects on investment in wind power and other renewables.

– By solving Eq. (3.4) for T, one obtains the break-even payback time T^*. This is the time needed for recovery of a given investment outlay including compound interest through future revenues. For simplification, introduce $AN = (p_E - c_{var}) \cdot Q$ in Eq. (3.4), use Eq. (3.5), and solve for Inv_0 to obtain

$$Inv_0 = AN\left(\frac{1}{i} - \frac{1}{i(1+i)^T}\right) = \frac{AN}{i} - \frac{AN}{i(1+i)^T}. \tag{3.9}$$

– By multiplying both sides by i/A, one obtains

$$\frac{i \cdot Inv_0}{AN} = 1 - \frac{1}{(1+i)^T} \quad \text{or} \quad 1 - \frac{i \cdot Inv_0}{AN} = \frac{1}{(1+i)^T}. \tag{3.10}$$

[3]Market premiums are payments to wind power operators on top of the revenues they receive from selling to the market or directly to final customers.

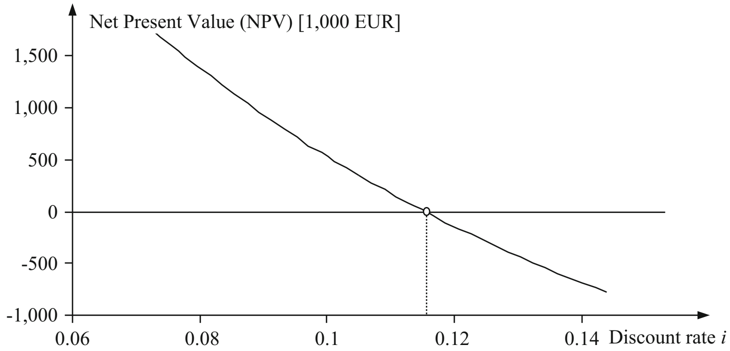


Fig. 3.1 Net present value as function of the interest rate. Assumptions: Investment outlay $Inv_0 = 5500$ EUR; variable cost $c_{var} = 200$ EUR/a; sales revenue 850 EUR/a; operation period $T = 20$ years

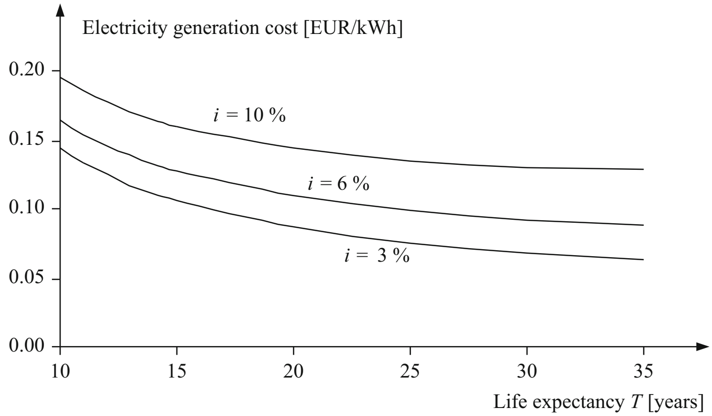


Fig. 3.2 Energy cost as a function of lifetime and interest rate. Assumptions: investment cost $Inv_0 = 2000$ EUR/kW; variable cost $c_{var} = 0.01$ EUR/kWh; capacity factor $\nu = 0.2$

Taking the logarithm and solving for T gives break-even payback time,

$$T^* = -\frac{1}{\ln(1+i)} \cdot \ln\left(1 - \frac{i \cdot Inv_0}{(p_E - c_{var}) \cdot Q}\right) \tag{3.11}$$

Therefore, a project characterized by high initial investment expenditure Inv_0 needs to have a short payback time *ceteris paribus* to be economically viable—a condition not easily satisfied in the energy sector. Conversely, a high profit margin $(p_E - c_{var})$ and a large volume of expected future sales Q both make a project attractive, which is also true of a low rate of interest i.

3.2 Interest Rate and Price of Capital

Due to the long-term character of most investment in the energy sector, the result of a financial appraisal is greatly affected by a variation of the discount rate i. The choice of the discount rate must therefore be well-founded, calling for an understanding of the nature of interest rates and of the key variables influencing them.

According to economic theory, the interest rate amounts to the price for obtaining funds for a specified time; thus, short-term interest rates generally differ from long-term ones. In the following, a contract duration of 1 year is assumed. Since lenders have no access to their money during this time, they expect investors to provide an appropriate financial incentive in addition to a compensation for the risk that the creditor may default. As in any other market, price is determined by the intersection of supply and demand so that the market is cleared. Supply of capital is provided by savings, while demand originates with entrepreneurs in need of funds to finance their investments.

The supply of savings importantly depends on the (marginal) time preference of consumers q_s. They are willing to abstain from one unit of consumption at time t_0 if they can consume at least $(1+q_s)$ units in the next period t_1. Thus q_s is referred to as the (marginal) rate of substitution between present and future consumption. As long as the yield on savings outweighs this rate ($i > q_s$), individuals will normally[4] delay consumption, permitting them to offer funds on the capital market up to the point where $i = q_s$.

The demand for capital depends on the expected return on investment (*ROI*). It increases as long as *ROI* exceeds the rate of interest i investors have to pay for funds. Equilibrium is reached where *ROI* (which equals the internal rate of return of the last (marginal) investment project, denoted by *IRR*) is just enough to cover the cost of funds, thus where $i = IRR$.

Since both saving and investment are influenced by the market interest rate, the interest rate balances the two, causing supply of and demand for capital to match (see Fig. 3.3). Assuming a perfect, fully transparent capital market without transaction costs, equilibrium yields

$$q_s = q_i = i = ROI = IRR. \tag{3.12}$$

The importance of the cost of capital for the macroeconomic assessment of an energy investment is illustrated by the following example. At decision time t_0, let the project call for investment outlay of 1 EUR; therefore, other economic sectors must reduce consumption or investment by the same amount. Let the project have a benefit of $G(t_1)$ EUR in the next period t_1, expressed in additional consumption

[4]This holds provided the substitution effect—the incentive to move consumption from today to tomorrow holding wealth constant—outweighs the wealth effect of interest and dividend payments, which may induce consumers to consume, i.e. to reduce saving.

