Chapter 20
Wind Turbine Economics

When considering the negative effects of conventional fuels on the environment and their limited availability, or the safety questions associated with the use of nuclear energy, renewable energies must not be looked at from an economic point of view only. However, this does not mean that the utilisation of renewable energy sources makes sense "at any price". Exorbitant energy prices are not acceptable to industry or to the economy in general. Profitability from a business management point of view and profitability for the national economy are, however, two different aspects entirely.

Regardless of any macroeconomic significance, it is the duty of an operator operating as a business, and also his right, to demand cost effectiveness. However, the business results are also influenced by numerous macroeconomic conditions. Particularly in energy generation, there are political conditions which determine to a large extent what proportion of the costs is passed onto the community as a whole and which costs really enter into the balance sheet of the energy producer. These factors affect both the energy prices and the competitiveness of the various energy sources.

Economic viability in the sense of being cost effective for the investor, therefore, always means whether or not the system is cost effective "within the framework provided by the relevant energy policy". Whether this framework is indeed concerned with the interest of the public is a different question. This is a political task and not the responsibility of an operator working as a business. The latter can only be economically active under the existing macroeconomic conditions.

The current economic situation of wind energy has two faces. On the one hand, there is its application at the consumer end. Measured against the consumer prices of electrical energy, not only for the end user, but also for communal or regional power distributors, the generation of electricity from wind energy is economical, provided that the site has appropriate wind conditions.

On the other hand, there is the electricity generation by the utilities. In this case, the economic standard is set by the power generation costs of the large power plants. From the standpoint of the large utilities, these much more restrictive economic conditions did not yet allow a profitable utilisation of wind energy even just a few years ago. However, the situation has changed in recent years with the rising power generation costs, especially if the power is generated by power stations newly to be built. This will apply, above all, when the utilities are prepared to integrate wind turbines into the organisation of their existing pool of power plants in such a way that power generation from wind energy can be allowed to make some contribution to the firm power station capacity, apart from the energy generated.

Calculating the economics of an investment project is not realistic without including the conditions of financing. Even if the economical assessment deals primarily with the economic potential of the technology, the financial aspect has to be considered. Innovative and courageous "financial engineering" frequently provides the decisive impulse for helping new ideas to achieve a breakthrough and this also applies to the success of wind energy.

20.1 Corporate Organisation of the Project and Financing

The capital required for implementing a wind turbine project is firstly determined by the overall investment costs. However, the method by which the funds are raised, that is how the investment is financed, is not without influence on the recurring and non-recurring costs. The financing method, in turn, is itself influenced by the legal form of the "owner" or "operator" (legal entity) of the wind energy project. If, for example, a corporate organisation, a "project company", carries out the investment, other forms of financing are possible than in those cases where wind turbines are purchased and operated by private individuals.

Analysing the economics thus requires that the legal form of the owner, and the associated possibilities for financing, are taken into consideration. It is, therefore, impossible to make a completely abstract and generally valid statement about the economic viability which will always remain subject to the individual situation to a certain degree.

Commonly, the investment will be largely financed by bank credits (borrowed capital), thus predetermining the interest and repayment service. If the investment is completely financed by equity in exceptional cases, an operator thinking in business terms will calculate a return for his investment, which will provide for a return of the equity within a given period and for a minimum interest rate. This calculatory service of the equity is of the same magnitude as for the borrowed capital so that there is no difference between equity and borrowed capital as far as obtaining a rough estimate of the economics involved is concerned.

Banks grant credits only with certain securities which must be provided by the borrower. Traditional bank financing is secured by so-called "real securities", that is mortgages or the transfer of ownership of buildings and assets. An increasing number of banks has been venturing into so-called *project financing (non-recourse financing)* where the loans are no longer secured with real securities. The borrower commits himself to allocate the revenue from his project predominantly to servicing his debt to the bank. The bank's security thus rests exclusively on their faith in the long-term security of the income, i.e. the technical and organisational stability of the project and its economic viability [1].

This type of financing practice is widely used for larger investment projects. It goes without saying that under these conditions banks demand a very detailed technical and economic examination of the projects and ultimately also exerts influence on the investment decision itself. As an additional security, the banks demand a minimum share of equity in order to reduce their credit risks.

In some countries, e.g. Germany or Denmark, bank loans for investment projects in the energy and environment sector are provided at cheaper prices. For example, loans paid out via the commercial banks are available at lower interest rates for various refunding programmes supported by state-owned banking organisations. These credits are requested from the commercial banks for the investment project to be financed and are then available to them as refinancing means. Most wind turbine projects in Germany were financed in this way in recent years. The average interest rate was about 1.5 to 2 % below the direct loans provided by the commercial banks.

Apart from bank financing, direct public grants also played a role in the field of renewable energies in the past. A variety of direct and indirect funding programmes was available in most countries. Public grants provided an important impulse in the early phase of wind energy utilisation, but lost their importance with the improvement of wind energy economics. Today, public grants only play a role in research and development projects.

Financing an investment project requires a legal framework on the owner's side. In the simplest case, when the owner is a natural person, he or she will register a business, unless this is already the case. The liabilities towards the creditor bank for the credits as well as the tax assessment are basically the same as in any other trade or business. With larger projects, a “special purpose company” (SPC) which owns the project legally will be established, particularly when external investors are involved. In this case there are several options with regard to the legal form:

Private company

A private company is the most uncomplicated legal form and can be formed by a number of persons (at least two). The tax advantages (writing off the operating losses) can be taken advantage of directly by the individual person. All partners in the company are personally liable for up to the total sum of obligations.

Limited company

In the case of the limited company, the liability is theoretically restricted to the nominal capital. In real life, however, banks demand a personal liability or other real securities for loans to small limited companies. Tax advantages with regard to depreciations remain within the limited company and cannot be used by the individual partners. Larger projects can be handled better by a limited company than by a private company since a manager must be appointed and an annual account must be kept.

Limited partnership

This legal form is mainly used in the form of a limited partnership with a limited company as general partner. This complicated construction has the advantage that the "unlimited partner" who otherwise is personally fully liable can be replaced by a company with limited liability. In the limited partnership, capital can be obtained to a greater extent through any number of "limited partners" who are only liable with their capital invested. In addition, the limited partners can use the tax losses of the company. Numerous wind farms are operated by such a combined limited company & limited partnership. This legal form is of significance with respect to the economic viability of wind energy utilisation since the nominal return on one's own capital can be comparatively low. The investors (limited partners) will achieve a higher effective return "after tax" due to tax advantages. Their own capital thus becomes cheaper for project financing. This legal form of wind park financing was of great importance particularly in Germany. In other countries, limited partnerships are relatively unknown, depending on the tax laws in force. Companies, for example in the form of the limited company & limited partnership, are frequently called "tax-shelter companies" somewhat condescendingly. However, critics are obviously not aware of the fact that all reputable companies will make use of their tax advantages as extensively as possible. The only difference between them and the "tax -shelter companies" is that these publish their tax advantages and dividend payments for the investors in brochures, as prescribed by law and are, therefore, regarded as objectionable. Whether or not these tax laws are "just" is quite a different issue and belongs exclusively into the realm of politics. At any rate, any individual calculation of economic viability which does not take into account the tax effects is unrealistic from the point of view of a professional operator.