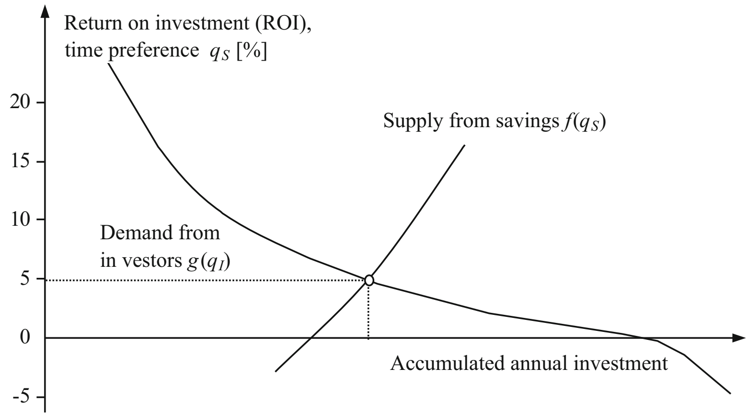


Fig. 3.3 Aggregated capital demand and supply

possibilities. Focusing on private consumption for simplicity, one can say that the project has a positive effect on the economy as long as its net present value (discounted using time preference q_s of savers) is greater than the loss in terms of current consumption caused by the drain on capital. This condition can be written as $G(t_1)$ > $1+q_s$.

On the other hand, realization of the project may 'squeeze out' investment elsewhere in the economy. This occurs if it yields a return above the *ROI* of competing projects, which is the case if $G(t_1)$ > $1+ROI$. In a perfect capital market, equality (3.12) shows that a sacrifice in terms of current consumption and current investment lead to the same conclusion: The opportunity cost of a project is independent of the way it is financed because its benefits (returns, respectively) as well as costs should be discounted using the market interest rate.

3.3 Inflation-Adjusted Interest Rate

For the evaluation of long-term investments, expected future inflation must be taken into account (past inflation is irrelevant for a decision concerning the future). If nothing else changes, inflation causes nominal costs and revenues to increase over time. Let its expected rate $\Delta p^e/p$ be the same for both unit variable cost c_{var} and price p_E. If in addition it is constant over the entire planning period, inflation can be introduced into net present value calculation in the following simple way,

$$p_{E,t} = p_E \cdot \left(1 + \frac{\Delta p^e}{p}\right)^t \quad \text{and} \quad c_{var,t} = c_{var} \cdot \left(1 + \frac{\Delta p^e}{p}\right)^t \tag{3.13}$$

with current energy prices p_E and current variable unit cost c_{var}. Inserting this into Eq. (3.3) results in

$$NPV \quad = \quad -Inv_0 + (p_E - c_{var}) \cdot Q \cdot \sum_{t=1}^{T} \frac{(1 + \Delta p^e/p)^t}{(1+i)^t}. \tag{3.14}$$

As long as the future expected rate of inflation is low (below 10%, say), this equation can be approximated by

$$NPV \quad \approx \quad -Inv_0 + (p_E - c_{var}) \cdot Q \cdot \sum_{t=1}^{T} \frac{1}{\Big(1 + (i - \Delta p^e/p)\Big)^t} \tag{3.15}$$

Accordingly, inflation effects can be accounted for by subtracting the expected inflation rate $\Delta p^e/p$ from the rate of discount rate. Accordingly, one defines an expected real rate of discount,

$$i^e := i - \frac{\Delta p^e}{p} \tag{3.16}$$

to be used in discounting inflation-adjusted cash flows and costs. Conversely, Eq. (3.16) states that the nominal market rate of interest rate i is the sum of the real rate i^e (which in turn equals time preference of savers who are interested in real rather just nominal consumption) and the expected rate of inflation $\Delta p^e/p$.

Inflation confers an advantage on owners of physical assets, which appreciate in value. Conversely, creditors suffer to an equivalent degree. Therefore, inflation gains and losses correspond to each other. Suppose that consumers, expecting an inflation rate of 3%, would like to see their real consumption possibilities increase by 5% within a year, equal to their rate of time preference. They then would ask for a nominal interest rate of 3+5 = 8%. Investors who expect that their net revenues will also rise in correspondence to the inflation rate would be willing to pay that rate.

Yet on closer inspection, this line of argument is short-sighted. Neither creditors nor investors are immune to erroneous predictions. The greater the uncertainty about future inflation rates, the greater the risk to lenders of capital. If they should underestimate the real rate of inflation, they may end up with a negative real rate of interest and hence reduced rather than enhanced consumption possibilities. Taking such risk into account, lenders may ask for a risk premium, resulting in a still higher nominal rate of interest. Alternatively, they may place their savings in tangible assets such as gold and other precious metals rather than the capital market. For this reason alone, economists widely view inflation as something that should be avoided. Moreover, they fear its tendency to accelerate once inflationary expectations are built into wage negotiations and pricing decisions, resulting in the so-called wage-price spiral.

3.4 Social Time Preference

When evaluating energy investments with an economic life of 40 years or more, high discount rates have a strongly negative effect on the viability of a project. This is because cash flows occurring late in time are reduced to just about zero in present value through discounting. Capital-intense investments in renewable energy or in energy efficiency are affected in particular because their evaluation depends on the expectation that the real price of conventional fuels rises over time. However, the Hotelling rule of Sect. 6.2.1 predicts that this rise is no faster than the real rate of interest. If the *ROI* currently applied by investors exceeds this rate (for instance because they are skeptical about the longer-term prospects of the economy, causing their planning horizon to be short), future cash flows contribute little to net present value.

Indeed, the discount rate can be interpreted as the market's 'shortsightedness'. Figure 3.4 illustrates this. An investor assuming an interest rate of 4% discounts 1 EUR of cash flow that comes in after 40 years according to the formula of compound interest, resulting in

$$\frac{1}{(1+i)^t} = \frac{1}{1.04^{40}} = 0.208. \tag{3.17}$$

Therefore, only 20% of this cash flow contributes to the project's *NPV*. If the investor applies an interest rate of 8%, this contribution is reduced to even less than 5%. Evidently, the higher the discount rate, the less likely is a positive *NPV* for a project with a long life such as 40 years, *ceteris paribus*. Short-term projects have a better chance. Thus, one can say that high rates of discount cause investors to become myopic.

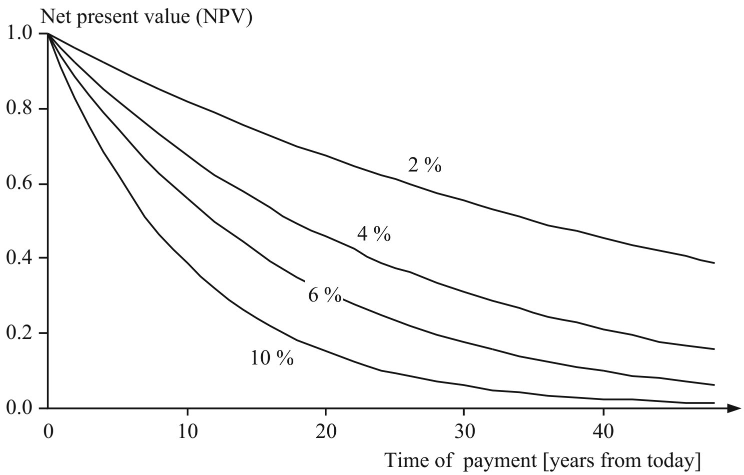


Fig. 3.4 Net present value of future financial flows at different interest rates

From a macroeconomic point of view, the question arises whether investments that have the benefit of sustainability should not be evaluated using a lower social rather than the market discount rate. In the scientific literature, lower values and even a zero value for the discount rate have been proposed (see Lind et al. 1982), partly on philosophical rather than strictly economic grounds:

– The human being is in a permanent conflict between the subconscious (considered to be irrational) and the conscious (associated with rationality). The irrational part seeks the fast, instant satisfaction of desires, while mid-term or even long-term projects require a higher tolerance of frustration. The interest rate is the economic equivalent of this behavioral fact but in the end reflects irrational myopia. Pigou (1932) called this effect 'defective telescopic faculty'; Harrod (1948) referred to it as 'pure time preference'.
– The choice of a social discount rate can be seen as the outcome of a negotiation between different social groups. In the case of long-term projects in the interest of sustainability, relevant stakeholders such as future generations are not represented at the negotiating table, causing the outcome to be distorted if present market conditions and in particular the market discount rate are used for the evaluation of these projects.
– In addition to their pure time preference reflected by market behavior, citizens of today may have diverging social rates of time preference. This is expressed on the political level; people may want the government to take responsibility for future generations but are not willing to include it in their individual decisions. They use a social discount rate when participating in political referendums on projects in the interest of society. Since voters differ with respect to this rate, it is the median voter (who turns a minority into a majority in a two-party system) who determines the social discount rate. This rate (implicit in the outcome of pertinent referenda) may be used for calculating the net present value of long-term projects.
– A similar argument can be derived from the distribution of wealth, which is heavily skewed in most societies. Wealthy individuals, disposing of substantial capital funds, influence the market interest rate more than poor ones. When deciding on projects in the interest of the society and of future generations, democratic decision rules require that poor individuals have the same weight as wealthy individuals.

Although those arguments seem reasonable at first glance, one should be careful to promote the use of social discount rates that are different from the market interest rate when it comes to evaluating energy investments of public interest. A low social discount rate would indeed support 'sustainability projects'. Yet projects of this type could be harmful to future generations because they need to be financed by government, private investors requiring a *ROI* in excess of the social rate of discount. To the extent that government debt increases, future generations are burdened with a debt that can be substantial in view of the high capital intensity of these projects. Indeed, future capital costs could outweigh the benefits of the project to them. An artificially low discount rate thus may run counter the good intentions of their promoters in the long run; the way to a more sustainable development cannot be cleared by manipulating the discount rate.

More generally, a basic principle of economic policy applies in this context. The Dutch Nobel prize laureate Tinbergen (1967) realized the analogy between a system of equations and the relationships linking a set of objectives to a set of policy instruments. The objectives can be viewed as dependent variables and the policy instruments, as arguments in a system of equations. A policy maker who wants to know how to reach his or her objectives needs to solve for the arguments; however, an equation system generally has a solution only if the number of functional relationships and hence arguments is at least as large as the number of dependent variables (for instance, a system of two unknowns can be solved only if there are at least two equations). This implies that by using only a single control variable such as the discount rate, policy makers cannot simultaneously attain the two goals of maximum inter-temporal efficiency (i.e. a high productivity of investment) and maximum inter-generational distributional justice.

Through some of its economic activities, the present generation puts the livelihood of future generations at stake. This can be counteracted by the introduction of fundamental rights of future generations to live in an unspoiled and livable environment on a par with the (constitutional) human rights of the current generation. These fundamental rights should not be discounted when deciding investment projects. However, long-term investment projects that do not affect them should be discounted using the market interest rate, with inflationary expectations taken into account as shown in Sect. 3.3.

3.5 Interest Rate and Risk

For most real-world investment, knowledge about future returns is limited. They are subject to a multitude of risks:

- Engineering and construction risks;
- Financial risks;
- Technical risks during operation;
- Customer risks (e.g. default of payments, declining demand);
- Supplier risks (e.g. supply interruptions);
- Price and exchange rate risks;
- Social risks (e.g. strikes);
- Political risks (market interventions).

Investors may try to quantify these risks by defining a set of possible scenarios, assigning to them subjective probabilities w_k describing the likelihood of occurrence,

$$0 \leq w_k \leq 1, \quad k, k = 1 \ldots, N, \quad \text{with} \quad \sum_{k=1}^{N} w_k = 1. \tag{3.18}$$

In the limiting case, one of the scenarios has a probability of one while all other probabilities are zero. This is the case of certainty.