Joint stock company

The joint stock company, typically the legal form of large companies, does not yet play an important role in wind energy utilisation. It is not possible to generate any personal tax advantages for the shareholders in a joint stock company. However, the basis for raising capital by issuing shares is very large. Stock companies are subject to strict supervision under the provisions of the Shares Law and must regularly publish their business report. It is conceivable that future large-scale projects such as offshore wind parks will be financed and operated on this basis. An accurate analysis of the economics involved must take into consideration the characteristics of these legal forms, including the tax effects. These are quite different in the various countries so that the preferred forms of companies are also different in the individual countries for this reason, too.

20.2 Power Production Costs and Repayment Periods

How much does wind power cost? Any discussion about the economics of wind turbines will ultimately return to this simple point. In a concrete case, however, the problem of economics is often not a direct question about the costs of energy generation. Instead, given proceeds from the sale of electricity will include the *repayment period* for the capital used. This situation exists for almost all generating plants feeding their energy into the grid since calculations are based here on legal regulations or electricity supply contracts with predetermined infeed tariffs.

20.2.1 Basics for Calculating the Costs of Electricity

For calculating the cost of electricity or the repayment period, it is important to recall first the order of priority of the parameters influencing the results:

- mean annual wind speed at rotor hub height,
- performance characteristics of the wind turbine, in particular the power curve,
- investment costs,
- technical availability of the wind turbine,
- running costs, essentially for operation and maintenance.

The repayment time granted for the capital invested can be considered from various perspectives. There are many good reasons why, from a socio-economic point of view, a wind turbine could be granted a repayment time corresponding to its life time. But from the point of view of a commercial investor, a payback period of twenty or more years for an investment of some hundreds of thousands of dollars is unrealistic. Capital recovery periods exceeding 10 years run counter to good market practices, particularly for small turbines bought by private users. A private investor who accepts an amortisation time of ten years for a small wind turbine does so with quite a lot of idealism.

It is a different story with wind park projects including large wind turbines of the megawatt power range. The public utilities are used to having to write off large conventional power stations over twenty or more years. Moreover, a wind turbine in the megawatt power range will certainly have a longer life expectancy than a small 50 kW turbine. For these reasons, there would be some justification in granting longer repayment periods to larger wind turbines.

The capital raised for an investment, in particular the bank loans, will in many cases be redeemed by regular repayments over a certain period of time, called the “redemption” or “amortisation time” or better, the “capital repayment time”. The constant repayment rate comprising constant interest rate and an increasing repayment is called "annuity". It represents the capital costs to be raised annually. The annuity can be calculated in dependence on the period of capital repayment and the interest rate by using the familiar formula:

$$A = p + \frac{p}{(1+p)^n - 1}$$

where:

A = annual capital costs, (annuity in % of the capital invested)
p = interest rate (%)
n = period of capital repayment (years)

Figure 20.1 shows the annuity with sufficient accuracy for rough estimates without using a calculator.

In many cases a capital service, paid as annuity, is too high with respect to the cash-flow generated by the project in the first years. Therefore the repayment is arranged in equal or variable rates over the period of the loan, this means a lower service of capital in the initial years. Furthermore it is common practice to agree with the bank upon one or two years free of repayment. Summing up the capital service over the period of the loan there is only a small difference compared to the annuity method, so the average values of power production costs do not depend very much on the kind of repayment.

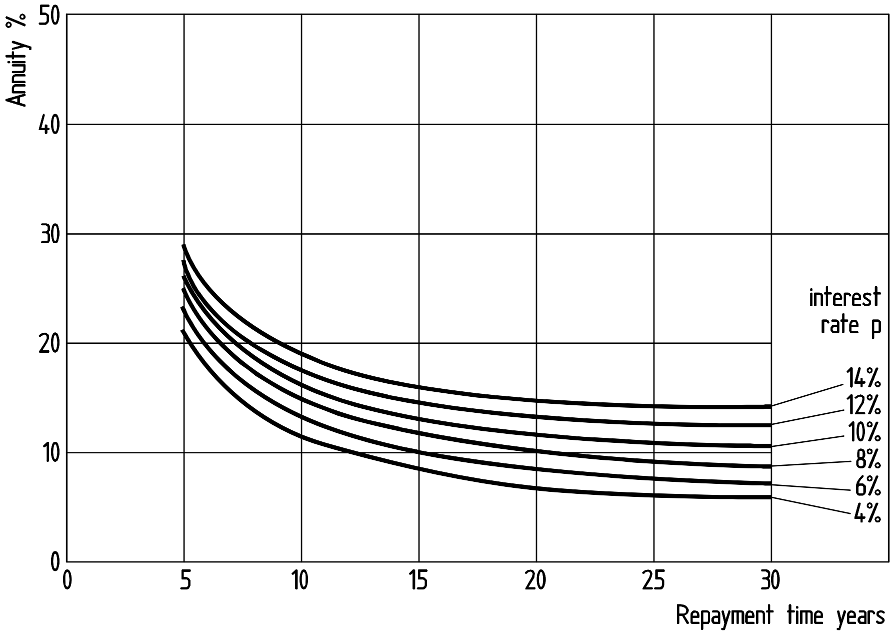

Fig. 20.1. Annuity as a function of the interest rate and the period of capital repayment

20.2.2 Static Annuity Approach

As soon as specific figures are available for these parameters, a simple "static" calculation of the achievable power generation costs should mark the beginning of every analysis of the economics. This is the only way to show the objective potential of the technology to be assessed. More complicated "dynamic" calculations of the economics are indispensable for long-term investment decisions, but they necessarily introduce numerous speculative elements into the calculation. The result is then determined not only by the economic potential of the investment itself, but also by the assessment of certain overall economic conditions and their evolution over a relatively long period.

In many cases, the problem of economics is not one of direct inquiry into the costs of power generation but of calculating the repayment or amortisation period of the investment with a given revenue from power generation. This situation exists almost always when the energy produced is fed into the grid. Calculations must then be based on existing electricity rates stipulated by legal regulations or power purchase contracts. The calculation of economics is the same as in the case of calculating power generation costs, except that the repayment period is derived indirectly from predetermined power payments.

The costs of generating electricity from wind energy can be demonstrated on the example of a medium-sized wind turbine in the power range of 500 kW and of a large wind turbine with 2 MW rated power. The calculation is based on a site with a mean annual wind speed of 5.5 m/s at 30 m height. These wind data characterise a good inland site at some distance from the coast.

The second most important factor after the wind conditions is the service of capital for the investment costs. Usually, a relatively small proportion of the means for the investment is raised using the investor's own capital and the greater proportion is financed through bank credits. Depending on the economic stability of the project as estimated by the banks, the latter usually demand equity of between 20 and 30 %.

In calculating the required service of capital, no distinction has been made between equity capital and bank loan in the example. In a first approximation, an investor will expect at least the same interest rate for his own capital as for the bank loan. Professional investors will generally expect a shorter repayment time for their equity capital used.

Medium-sized wind turbines

It is true that wind turbines of the 0.5-MW power rating type no longer play an important role on the market at present since, as a rule, the usual wind parks consist of turbines of 1.5 to 3 MW rating. However, medium-sized wind turbines are still of interest as single units for private operators and, above all, in third-world countries. Table 20.2 shows the static calculation of the power generation costs for a wind turbine of this size.

If the calculation is based on a service life of the wind turbine of 20 years, the power generation costs amount to only about 0.07 $US/kWh (Table 20.2). This is considerably below the level of the price which must be paid by an electricity consumer under current tariffs. If it were technically possible to use the generated power oneself, i.e. directly on the consumer side, wind power would be an almost unrivalled economical power source. Even if a practical repayment period of 10 years is used as a basis, the power generation costs are still favourable at about 0.10 $US/kWh.

In practice, however, the real situation for the operator of a wind turbine is determined by the income he receives when the electricity generated is fed into a large interconnected power system. Assuming that the price for the power generated is 0.09 $US/kWh, this amounts to a repayment time of about 12 to 13 years. From the point of view of a commercial operator, this value is quite acceptable for a long-term investment, or the development of wind energy utilisation would not have been quite as meteoric. This time also corresponds to a usual credit period for the investment credits for financing wind energy projects.

The characteristic figure "invested capital per kilowatt-hour generated annually", which is 0.61 $US/kWh in the example calculated, can be used as criterion for the economic viability of the project (Chapt. 19.1). Under the assumed conditions of payment for electricity, this value must not be significantly higher than 0.60 $US/kWh if it is to be used for achieving an economic situation "wind turbine at a particular site". The prerequisite for the validity of this criterion is, however, that the operating costs are at the normal level (Chapt. 19.9).

Table 20.2. Calculation of the electricity generation costs of a medium-sized wind turbine (rotor diameter of 40 m, 500 kW rated power, mean annual wind speed 5.5 m/s at 30 m height)

Investment Costs	$ US
Ex-works price of wind turbine	450 000
Planning, installation, infrastructure and financing (30 % of ex-works price)	135 000
Total investment costs	585 000
Annual Costs	
Maintenance, insurance, land lease (4 % of ex-works price)	18 000
Service of capital (6 % interest rate p.a.,), repayment period within:	
- 10 years (annuity = 13.59 %)	790 501
- 20 years (annuity = 8.72 %)	51 012
Site	
Annual mean wind speed at 30 m height	5.50 m/s
Roughness length z_0	0.1 m
Mean wind speed at hub height (50 m)	6.00 m/s
Annual Energy Yield at 98 % technical availability	950 000 kWh
Specific Investment Costs with respect to annual energy yield	0.61 $US/kWh
Power-generation Costs	
- with repayment in 10 years	0.10 $US/kWh
- with repayment in 20 years	0.07 $US/kWh

Large Wind Turbines

With the introduction of commercial wind turbines in the megawatt power class, the economic situation of wind power utilisation has moved forward another step. Large wind turbines with tower heights of 80-100 m have advantages at sites with weaker wind regimes so that the economic area of the application of wind energy utilisation is clearly extended geographically (Table 20.3).

Apart from these economic figures, the fact also plays a role that scarce sites in densely settled areas are becoming more and more valuable. It will always be attempted, therefore, to utilise these sites with the largest turbine possible, an argument which has a decisive influence on the trend to use turbines of ever-increasing size.

Or, in other words: the amount of electricity yielded by a given area of land could become the decisive criterion for long-term profitability. This argument militates for the trend towards ever larger wind turbines, regardless of the fact, based on physics, that these will also become specifically more expensive because of their increasing specific structural mass.

Table 20.3. Calculation of power generation costs of a 100 MW wind park consisting of 50 wind turbines (rotor diameter 82 m, rated power 2MW, tower height 80 m, mean wind velocity 6.50 m/s at 80 m height)

Investment Costs	$ US x 1000
Ex-works price of 50 wind turbines, each 2.0 MW	130 000
Planning, infrastructure and financing (approx. 30 % of ex-factory price)	40 050
Total investment costs	170 050
Annual Costs	
Maintenance and repairs, insurance, land lease (3.5 % of ex-factory price of wind turbines, 2.7 % of investment costs)	4 550
Service of capital (6 % interest p.a., 20 years) Annuity 8.72 %	14 828
Site	
Annual mean wind speed at 30 m height	5.50 m/s
Roughness length z_0	0.1 m
Mean wind speed at hub height (80 m)	6.50 m/s
Annual Energy Yield at 98 % availability, 2 % electrical losses, 10 % array loss	210 Mio kWh
Specific Investment Costs related to annual energy yield	0.81 $US/kWh
Power-generation Costs with repayment in 20 years	0.092 $US/kWh

When considering the figures of Table 20.3, one should never lose sight of the significance of the mean wind speed at the site. Figure 20.4 therefore, shows the relationship between power generation costs and the mean annual wind velocity for the example shown in Table 20.3.

Taking into consideration the total wind speed spectrum available in most countries, the power generation costs of a medium-sized or large wind turbine can be assessed as follows: At a reasonable site (6.5 m/s at 80 m height), power generation costs of 0.07 to 0.09 $US/kWh can be achieved, if the entire service life of a wind turbine is granted as depreciation period for the capital investment. This value would be of significance if wind turbines were to be used in competition with conventional power stations by the electricity producers. An operator, who must assess the economic feasibility of the investment by means of the payment for feeding electricity into an interconnected system, can achieve an economically acceptable situation at a mean annual wind speed of above 6.0 m/s at rotor hub height. For large wind turbines with rotor hub heights of 80 m and more, this means that regions with mean wind speeds above about 4.0 m/s measured at 10 m height can be used economically.

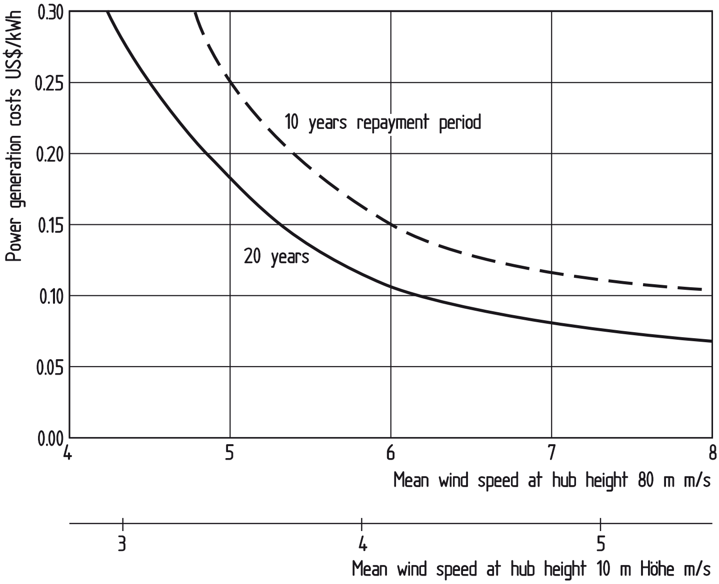

Fig. 20.4. Power generation costs for the wind park of Table 20.3 as a function of the mean annual wind velocity at rotor hub height (80 m) and at 10 m height (increase in wind speed with height according to log. formula with $z_0 = 0.1$ m)

20.2.3 Offshore Installations

The economic viability of offshore siting of wind turbines will firstly be judged by whether it can stand a comparison with a land site. On the one hand, there are higher investment costs and greater expenditure for maintenance and repairs and on the other hand there is the increased energy yield due to the higher wind velocities.

The investment and operating costs, and thus the profitability of the offshore erection of wind turbines, are a question of siting, far more than on land. The decisive criteria are the depth of the water and the distance from the coast. The range of offshore projects planned today can be illustrated in model form with two exemplary calculations.