Applied to investment decisions, for each scenario k a rate of return on investment ROI_k is calculated. The expected rate of return is given by

$$\mathrm{E}(ROI) = \sum_{k=1}^{N} ROI_k \cdot w_k \tag{3.19}$$

and the associated variance, by

$$\sigma^2 = \sum_{k=1}^{N} (ROI_k - \mathrm{E}(ROI))^2 \cdot w_k. \tag{3.20}$$

In the case of certainty, variance σ^2 is zero. The risk of a project increases with σ^2 (or with raising standard deviation σ, respectively).

To the extent that market participants are risk-averse, they ask for a risk premium in addition to the rate of return pertinent to a corresponding risk-free investment.[5] Thus, investment decisions under risk take not only the expected rate of return $\mathrm{E}(ROI)$ of the project into account, but also its uncertainty, usually reflected by variance σ^2. According to the Bernoulli criterion, investors maximize a linear combination of expected profit and variance of profit

$$\mathrm{E}(ROI) - \frac{av}{2}\sigma^2 \rightarrow \max!. \tag{3.21}$$

The term av denotes the individual's degree of risk aversion $av \geq 0$ (see also Sect. 11.3). Thus, Eq. (3.21) describes a trade-off between expected value and variance of returns promised by a project: Given $av > 0$, a project with higher expected profit is only preferable to a project with lower expected profit if it does not have the downside of a higher variance of profits.

3.5.1 Capital Asset Pricing Model (CAPM)

Up to this point, an investment project has been assessed in isolation. However, investors usually have a whole portfolio of project, providing them with the possibility of risk diversification (Markowitz 1952). This means that they evaluate a project not only in terms of its contribution to the overall expected return but also its contribution to the overall risk of their portfolio. In view of the trade-off discussed above, a single project may even lower the portfolio's expected rate of return provided it reduces the variance of the portfolio's return to a sufficient

[5] Risk-aversion exists if a possible loss has a higher influence on utility than a gain of equal size and equal probability of occurrence.

degree. This is possible if the project considered has a higher return than expected precisely when others perform worse than expected, and *vice versa*. Therefore, deviations from E(*ROI*) values of the project considered need to be negatively correlated with the *ROI* of the portfolio as a whole. Since a correlation coefficient is nothing but a normalized covariance, it is sufficient to calculate the covariance between the project's rate of return and the return of the entire portfolio held by the investor. For simplicity, investors are assumed to hold all assets traded on the capital market in proportion to their aggregate share, which is possible by buying stock of listed companies. Moreover, let the probabilities $w_{k,j}$ defined over the K scenarios of the project considered and the J scenarios of the market portfolio $q_{market,j}$ be the same. This is not unrealistic since the *ROI* values of individual investment projects and those pertaining to listed companies tend to move in parallel in response to the business cycle. With these simplifications, covariance is given by

$$COV = \sum_{k=1}^{K} \sum_{j=1}^{J} (ROI_k - \mathrm{E}(ROI)) \cdot \left(q_{market,j} - \mathrm{E}(q_{market})\right) \cdot w_{k,j}. \tag{3.22}$$

Thus, the deviations from expected values of *ROI* weighted by their probability of occurrence are summed up. Accordingly, *COV* can be positive (positive correlatedness, making some limited risk diversification possible; see below), negative (enabling marked risk diversification), or zero (enabling risk diversification especially for large portfolios). Note that calculating *COV* is confronted with at least three challenges. First, the relevant market portfolio needs to be defined. Frequently, the stock exchange of the investor's resident country has been used; however, especially big investors increasingly seek risk diversification across national capital markets. Second, the time window used for estimation makes a considerable difference. In particular, estimates of E(*ROI*) and *COV* depend strongly on how many years prior to the financial crisis of 2007–2009 are included in the sample. Third, *COV* values usually are employed for guidance 1 year ahead, sometimes even only a quarter into the future. Planning horizons this short do not match the long life of a typical energy investment.

With these caveats in mind, one can use the Capital Asset Pricing Model (CAPM) for determining the risk-adjusted rate of return required of an individual investment project ROI^* in case the investor's portfolio consists of very many components (Sharpe 1964),

$$ROI^* = i + \frac{COV}{\sigma^2_{market}} \cdot (\mathrm{E}(q_{market}) - i) = i + \beta \cdot (\mathrm{E}(q_{market}) - i). \tag{3.23}$$

Here, i denotes the risk-free interest rate and $\sigma^2{}_{market}$ the variance of *ROI* values characterizing the capital market. The ratio

$$\beta = \frac{COV}{\sigma^2_{market}} \tag{3.24}$$

describes the relationship between the *ROI* of the project and the *ROI* pertinent to the capital market (in fact, it is nothing but the slope parameter of a linear regression linking ROI_k to ROI_{market}). Note that investors' risk aversion has no influence. Five cases can be distinguished.

- $\beta = 0$: The project's rate of return is uncorrelated with the reference market return. According to the CAPM, no risk premium is required for such an investment project, since the risk associated with the project is fully diversified away. Accordingly, returns can be discounted using the risk-free interest rate i. The yield of government bonds[6] is often used as an indicator of the 'risk-free' market interest rate.
- $\beta = 1$: The project's expected rate of return fluctuates in parallel with the reference market portfolio. With $\beta = 1$, the CAPM Eq. (3.23) implies $E(ROI) = E(ROI)_{market}$: The project bears the same systematic risk as the general market portfolio and should therefore yield the same return.
- $0 < \beta < 1$: The *ROI* values of the project fluctuate less strongly than those of the market portfolio; the project contributes to risk diversification. Therefore, the appropriate value of the discount rate is below $E(ROI)_{market}$. Until recently, power plant projects used to be of this type. Electricity demand is rather stable, largely independent of economic cycles; moreover, in a regulated monopolistic market, investors typically obtain the right to adjust rates in order to achieve a guaranteed *ROI* on their projects.
- $\beta > 1$: In the wake of liberalization, *t*his case has become more common in the energy sector, reflecting an increase in riskiness due to competition. Since a higher required *ROI** reflects a shortened panning horizon (see Sect. 3.4) the discount rate applied to energy investments varies with it. Therefore, under a regulated monopoly, the appropriate value of the discount rate is below $E(ROI)_{market}$, while for companies operating in a liberalized electricity market, it is in excess of $E(ROI)_{market}$.
- $\beta < 0$: The *ROI* values of the project are negatively correlated with those of the capital market. One could say that the project in fact insures against the volatility of the capital market since its *ROI* is high when *ROI* values are low in general (and *vice versa*). An example could be a renewable energy project, whose earnings are particularly high when conventional energy sources become scarce and expensive, thus putting pressure on the *ROI* of listed companies who have to buy electricity. According to Eq. (3.23) the discount rate can even be below than the risk-free interest rate i *in this case*.