In the "coastal" area, in regions where the offshore wind parks implemented to the present day are located, the water depth rarely exceeds more than 20 m. The distances from the coast are within a range of 10 to 30 km. Given these prerequisites, the first experiences are available which can be used for determining the investment costs with relatively good accuracy. The long-term development of the operating costs is much more uncertain. None of the projects completed to the present supply any reliable data in this respect. In most cases, the first years of operation were still characterized by all sorts of failures and improvements on the wind turbines. In addition, the organisational and logistical structures for the technical service are still largely improvised and, therefore, not representative with regard to the costs. Regardless of these reservations, the annual operating costs for the future offshore wind parks planned are estimated to be higher by about 30 % than those for onshore installations (s.a. Chapt. 19.5.2).

Table 20.5 shows a sample calculation for a proposed wind park in the coastal offshore area of the Baltic Sea (s.a. Chapt.19, Table 19.25). In the example, the technical availability of the turbines was assumed to be less than on land with 95 % and the total operating costs to be 6 % of the technical investment costs. Moreover, the operating costs are not referred to the ex-works price of the wind turbines as in the case of onshore erection but to the total investment costs. This reference appears to be more realistic since the "residual" investments represent almost one half of the total investments. The wind velocity was applied as having a value of 9.0 m/s at a rotor hub height of 80 m in the coastal area.

Table 20.5. Power generation costs of a projected 300 MW wind park in the Baltic Sea (100 wind turbines of 3MW each, distance from the coast 30 km, water depth 15-20 m)

Investment Costs	$ US x 1000
100 wind turbines, ex-factory price	420 000
Project development, techn. infrastructure at sea and land, financing	382 000
Total project costs	802 000
Annual Costs	
Maintenance and repairs, insurance, land lease (8.3 % of investment costs, 4.5 % of wind turbine costs)	36 090
Service of capital (6 % interest rate p.a., 20 years Annuity 8.72 %	69 934
Site	
Mean wind speed at hub height (80 m)	9.0 m/s
Annual Energy Yield	
at 95 % availability, 5 % electrical losses, 12 % array losses	900 Mio kWh
Specific Investment Costs	
related to annual energy yield	0.88 $US/kWh
Power-generation Costs	
with repayment in 20 years	0.12 $US/kWh

The resultant power generation costs of about 12 cents/kWh with a repayment period of 20 years are clearly higher than on land. Given these assumptions, the higher investment and operating costs in comparison with onshore siting cannot be cancelled by the higher wind velocity or energy yield.

In the area "remote from the coast", i.e. in the regions in which most of the offshore projects are planned in the German North Sea, the situation is different. The distances from land are up to 100 km and the depth of water of the North Sea is about 30-40 m. This must be compared with a higher wind velocity which can be expected to be up to 10 m/s at a height of 100 m above the "open sea". The offshore projects planned in these regions provide for the use of wind turbines of the 5-MW class almost without exception. As mentioned in Chapter 19.5, specific investment costs of over 4000-4500 $US/kW must be expected under these circumstances from today's point of view (s. Table 19.26).

In addition, it will have to be assumed that under the given circumstances, the technical availability will be lower and especially that the operating costs per kilowatt-hour will be distinctly higher. Table 20.6 shows examples of the range in which the power generation costs can be expected. Considering the risks involved, a commercial operator will have to generate revenues of at least 17 cents/kWh.

Table 20.6. Assessment of power generation costs of a 300 MW offshore wind park in the North Sea (60 wind turbines of 5 MW each, distance from the coast 100 km, water depth 40 m)

Investment Costs	$US x 1000
50 wind turbines, ex.-factory price	540 000
Project development, techn. infrastructure, financing	730 000
Total project costs	1 270 000
Annual Costs	
Maintenance and repairs, insurance, land lease	
(11.8 % of ex-factory price, 5.0 % of investment costs)	63 500
Service of capital (6 % interest, 20 years)	
Annuity 8.72 %	110 744
Site	
Mean wind speed at hub height (100 m)	10.0 m/s
Annual energy yield	
at 95 % availability, 5 % electrical losses, 10 % array losses	1 050 Mio kWh
Specific investment costs	
related to annual energy yield	121 $US/kWh
Power-generation costs	
with repayment in 20 years	0.17 $US/kWh

The long-term nature of the investments constitutes a strong argument for the large offshore wind parks on the open sea. The investments are in the range of billions and must therefore also be conceived for a service life of at least 40 to 60 years like large conventional power stations. Within this period, the costs of power generation from conventional power stations will certainly rise to a level of 0.17 $US per kilowatt-hour. In addition, it is uncertain with respect to these costs how the fuel costs will develop within this period. In contrast, the power from wind can be calculated with almost constant power generation costs since these are essentially determined by the capital costs expended once.

It should be pointed out, however, that the economic perspectives can only be assessed "from the current point of view". The development of wind energy technology in recent years has shown how all the forecasts were beaten by reality. It is certain that the development of wind energy technology will still make significant advances in the near future. Cost savings can be expected especially in the area of the costs for the very large wind turbines in the present 5 MW class.

In the near future an even larger generation of wind turbines will be available. In 2011 the leading manufacturers of wind turbines have announced offshore wind turbines with rotor diameters of more than 160 m having a rated power up to 7 MW (for example Vestas V165).

20.2.4 Dynamic Calculation of Economic Viability

The static calculation of power generation costs conveys only a momentary picture of the economics. A long-term investment decision requires a more far-reaching perspective. This means that a "dynamic" approach must include the anticipated development of certain economic conditions in the investment period. This unavoidably introduces speculative elements into the calculation of economic viability, but a long-term investment decision without this uncertainty is impossible anyway.

These speculative elements include the general inflation rate and the increase in electricity prices. These two factors have been the issue of many contentious discussions. Regardless of developments in recent years, it can be assumed, according to the opinion of the majority of economic experts, that inflation will amount to several percent per annum in the long-run and that the prices of electricity from fossil fuels will rise much more quickly than the remaining costs rising at the rate of inflation. Not least, there will be increasing expenses for the environmental compatibility of conventional power generation which will contribute to rising electricity prices.

Calculation methods which consider the dynamic development of the relevant economic factors are based on the *present-value* or *cash-value method* [2]. It is characteristic of this method that the different times of the occurrence of costs and income are taken into account regardless of whether the money has been or will be paid or received in the past or in the future. This is done by deduction of unaccrued interest (discounting) of all payment flows to a common reference time. The value of the payment flows at the respective time is called the *present value.* The sum of all present values is called the *net present value (NPV).* Comparing the return flows discounted to a time with the value of the initial investment provides a picture of the profitability of the project.

The net present value is calculated as follows:

$$C_0 = \sum_{i=1}^{n} \frac{E_i - K_i}{q^i} - \frac{R_l}{q^l} + \frac{S_n}{q^n} - I_0$$

where:

C_0 = capital value (net present value)
n = economic life of the investment in years
E_i = revenue in the year i
K_i = expenses in the year i
q = $(1 + p)$ with the discount interest rate p
R_l = renewals investment in year l
S_n = residual value of the investment in year n
I_0 = initial capital investment

The net present value (NPV) can be calculated for any point in time of the economic operating period. It evolves from negative values at the beginning of the operating period to positive values at the end of the economic operating period. An investment is economic when the NPV added together over the period of investment, is positive. A negative value indicates an uneconomic investment.