[6]The yield of a bond is defined as its internal rate of return calculated by setting all discounted cash flows from that bond equal to its current market value.

3.5.2 New Asset Pricing Methods

In recent decades, the methods of risk-based evaluation of investment projects have been developed further. The point of departure is present value calculation, which however suffers from neglecting risks inherent in all components of future cash flows, such as sales prices, sales volumes, prices paid for energy inputs, and operating costs. Moreover, these components of cash flow cannot be assumed to be subject to the same risk. For example, if the energy company strikes a long-term sales contract with a reliable counterparty, the risk associated with future revenue is a minor one; at the very least, it can be assessed with some accuracy at the time of deciding about an investment.[7] However, future production costs may also be uncertain; for instance, a generator using gas as a fuel is exposed to the risk of price hikes. Present value calculation can be extended to take into account risks inherent in cash flow component by component (this is also known as Asset Pricing Method). Cash flow components assumed to be devoid of risk are evaluated according to the risk-free rate of return i.

Consider the sale of electricity in a future period T. Rather than selling on the (wholesale) market at the uncertain price prevailing at T, the generator can hedge the price risk by selling forward. This means striking a contract specifying delivery of Q_T units (MW) electricity in period T at the forward price p_F, which is usually comparatively low because the buyer acts as an insurer (see Sect. 12.2.5). The present value of the forward contract is

$$PV = p_F\, Q_T \frac{1}{(1+i)^{T-t}}, \tag{3.25}$$

with i denoting the risk-free interest rate since it is now the counterparty who bears the price risk.

Alternatively, the generator can decide to bear the price risk, hoping that the spot price in period T will be higher than the current price. The first step is to replace the future spot price by its expected value, $E[p_{E,T}]$. However, the issue remaining is how to discount a risky future sales price to present value. As stated above, the forward sales price is usually relatively low. Therefore, the ratio p_F/p_E is substantially below one if buyers and sellers on the forward market deem the price risk to be important. Indeed, the forward price represents the best estimate of a risk-adjusted future spot price. Evidently, the ratio p_F/p_E takes the price risk into account. Hence, Eq. (3.25) can be rewritten as follows,

[7]More generally, there is so-called counterparty risk, meaning that a contractual partner fails to fulfill the contract. Sometimes counterparty risk can be transferred to a third party. For example, a company may sell power through an energy exchange. In this case, the exchange covers the counterparty risk, acting as a clearing house.

$$PV = \underbrace{\mathrm{E}(p_E) \cdot Q_t}_{SR_T} \cdot \frac{p_F}{p_E} \cdot \frac{1}{(1+i)^{T-t}}. \tag{3.26}$$

The first two factors represent the expected sales revenue SR_T when selling to the spot market rather than concluding a forward contract. The ratio p_F/p_E takes the price risk into account, while the factor $1/(1+i)^{T\text{-}t}$ discounts to present value, using the risk-free rate because the price risk has been already corrected for.

The Asset Pricing Method assumes a market without transaction costs, permitting to switch freely between spot trades and forward contracts. In addition, cost of carry and convenience yield are neglected.[8] Their inclusion in the economic evaluation of investment projects is beyond the scope of this book, being the subject of ongoing research.

3.6 Real Option Valuation

Investment decisions are based on several assumptions that need to be scrutinized. Uncertainties characterizing them can be taken into account using the correction factors discussed in the preceding sections or sensitivity analysis. A particular problem is that the risk factors can change during a project's lifetime, a fact that has not been considered thus far. At the same time, investors may react with more or less flexibility to these changes. This flexibility needs to be integrated into the evaluation of an investment in ways to be expounded here.

According to Myers (1974), a project offering flexibility during its lifetime can be viewed as an option. This insight permits to apply financial option theory to the evaluation of physical investments, with the term 'real option' used to distinguish them from a financial option. The theory of real options has been developed starting in the mid-1990s (see Laughton 1998) and has found its way into project management since. Pioneers in adoption were energy companies with activities in mining and extraction (crude oil, coal, and natural gas in particular). These companies had gained a lot of experience in trading financial derivatives on commodity exchanges designed to hedge the risk of volatile sales prices on wholesale markets. While a detailed description of real option theory is beyond the scope of this book, some of its basics shall be discussed. For an introduction to the topic, the work of Dixit and Pindyck (1994) serves as the standard reference.

[8] Cost of carry refers to interest income forgone by receiving the sales revenue later (the cost of storage is of little relevance in the context of electricity). The convenience yield comprises all positive effects that are related to the physical possession of a good, in particular the option of selling it when its price is high.

3.6.1 Energy Investments as Real Options

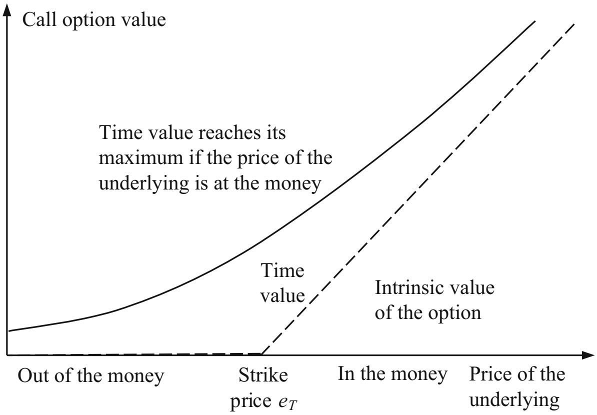
To explain the theory of real options, terms used for both financial and real options need to be defined.