Besides the net present value, which provides a criterion for the investment's economics, the repayment (amortisation) period is an important further criterion. Formally, this is the period where the difference between costs and earnings is equal to the initial investment. This also means that the repayment period occurs at the time at which the net present value becomes equal to zero. This occurs in year ten in the example considered.

Utilities often calculate for their investment projects (power stations) the average cost of power generation calculated over the lifetime of the investment and compare this with an alternative in order to find out which is the economically more advantageous project. Naturally, both investments must be calculated by using the same method and under no circumstances must the actual power generation costs be compared with those calculated by the discounted cash-flow analysis method. The average power generation costs according to the present-value method can be obtained by the formula:

$$K_W = \frac{\sum_{i=1}^{n} \left(\frac{I_0 f_W + K_i}{(1+p)^i} \right)}{\sum_{i=1}^{n} \frac{E_i}{(1+p)^i}}$$

where:

K_W = average power generation costs over the economic life
n = economic life of the investment in years
E_i = annual energy yield
I_0 = initial capital investment
f_W = recovery factor (annuity)
K_i = expenses in the year i
p = discount interest rate

The factor f_w contained in the formula is called *annuity* or *recovery factor:*

$$f_W = \frac{(1+p)^n\, p}{(1+p)^n - 1}$$

It should be noted, that the energy costs calculated by the static approach correspond to the average power generation costs if the increase of income from the energy yield would be the same as the increase of costs over the calculated economic life time.

For the example of Table 20.7 and Table 20.8, the increase in annual operating costs and the electricity sales revenue were assumed to be 2 % per annum (inflation rate) and in addition it was supposed that the residual value of the wind park is still 15 % of the initial capital costs at the end of its economic service life of 20 years. Given these assumptions, a positive capital value of 1,027 € million is obtained.

Average power generation costs of K_W= 9.0 Cent/kWh are obtained. The recovery factor (annuity) is f_W = 8.72 %. If the increasing factors for the inflation and the electricity price are assumed with the same figure, as it is in this example, the results are the same as calculated with the static approach (see Chapt. 20.2.2)

By themselves, these figures do not provide much information. They are of significance when several different investments are compared using these criteria as reference. This is the case with large utilities where often a number of alternatives are compared with respect to technology and site. Such choice is usually not available for wind energy utilisation which is why cash-flow calculation is more informative for large wind energy projects. This is described in the next chapter.

20.2.5 Cash-Flow Projection

Today, large investments are assessed economically almost exclusively by applying a cash-flow calculation over the economic service life of the investment object. This method is generally called a *cash-flow calculation.*

The cash-flow method is based on an accounting "spreadsheet" that is a year-by-year listing of revenue income and expenses over the service life of the project, taking into consideration such dynamic factors as price increases, variable tax payments and so on. The result of the continuous comparison of earnings and expenses is the so-called *cash flow*. Unfortunately, the term "cash flow" is not clearly defined in the relevant literature. One widely used definition is that cash flow is the difference between income and object-related expenses including interest payments. Accordingly, cash flow is the money available before depreciation, redemption, tax payments and profits. In other words, these are the liquid means generated which are available for repayment, taxes and dividend payments.

The cash-flow calculation thus provides a complete overview of the most important economic figures of the investment object in its assumed lifetime. As always, however, the truth is much more complex. Only a slight change in the input data, for example in the indices of price and cost increase, will dramatically alter the numerical values after a few years. It could also be said that, with the appropriate input data in one's calculation, any investment can be made to appear to blossom or to wilt. Moreover, the profitability criteria derived from the cash-flow calculation, e.g. the *internal interest rate or internal* *rate of return (IRR),* can be altered considerably by formal manipulation, for example by changing the period of observation.

Regardless of these doubts, today no profitability analysis of investments is complete without cash-flow calculation. Like all complex methods, it must be generated responsibly and used with the necessary care. It also provides valuable service by revealing the influence of certain factors in the sense of a "best case" and "worst case" consideration by means of "sensitivity analyses". This throws light on the economic stability of the investment with changes in technical and economic parameters.

The example of the before outlined wind farm consisting of 50 wind turbines of 2.0 MW rated power each in Table 20.3 shows the results of a cash-flow projection. Table 20.7 provides the necessary input data for the calculation. Table 20.8 shows the development of income and expenses over an operational period of twenty years. The relative order of magnitude of the cash flows becomes quite clear in the graphical representation of Figure 20.9. The predominating significance of the service of capital over the assumed credit period of 15 years is immediately obvious. Within this period, the result for the investor is quite modest, and it is only after the credit has been repaid that the project really becomes attractive from an economic point of view. With the assumed electricity revenue of 9 Cent/kWh at the beginning, the repayment period for the equity used will be reached in ten years.

The IRR provides information on the profitability of the equity used. The value depends to a certain extent on the assumed times of supply and withdrawal of payments so that the exact method of how it was determined should always be specified. In the example calculated, the internal rate of return is 10.1 % over the term of 20 years. This value does not quite meet the expectations of so-called "institutional investors" who generally expect a return of about 15 % on their capital investment and a shorter term. For many private investors, however, who initially can still link their investment to tax advantages, the fact that after the loans have been repaid, the available cash flow becomes very high, acts as an incentive for this type of investment.

From the point of view of the banks providing finance, the *debt service cover ratio* (DSCR) is a measure of the economic stability of the project. It indicates the amount by which the available cash flow exceeds the payments for interest and repayments of loans. The banks often demand a DSCR of at least 1.3.

In real cases, professional cash-flow projections for large investments projects are carried out in much more detail, as in the example of Table 20.7. In particular, it contains variable interest payments and repayment rates, different durations of various bank loans and more detailed tax payments.

Overall, cash-flow projections are an indispensable tool in the development of complex financing models. Large investment projects can no longer be realised without them today. The risk inherent in long-term investments can generally only be managed by means of a combination of equity capital and outside capital and by very careful distribution of the risks. In particular the commonly applied project- or non-recurring financing for large projects are based on cash-flow projections (s. Chapt. 20.1). The banks, which grant the loans, pay very close attention on these calculations and the underlying assumptions.

A specific risk which has to be pointed out is the variability of income due to the unsteadiness of the mean annual wind speed from one year to the next (see Chapt. 13.3.3). The cash-flow projection as the basis for the project financing is based on the long-term average of the wind speed, but the experience is that several successive years of lower wind speed can occur. If this happens, the project runs into liquidity problems if no financial reserves are available. In many single-purpose companies based on project financing and on the cash-flow projection described, this situation can cause severe problems.

Table 20.7. Input data and economic conditions for the cash-flow projection for the operation of a wind farm (s. Table 20.8)

Wind Park	
50 wind turbines of 2.0 MW rated power each	$ US x 1 000
Rotor diameter 82 m, Tower height 80 m	
Investment Costs	
Ex-works price of wind turbines (includes transport and erection)	130 000
Planning, techn. infrastructure and financing	39 300
Total project costs	169 300
Annual Costs	
Maintenance and repairs (full service contract for 15 years incl. repair reserves)	2 100
Insurances (with full service contract)	300
Administration, operation	650
Land lease (wind turbines and auxiliary facilities)	1 000
Misc. (energy consumption, consulting, etc.)	500
Financing	
Equity 20 % of investment	
Loan 80 % of investment (interest rate 6 %, 15 years term)	
Depreciation	
Book depreciation 16 years (linear)	
Tax	
Approximately 10 % of profit is assumed	
Variations	
Cost increase	2.0 % p.a.
Electricity sales revenue increase	2.0 % p.a.
Energy Yield	
Mean wind speed at hub height	6.5 m/s
Net energy production	210 Mio kWh
Electricity sales price at the beginning	0.095 $US/kWh

Table 20.8. Cash-flow projection for the operation of a wind farm

Cashflow Projection
(Values in Thousand of USD)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
A. Income Statement																					
Revenues																					
Energy sales	19.950	20.349	20.756	21.171	21.595	22.026	22.467	22.916	23.375	23.842	24.319	24.805	25.301	25.807	26.324	26.850	27.387	27.935	28.494	29.063	484.733
Residual value windpark																				19.500	19.500
Total Revenues	**19.950**	**20.349**	**20.756**	**21.171**	**21.595**	**22.026**	**22.467**	**22.916**	**23.375**	**23.842**	**24.319**	**24.805**	**25.301**	**25.807**	**26.324**	**26.850**	**27.387**	**27.935**	**28.494**	**48.563**	**504.233**
Operating Expenses																					
Full service contract (15 years)	0	0	2.310	2.310	2.310	2.520	2.520	2.520	2.520	2.520	2.730	2.730	2.730	2.730	2.730	2.940	2.940	2.940	2.940	2.940	47.880
Insurances	0	0	312	318	325	331	338	345	351	359	366	373	380	388	396	404	412	420	428	437	6.683
Land rent	1.056	1.077	1.098	1.120	1.143	1.165	1.189	1.213	1.237	1.261	1.287	1.312	1.339	1.365	1.393	1.421	1.449	1.478	1.508	1.538	25.647
Administration	650	663	676	690	704	718	732	747	762	777	792	808	824	841	858	875	892	910	928	947	15.793
Miscellaneous	500	510	520	531	541	552	563	574	586	598	609	622	634	647	660	673	686	700	714	728	12.149
Total Operating Expenses	**2.206**	**2.250**	**4.917**	**4.969**	**5.022**	**5.286**	**5.342**	**5.398**	**5.456**	**5.514**	**5.784**	**5.845**	**5.908**	**5.971**	**6.036**	**6.312**	**6.380**	**6.448**	**6.519**	**6.590**	**108.152**
Depreciation	10.362	10.362	10.362	10.362	10.362	10.362	10.362	10.362	10.362	10.362	10.362	10.362	10.362	10.362	10.362	10.362	0	0	0	0	165.795
Net Income																					
EBIT	7.382	7.737	5.477	5.840	6.210	6.378	6.763	7.156	7.557	7.966	8.172	8.598	9.032	9.474	9.925	10.176	21.007	21.486	21.975	41.973	230.285
Interest payments	7.969	7.643	7.268	6.870	6.447	5.999	5.523	5.017	4.481	3.912	3.308	2.666	1.986	1.264	497	0	0	0	0	0	73.324
Interest earnings	181	303	363	366	369	372	376	379	382	386	389	393	397	401	404	351	355	360	364	368	7.257
Tax paid	26	195	48	116	186	237	313	392	474	559	626	719	815	915	1.020	1.078	2.174	2.223	2.274	4.297	18.686
Net Income	-432	201	-1.477	-780	-54	514	1.303	2.126	2.984	3.881	4.628	5.606	6.627	7.696	8.813	9.449	19.189	19.623	20.065	38.044	148.005
B. Cash-Flow Statement																					
Liquidity Reserve	1.031	5.000	6.900	6.900	6.900	6.900	6.900	6.900	6.900	6.900	6.900	6.900	6.900	6.900	6.900	5.000	5.000	5.000	5.000	5.000	0
Net income + depreciation	9.930	10.564	8.886	9.582	10.308	10.876	11.665	12.488	13.346	14.243	14.990	15.968	16.990	18.058	19.175	19.812	19.189	19.623	20.065	38.044	313.801
Debt repayments	5.788	6.114	6.489	6.887	7.310	7.758	8.234	8.740	9.276	9.845	10.449	11.091	11.771	12.494	13.260	0	0	0	0	0	135.507
Cashflow for dividend	173	2.550	2.397	2.695	2.998	3.118	3.431	3.748	4.070	4.397	4.541	4.877	5.218	5.564	7.815	19.812	19.189	19.623	20.065	43.044	179.325
in % of equity	*1%*	*8%*	*7%*	*8%*	*9%*	*9%*	*10%*	*11%*	*12%*	*13%*	*13%*	*14%*	*15%*	*16%*	*23%*	*59%*	*57%*	*58%*	*59%*	*127%*	*530%*
Debt Service Cover Ratio (DSCR): 1,3	-	1,32	1,17	1,20	1,22	1,23	1,25	1,27	1,30	1,32	1,33	1,35	1,38	1,40	1,43						
Internal Rate of Return (IRR): 12,7%																					

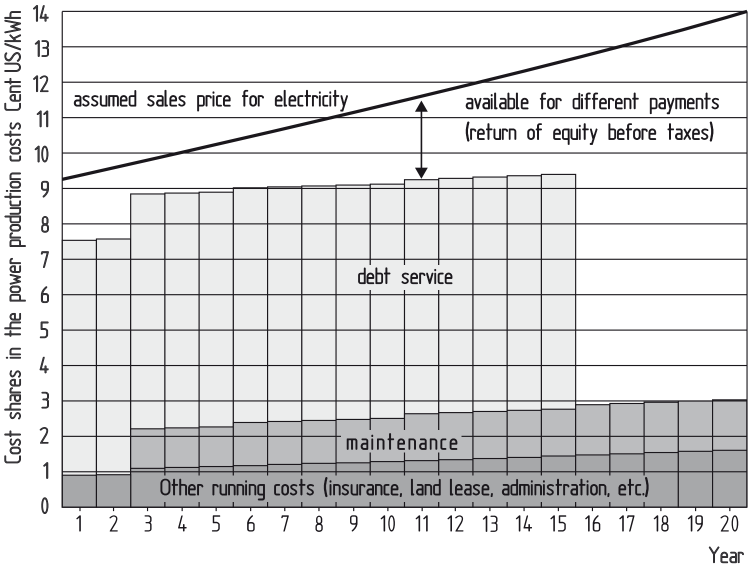

Fig. 20.9. Cash-flow shares in the cash-flow projection for the operation of a wind farm

20.3 Competition with Conventional Energy Sources

In principle, the economic viability of electricity generation from wind energy on the basis of the calculated power generation costs can be assessed under three different frames of reference:

- The electricity price to be paid by a user who is able to use the wind power himself,
- the income received by an operator of a wind turbine on feeding the current into the public grid,
- the power generation costs of an electricity producer who wants to generate electricity from wind energy as an alternative to other power stations.