- Underlying: In a nutshell, most financial products are bets on some future outcome. The outcome the bet is placed upon is called underlying. For instance, in the case of an option (of the call type, see below) which entitles its owner to buy 1000 bbl of crude oil at the end of next year at a price of 80 USD/bbl, the underlying is 1000 bbl of crude oil possibly worth 80,000 USD.
- Derivatives: This term refers to all types of contracts that are not executed 'on the spot' (i.e. delivery now, payment with minimum delay). Derivatives include forward contracts (delivery delayed, payment now or possibly delayed somewhat) and options (delivery at the discretion of the buyer or seller, payment of an option premium now, remainder later).
- Call option: This option entitles its holder to the right, but not the obligation, to buy the underlying at a specified price (the so-called strike price) during a limited time specified in the contract (so-called time to maturity). The seller of the option (called option writer) is obliged to sell the underlying when the buyer exercises the option but keeps the underlying in case the option holder fails to exercise it. Option writers charge an option premium to compensate them for the risky position they take in the meantime.
- Put option: This is the opposite of a call option. It entitles the option holder to the right, but not the obligation, to sell an underlying at a specified price (strike price) during a limited time specified in the contract (time to maturity). The option writer is obliged to buy the underlying at the demand of the option holder but does not have to if the option holder fails to exercise it. Option writers also ask for an option premium to compensate them for the risky position the take in the meantime.

Besides applying classical strategies of risk mitigation (such as diversification), holders of a financial option can actually benefit from risk thanks to the flexibility offered by an option (see the discussion below). However, flexibility is not costless. Whether paying the option premium is justified depends on the value of flexibility to the option holder. Investments in projects which increase the ability to adapt flexibly to changes in market conditions are similar to financial options, except that they are 'real' in the sense of being written on tangible underlyings such as gas turbines. As will be shown in greater detail below, options are particularly valuable if

- the economic viability of the project depends on exogenous influences whose future development is highly uncertain;
- the company pursuing the project is able to react to these uncertainties in a flexible way;
- the project's *NPV* is not so high (or not so low) as to make it profitable (unprofitable) in just about any circumstance.

Fig. 3.5 Value of a call option



The first point is striking: The greater riskiness, the greater is the probability that during the project's lifetime new information becomes available on which the investor may react. Therefore, option values increase rather than decrease with volatility (using financial jargon again). While in the traditional view the value of an investment declines with risk, it increases with risk when its option value is considered.[9]

These factors are illustrated for the case of a call option in Fig. 3.5. The horizontal axis depicts the possible future prices of the underlying (of the barrel of crude in the example) e.g. during 3 years hence; therefore, the price of the underlying is not known at decision time. Focus is first on the kinky dashed line of Fig. 3.5. This component of the payoff function of an option is called its intrinsic value. Below a certain price of crude oil (the strike price), it will not be attractive for the investor to e.g. construct a platform for drilling in the sea because the *NPV* of future revenues does not cover the investment outlay. The project is 'out of the money'. However, as soon as the price of the underlying exceeds this strike price, the value of the project will increase proportionately. It will be 'in the money', causing the investor to exercise the option. Its intrinsic value increases in step with the price of the underlying, as indicated by the 45° slope of the payoff function.

The investor is assumed to hold expectations regarding the future price of the underlying. Let these expectations be reflected by a probability density function over the possible prices of the underlying (not depicted in Fig. 3.5), typically centered to the right of the strike price. Let this distribution first exhibit low uncertainty; it thus has little probability mass on both sides of the strike price. Due to the kink in the payoff function, the investor suffers no loss on the downside (by deferring construction) but does not stand to gain much either in case the option

[9]The positive relation between risk and the economic value of a project might convince investors to enter into especially risky projects. In the academic literature, this effect is seen as one of the reasons for the emergence of the new economy bubble at the beginning of this century and the banking crisis of 2008.

is in the money. In a second scenario, let the future price of the underlying possibly diverge by a great amount from the strike price, reflecting higher riskiness. This time, the distribution function is characterized by much more spread because extreme values are possible now. However, this means that while the probability of the option being out of the money is higher, it also has more probability mass to the right of the strike price. Therefore, the investor, while still not suffering a loss on the downside, stands to gain greatly from the call option (i.e. the opportunity to invest in the platform). This shows that volatility is in the interest of investors, especially if they are in fact diversified shareholders of many companies who lose little if any one of these companies ends up in bankruptcy. Note that the value of their shares can never be less than zero.

Turning to the second factor mentioned above, the intrinsic value of an option neglects the value of flexibility to the investor, who can either produce crude oil at a given price or decide against production depending on the market clearing price at any time of the option's lifetime. Again, consider two scenarios. In the first, let the probability density function reflecting beliefs be centered above the strike price, with limited spread. While this makes the investment somewhat attractive, very high values of the underlying are unlikely during the next 156 weeks (3 years) in the example given. Flexibility in the timing of the decision to invest is of little relevance in this case. Accordingly, the so-called time value of the option is close to zero, as reflected by the small vertical distance between the total payoff function and its dashed component (equal to the intrinsic value). Next, let the probability density function be centered below the strike price, again with little spread. This indicates that the investor is highly certain that the option will be out of the money for some time. Again, flexibility with respect to (not) exercising the option does not have much value. In sum, the time value of an option is small at the two extremes of the price line; conversely, it is highest when the probability distribution is centered at the strike price because it is there where the project has much probability of being in the money for a sufficient amount of time to make it economically viable. Being able to pick the time of deciding has great value in this case.

Finally, the importance of the third factor cited above can be illustrated as follows. First, let the probability distribution be centered at a value far above the strike price, with limited spread. This means that there is little (possibly even zero) probability mass at and below the strike price; the project is in the money in (almost) all circumstances. In addition, the time value of the option is close to zero, indicating that flexibility in timing of the decision is of little importance. Traditional economic project evaluation yields a clear conclusion in favor of the project in this case. Second, let the probability distribution be centered at a value far below the strike price, again with limited spread. Therefore, there is little probability mass at and above the strike price; the project is almost certainly out of the money. In this situation too, the option property of an investment project hardly matters. Conversely, the option property does matter when it is not clear whether the project is economically attractive or not.

3.6.2 Black-Scholes Model

The choice of methods available for assessing a risky investment presented so far is still not complete. Indeed, it comprises the following alternatives.

- Risk-adjusted interest rate: For the present value (*PV*) calculation of future cash flows, a risk-adjusted discount rate i is used. Since $\partial PV/\partial i < 0$, a project is more likely to be rejected when the discount rate is high (see Eq. (3.4)).
- Sensitivity analysis: A project's net present value (*NPV*) calculation is repeated, using different combinations of parameters (investment outlay, revenue and cost streams, useful life of the project, and values of i). In this way, one can identify the critical scenarios in which its *NPV* becomes negative.
- Monte Carlo simulation: First, the stochastic properties of the factors influencing the *NPV* of the project are analyzed, such as the distributions of and covariances between possible future prices, sales volumes, and costs. In each round of simulation, values of these parameters are drawn at random and the *NPV* calculated, resulting in a distribution of *NPV* values. Depending on the investor's risk preference, the project is accepted if the *NPV* is positive in more than e.g. 95% of simulations.
- Decision tree analysis: First, all possible outcomes of the project and the sequence of events leading to them need to be defined. Some so-called nodes of the tree are controlled by the investor (management, respectively), while some are controlled by Nature as it were. Next, the branches of these latter nodes are associated with their respective probabilities, permitting management to choose the action associated with the highest expected payoff at the nodes under its control. Also known as dynamic programming, this method yields optimal decision paths.
- Valuation of the project as a call option: The great insight of Black and Scholes (1973) was that a risk-free portfolio can be constructed by combining options. To see this, consider a so-called European option that can only be exercised at maturity, i.e. at the end of the contract period. Therefore, this type of option does not offer flexibility and thus can be depicted by the kinky dashed line of Fig. 3.5. If this line is matched with another one that slopes down to the right of the strike price, the resulting payoff function runs horizontal, indicating that such a portfolio is risk-free since it yields a payoff that is independent of possible future prices of the underlying. To achieve this, the investor would have to write a call option entailing the obligation to deliver the underlying in case the purchaser of the option exercises it, i.e. when the price of the underlying exceeds the strike price (recall that this would generate an option premium, which is abstracted from in Fig. 3.5). Alternatively, the investor could buy shares issued by a generating company with a similar project amounting to the value of the investment to hedge it, selling a call option as well as buying a put option on them. In this way, he or she incurs a loss on the call option if the project is 'in the money', which is offset by the value of the project in this case. In case the project does not perform and is 'out of the money', so is the call option on the shares; however, the put option has value in this case. Evidently, options on shares can also be used to form a risk-free portfolio (justifying the put-call parity mentioned

below). However, a risk-free portfolio can be discounted applying a risk-free interest rate, which simplifies the valuation problem decisively.

The basic assumption of Black and Scholes is that the market price p of the underlying follows a so-called standardized Wiener process with drift μ and volatility σ, with dz denoting stochastic shocks drawn from a normal $N(0,1)$ distribution

$$\frac{dp_t}{p_t} = \mu \cdot dt + \sigma \cdot dz. \tag{3.27}$$

In this case, price changes between the present time t and a future date T are log-normal distributed[10] with mean

$$\ln p_t + \left(\mu - \frac{\sigma^2}{2}\right) \cdot (T - t) \tag{3.28}$$

and standard deviation

$$\sigma \cdot \sqrt{T - t}. \tag{3.29}$$

Finally, the right to any dividends is assumed to be retained by the owner of the share (the underlying). Then, the Black-Scholes formula for the valuation of a European call option is given by

$$CALL_t(T) = p_t \cdot \mathrm{N}(d_1) - e_T \cdot e^{-i \cdot (T-t)} \cdot \mathrm{N}(d_2) \tag{3.30}$$

$$d_1 = \frac{\ln\left(\frac{p_t}{e_T}\right) + \left(i + \frac{\sigma^2}{2}\right) \cdot (T - t)}{\sigma \cdot \sqrt{T - t}} \tag{3.31}$$

$$d_2 = d_1 - \sigma \cdot \sqrt{T - t} \tag{3.32}$$

p_t Present spot market price of the underlying
e_T Exercise price of the option at maturity T (strike price)
i Risk-free interest rate
σ Annualized volatility of p_t
T Time to maturity (in years)

The value of a put option can be calculated from the so-called put-call parity,

$$PUT_t(T) = CALL_t + e_T \cdot e^{-i \cdot (T-t)} - p_t. \tag{3.33}$$

[10] Log-normal distribution means that the logarithm of the random variable is normally distributed.

Table 3.2 Variables used for financial and real option valuation

	Option on a financial asset	Real option
Option right	Right to purchase or sell an underlying against paying the exercise price	Right to the cash flows of a project against paying the investment outlay
p_t	Current spot market price	Present value of cash flows (expected contribution margin) (+)
e_T	Exercise price (strike price of the underlying)	Investment outlay (−)
σ	Annualized volatility of the underlying	Riskiness of cash flows (+)
T	Time to maturity	Time by which the investment project ceases to generate cash flows (+)
i	Risk-free interest rate	Risk-free interest rate (+)

(+) and (−) indicate the direction of the influence on the option value

The put-call parity follows from the fact that options can be combined in a way as to result in a risk-free asset; note the crucial role of discounting the exercise price e_T to present value using the risk-free rate of interest i in Eq. (3.33). Evidently, the parameters of the Black-Scholes model, which refer to financial options, need to be translated into terms referring to investment projects. The corresponding equivalencies are shown in Table 3.2, along with the influence of the parameter on the option value. In particular, the exercise price becomes the investment outlay; the higher its value, the more the kink in the payoff function of Fig. 3.5 shifts to the right, indicating a reduction of probability mass over positive payoffs and hence a reduction in the value of the call option. Also, a high risk-free interest rate means that the purchaser of the option can reap substantial benefits from an investment in a risk-free asset up to maturity, which lowers the present value of payment for the option and therefore increases its value. This effect is the more important, the farther maturity T lies in the future (see Eq. 3.30). Finally note the crucial importance of the normality assumption of the Wiener process; N(d_1) and N(d_1) symbolize the probability of the price of the asset attaining a certain value (T-t) periods in future. However, returns of investment projects typically are characterized by an asymmetric distribution, with substantial probability mass to the left of the expected value (positive skewness). While a log-normal random variable does exhibit positive skewness, returns to investment have been found to have 'flat tails', i.e. a higher probability of extreme values occurring than indicated by log normality. Therefore, the Black-Scholes formula may lead investors to underestimate the riskiness of a project.