For the reasons discussed in Chapter 16.3, the self-use of wind energy is restricted to a few exceptions and, therefore, virtually of no significance in wind energy utilisation. Today, wind turbines are operated almost without exception for the purpose of feeding the generated power into the grid. The legal conditions for feeding into the grid are subject to regulations in almost all European countries. The decisive question is, therefore, what price is offered to the operator of a wind turbine for one kilowatt-hour of electricity fed in. In some countries, there are legal or semi-legal regulations for payment for feeding-in power (such as Germany, Denmark, Spain, Greece, and France). In other countries, particularly in the United Kingdom, the turbine operator must negotiate the electricity price with the utility or compete with others. Table 20.10 shows the payments made for wind power in some countries of the European Union in recent years.

Table 20.10. Prices paid for wind energy in some member states of the European Union (€Cent/kWh) and in the US ($US Cents/kWh)

Country	Payment	Legal Basis
Germany	8.8 - 9.2	Law (EEG), 2000
Denmark	7.5	Law
Netherlands	7 - 8	Certificates Dealing
France	8.3	Law since 2002
Italy	15 - 20	Certificates Dealing
Spain	8 - 9	Law since 1997
Portugal	8.5	Law
Greece	8.2	Law
UK	10 - 11	Tendering
Sweden	5 - 6	—
US	4.86 + 1.7	purchase price + tax refund

In many cases, the costs of generating electricity from wind energy are derived from average values of the general electricity prices. The increasing liberalisation of the electricity market in the EU has resulted in a continuous movement in the electricity prices in recent years which also affect the payments for electricity fed in from renewable sources so that the current payments for supply must be ascertained with respect to the present day. However, in Germany, the Renewable Energies Law (REL) has resulted in the link between payment for supply and the general electricity prices being broken as was intended politically. This provision, which is advantageous for the development of renewable energies, was initially very controversial but, on the other hand, proved to be a decisive economic foundation for expanding the utilization of wind energy. But in recent years, the electricity prices have been rising again and nobody is seriously expecting any longer that the electricity prices will drop again in the future. In view of this perspective, the electricity-price-independent payment for electricity fed in according to the REL can no longer be considered to be future-oriented.

Those who calculate with increasing proceeds from the sale of electricity over a period of 20 years will obtain a quite different picture of the economic viability of the generation of electricity from wind energy. In most other countries, the payment for electricity is linked to the electricity prices, thus offering a better long-term economic perspective. The course has already been set in this direction in connection with the construction of the first large offshore wind parks. Looked at from this perspective, the decisive criterion is the comparison with the development of power generation costs of the conventional power stations over the next twenty or thirty years.

The reference for future power generation costs is the complete cost accounting for new power stations. A serious business calculation will show that power cannot be generated for less than 0.10 $US/kWh even with the most cost-efficient gas and steam power stations today or in the near future. Coal-fired power stations using imported coal have power generation costs of at least 0.10 to 0.15 $US/kWh (Table 20.11). It must be emphasised at this point that this is a purely "business" calculation. It does not take into consideration the much-quoted "external costs" of power generation from fossil fuels or from nuclear energy (s. Chapt. 20.7). The power generation costs of different types of power plants calculated by various organisations or authors are summarised in Table 20.11 [3, 4].

Table 20.11. Estimation of electricity generation costs of different types of power plants calculated for new power stations in the near future

	Coal	Gas comb. cycle	Wind onshore	Wind offshore	Site
Virginia Offshore Studies [3] $US/MWh	135 - 150	100 - 120	–	105 - 130	Atlantic
RWI (Germany) [4] Euro/MWh	104 - 107	106 - 118	–	–	North Sea
Tab. 20.3, 20.5, 20.6 (Chapt. 20) $US/MWh	—	—	90	120 - 170	North Sea

It is of interest in this connection to cast a glance at the composition of the electricity prices from the producer through to the industrial or private end-user. Even if the figures can only be taken as a rough guide - it is a well-known fact that the utilities never disclose their figures - their order of magnitude should be correct. In 2004, the following typical picture from the point of view of a private power user was obtained in Germany:

- Power generation costs	6.0	Cents/kWh
- Transmission costs		
Extra high voltage (380/220 kV)	1.0	
High voltage (110 kV)	1.5	
Medium voltage (20 kV)	2.5	
Low voltage (400 V)	3.0	
- License fee (municipalities)	1.0	(variable up to 2.0)
- Environmental tax	1.8	
- Value-added tax (19 %)	3.2	
Total:	20.0	Cents/kWh

A mixed electricity price of payment for demand and energy consumption price of approximately 20 Cent/kWh is thus an end-user price which, with honest complete cost accounting, cannot be lowered, at least not under the currently prevailing conditions. To this, profits and other costs have to be added.

Large industrial consumers often get their electricity at the 110-kV level and, therefore, only have to pay for the production costs and the long-distance high-voltage distribution costs. Neither do they have to pay electricity and value-added taxes.

The rising electricity prices are increasingly reducing the margin between the payments for feeding in electricity from renewable energy sources and the power generation costs of the energy industry. It is not presumptuous to suggest that power from wind energy competing with the conventional power stations will be competitive within a few years. This is already the case in some countries.

20.4 Energy Recovery in Wind Turbines

In discussions of renewable energy systems the question is frequently asked of whether the energy required for manufacturing the equipment is not greater than the energy yielded during the service life of the system. Quite generally, this can be countered with the argument that when an energy-generating system has a fairly acceptable commercial capital recovery time, its energy recovery period will in any case be shorter since the energy costs constitute only a fraction of the manufacturing costs. Even if the manufacturing costs are greater by one order of magnitude than what is required for achieving commercial redemption, the system repays itself from an energy point of view.

When determining the energy requirement of the manufacturing process, attention must be paid to the fact that an assessment is made of the different types of energy used. Due to their conversion efficiencies of 0.3 to 0.4, the value of electrical and mechanical energy must be rated about three times higher than thermal energy. Owing to its high conversion efficiency of 0.8 to 0.9, the amount of thermal energy obtained can be considered as equal to the primary energy used, in a first approximation. Table 20.12 shows the energy recovery time of a medium-sized wind turbine. The specific primary energy values listed indicate the energy required for semi-finished production and processing.

Table 20.12. Energy requirement for manufacturing a medium-sized wind turbine with 53 m rotor diameter and 1000 kW rated power. Annual energy yield 2.4 million kWh

Material	Mass (kg)	Specific primary energy requirement (kWh/kg)	Primary energy requirement (kWh)
Steel (nacelle, rotor, tower)	105 000	15.5	1 627 500
Copper (generator windings, cables)	2 700	25.0	67 500
Glass-fibre composite (rotor blades, nacelle)	9 600	28.0	268 000
Concrete (foundation)	100 000	0.5	56 000
Total requirement			2 013 800

Accordingly, the primary energy requirement amounts to 2 million kWh for the manufacture of the wind turbine. The primary energy equivalent of the annual electrical energy yield of 2.4 million kWh amounts to 6.85 million kWh. Thus, the resultant energy redemption time is 34 months. If a wind turbine has an assumed life of 20 years, a *recovery factor* of 70 is achieved. Compared to conventional power plants, this value is very good. Relevant literature indicates a recovery value of 20 to 30 for conventional power plants [5].