3.6.3 Application to Balancing Power Supply

Often, the dispatch of a power plant is flexible in so far as the rate of production per time unit (usually, a quarter of an hour) can be increased or decreased. This gives the plant operator the possibility to balance deviations from day-ahead schedules by increasing or decreasing production output, and thus save on purchases of balancing power from the grid operator (see also Sect. 13.1.3). Therefore, investment in a flexible power plant can be considered as the purchase of a real option which can be exercised to minimize cost caused by deviations from the schedules.

The underlying of the option is the avoided cost associated with the purchase of balancing power from the grid operator. Let this cost be log-normally distributed with a mean of 0.9 EUR ct/kWh and an annualized volatility of 40.5%, which determines the values of d_1 and d_2 as well as their associated probabilities given a log-normal distribution. For an estimated annual operating time of 5500 h/year, the expected annual contribution margin adds up to $5500 \cdot 0.009 = 50$ EUR/kW installed capacity. The calculation is carried out on the basis of a time to maturity of 10 years.

Table 3.3 shows the input values, the interim values, and the results of the Black-Scholes model for this example. Given the assumptions, the call option value of the capacity is 23 EUR/kW/year. Capitalizing this value yields the additional value the plant operator should be willing to pay for the possibility to avoid the purchase of balancing power.

Additional insights can be obtained by calculating the partial derivatives of the Black-Scholes formula with respect to the input variables. These derivatives quantify the sensitivity of the option value in response to marginal changes in these variables.

- Delta: Change of the option value due to a change of the price of the underlying or of the expected annual contribution margin p_t;
- Gamma: Change of Delta due to a change of the annual contribution margin p_t;
- Theta: Change of the option value due to a different time to maturity T;
- Vega: Change of the option value as a function of changing volatility of the expected contribution margin p_t;
- Rho: Change of the option value due to a change of the risk-free interest rate i.

Figure 3.6 shows the intrinsic value of the real option (represented by the kinked broken line) and the associated option value (the solid line) as a function of the expected annual contribution margin. The slope of the solid line corresponds to the Delta defined above. At 50 EUR/kW, the option value amounts to 23 EUR/kW installed capacity per year (see Table 3.3 again). The vertical dashed line at that

Table 3.3 Value of the real option 'power plant' according to the Black-Scholes formula

	Inputs		Output
Annualized contribution margin	p	50.00 EUR/(kW·a)	$d_1 = 0.592$
Annualized investment cost	e_T	58.75 EUR/(kW·a)	$d_2 = -0.688$
Volatility	σ	40.5%	$N(d_1) = 0.723$
Risk-free interest rate	i	1.0%	$N(d_2) = 0.246$
Project lifetime	T	120 months	$CALL = 23.09$ EUR/kW p.a.

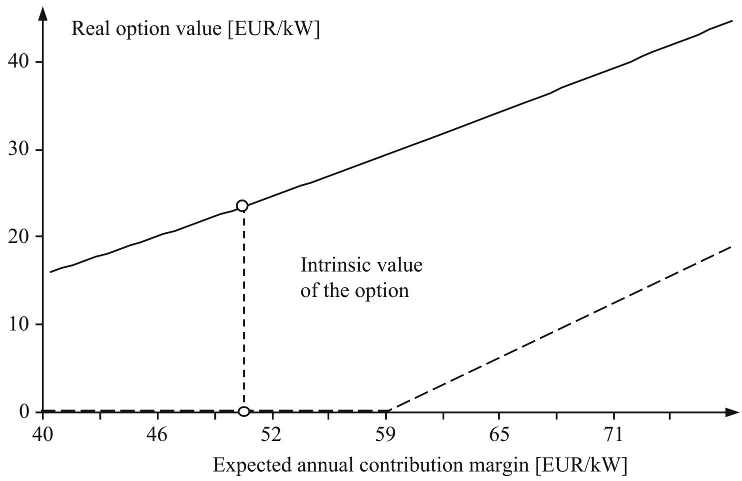


Fig. 3.6 Option value as a function of the expected contribution margin

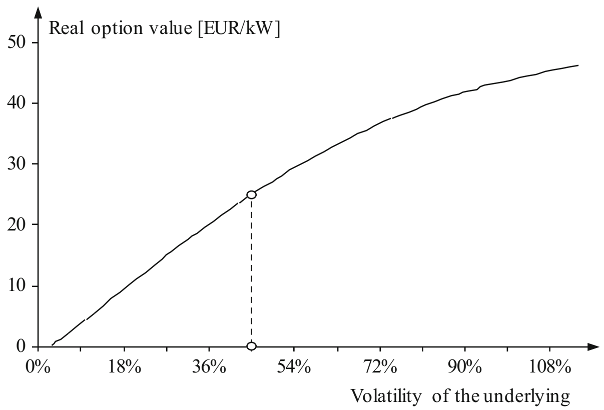


Fig. 3.7 Option value as a function of volatility (Vega)

point reflects the time value of the option due to the flexibility in production afforded by the investment in capacity. With the assumptions of Table 3.3, the real option has an intrinsic value of zero at 50 EUR/kW per year, while the total value of the option boils down to its time value.

Both the relationships between the present value of cash flows and the volatility of the underlying on the one hand and the option price on the other hand are monotonously increasing. If all the other parameters are known, the market price of a call option can be used to determine the inherent volatility, which is nothing but the amount of risk perceived by market participants (Fig. 3.7).

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