20.5 The Effect of Wind Energy Utilisation on Employment

An important question to be asked today in the context of every new technology is its effect on employment. The worry that the introduction of a new technology will turn into a "job-killer“ or the hope that it will create new jobs concerns an ever-increasing number of people. Therefore the effect of wind energy utilisation on employment has been investigated in numerous studies. In Germany the Federal German Wind Energy Association (BWE - Bundesverband Windenergie), in collaboration with the Association of German Engine and Plant Manufacturers (VDMA - Verband Deutscher Maschinen- und Anlagenbauer) is creating so-called "job statistics" for the wind energy industry at certain time intervals [6]. According to these statistics, the jobs are distributed over the fields:

- wind turbine manufacturers,
- supply industry,
- services and operation.

One outcome of those studies are specific numbers for the created jobs with reference to the turnover or directly to the installed megawatts.

The jobs created directly at the wind turbine manufacturers can be estimated using a characteristic number from mechanical-engineering manufacturing of approx. 250,000 to 200,000 $US turnover per job. The jobs for the total industrial field of manufacturers and suppliers amount to a characteristic number of 12 employees per 1 Mio $US turnover. The employment-related proportion of the O+M costs is specified as approx. 40-50 $US per kilowatt installed power for wind turbines on land and 80-100 $US/KW for offshore installations.

Other characteristic numbers relate directly to the produced megawatt. Land-based wind turbines with an investment of 1.8-2.0 Mio $US generate about 10-15 jobs per MW in Europe. For one megawatt offshore power with investment costs of 3.5 Mio $US the number is approx. 39 jobs in the US [3].

Some examples illustrate the effect. In Germany for example the turnover of wind energy equipment was 8,500 Mio € in 2008. Taking the number of 200,000 € per job, the generated employment was about 42,500 jobs. This corresponds to the statistics of the industrial associations quite well. In Denmark the turnover was 5,700 Mio € corresponding to 28,500 persons. In the US the possibilities for offshore wind energy utilisation in the coastal waters of Virginia has been evaluated [3]. A capacity of 3,200 MW has been identified. Assuming a building rate of 160 MW per year the generated employment is supported with 6,200 jobs over a period of at least twenty years.

It should be noted in this context that the production of wind turbines, even of very large wind turbines, does not mean employment for heavy industry only. Apart from a few aspects in research and development, wind turbines are not "large-scale high-tech products" like nuclear power plants or aircraft. Neither are they "do-it-yourself" kits which can be put together in a bright green world by the operators themselves in an attempt at self-realisation. Wind turbines are industrial products of medium-level technology, the production of which can be handled both by relatively small companies and by large companies.

20.6 Macroeconomic Framework and Renewable Energies

From the point of view of a commercially oriented investor, profitability of an investment is a demand which cannot be waived. Renewable energy systems must also meet this demand. Arguments for the utilisation of renewable energy sources other than economic ones - as important as they may be - can, therefore, not be addressed to the operator. The higher-order economic aspects must be reflected in the macroeconomic conditions. Drafting these in the interest of public welfare is a political task.

As is generally known, the economic action of the individual is determined by numerous macroeconomic conditions. Among these are the tax treatment of investments and profits, direct subsidies, but also less visible aids such as funding for research and development which benefit a particular branch of the economy but are paid out of public funds. This applies to almost any branch of the economy, but particularly to the energy industry.

In this way, the competition between the various primary energy sources such as coal, oil, gas, nuclear power and hydro-electric power is to a considerable extent controlled by macroeconomic considerations. In many countries, the use of domestic coal, for example, is supported by public funds and, as in Germany, the contractual obligation for the utilities to use domestic coal.

The utilisation of nuclear power, too, was, and still is, being considerably subsidised with public funds. Without the double-figure billion-dollar subsidies for research and development which have been paid within the past 50 years, there would be no commercial nuclear power stations, or the electricity from nuclear energy would be considerably more expensive if these sums had to be raised out of private pockets.

These two examples, and many more could have been named, show that free competition between primary energy sources in the sense of a free market, does not exist and has never existed. It would also be wrong to demand such a condition. The energy supply, particularly of an industrialised country, is of such great significance to its general economy and social life that it cannot be left to the accountants of profit-oriented companies alone to decide on this matter.

In the past, most countries set their policies with respect to energy supply targets only from strategic and economic points of view and also based the macroeconomic conditions for the energy industry on these considerations. But the times have changed. The requirements to be set for the supply of energy must also be re-evaluated. Attempts at self-sufficiency in energy supply cannot succeed, in any case. At the most, the dependence on a primary energy supply can be eased by diversification. A new awareness has grown with respect to the interrelationship between energy generation and ecology. Solving this problem may possibly be one of the questions of survival of the human race, if survival in an environment suitable for human life is meant.

Moreover, an increasing number of people are disturbed by the hazards which may be presented by the utilisation of nuclear energy. An energy form which in principle involves the risk of a catastrophe for humanity, will always be rejected by a part of the population, despite all safety precautions. And even if the technical safety measures were as perfect as has always been maintained by its supporters, the risk factor of "human error" will always remain. In order to eliminate this risk, for example in times of political instability, the entire energy cycle must be kept under surveillance. Many see in this an inevitable route to a "police state". In other words, after strategic independence and economic efficiency, "environmental compatibility" and "social compatibility" are also aspects which must play a role in formulating the contemporary political boundary conditions for the energy supply.

And what about the demand for inexpensive energy? Are not low energy costs the precondition for the economic power of an industrialised country? The question is what is cheap for whom? Surely not for the utilities alone, acting under specific political conditions. This would mean confusing cause and effect. Ultimately, it is only the "value for money" which can be the valid measure, considering all economical and ecological effects. This requirement must be met by all forms of energy supply including the utilisation of regenerative energy sources.

If all cost-related factors are included in the energy supplied, starting with the research about the processing of the fuel, e.g. coal mining, the investment costs of power plants, fuel costs, waste disposal and, not least, consequential ecological damage as well as expenses for public safety, the assessment of the competing primary energy sources becomes a very difficult issue to address. Despite many commendable approaches attempting a quantitative assessment, a generally accepted answer to this question is yet to be found. One thing can be said right from the start, however: The utilisation of renewable energy sources cannot possibly fail to impress in such a comparison [7].

What remains is the question of security of supply (firm power) for the consumer. An argument frequently used against renewable energy sources, above all against wind energy utilisation, is that it is unpredictable by its nature, and thus unsuitable. The answer to this is simple: No reasonable person would think of basing his energy supply on the utilisation of wind power alone. Wind power will always be only a part of the overall power supply system. The required availability, with or without wind turbines, will always be borne by the entire system of interconnected power stations. The comparatively low availability of wind turbines is reduced to the purely technical question as to what extent they can contribute to the firm power of system of interconnected power stations and thus becomes an economic problem, at most.

An attempt to draw a conclusion from all these macroeconomic considerations, and to derive from them requirements to be set for future energy supplies, could be summarised in four central points:

- Secure in the sense of firm power based on the total combined power supply system and not dependent on imported sources only.
- Economically acceptable costs including all cost-related factors from the primary energy source generation to waste disposal to environmental effects.
- As ecologically beneficial as possible according to the state-of-the-art. In case of doubt, always opt for the solution with better ecological impact.

- Socially compatible with respect to the hazards inherent in the technology.

Political conditions which take these contemporary requirements into account will create fair chances for the utilisation of renewable energy sources. Moreover, they will be indispensable for a future energy industry which will again be based on a broad consensus in society. In the end, however, it will not be laws which will guarantee a lasting change in the energy economy but a rethinking by every individual and, hand in hand with this, a change in values as perceived in our society.

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