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Economic metrics for wind energy projects

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Abstract
This paper presents an overview of economic metrics for wind energy projects. The attractiveness of the proposed wind energy can vary considerably between evaluation of the private and public sector. The financing structure is very important influencing factor for the attractiveness of wind energy project. In many cases, the economic activities practiced by economic agents of financing the project in order to earn sufficient income to meet the investors' needs and other economic agents involved. They are also characterized the assessment indicators and economic-financial management of projects implemented renewable energy exclusively for onshore wind energy systems. All indicators presented should be used in economic engineering analysis to meet specific information needs for decision making in situations of investment opportunity for renewable energy projects.

Keywords: Economic metrics; Wind farms; Evaluation; Management.

1. Introduction

Opportunities to use sun, wind, water, wood as energy sources are numerous. Renewable energy sources are naturally replenished energy in a relatively short period and generated by natural processes. While conventional sources of energy are finite (in human dimensions of time). Each case must be evaluated is the project economically. If the present high cost of energy produced compared to classical sources, the use of new technology is discredited by final consumers (and public opinion behind it). When there are different technical solutions, or when you offer multiple investment opportunities is necessary to evaluate the projects to decide what or who should be executed. This paper focuses on the economic and financial assessments for renewable energy projects.

The renewable energy projects can be of different sizes and can extend over different time horizons. But always involve technical, financial and human resources that must be combined to create the expected result. The renewable energy projects share the typical characteristics of all other projects [1]:

a. The project begins and ends that determine the "project´s life" that differentiates it from other activities of a permanent nature in existing organizations or companies (who may be involved in the project).
b. The financial and human resources available for project implementation are limited (usually pre-determined at the beginning of the project).
c. The project is a set of tasks and activities that are separate from other activities undertaken by the parties involved in a repeating basis ("the day-to-day").

The project requires a specific organization that unites all parties together, regardless of other (existing permanent) organizational ties or relational boundaries between the parties involved, as shown in Figure 1.

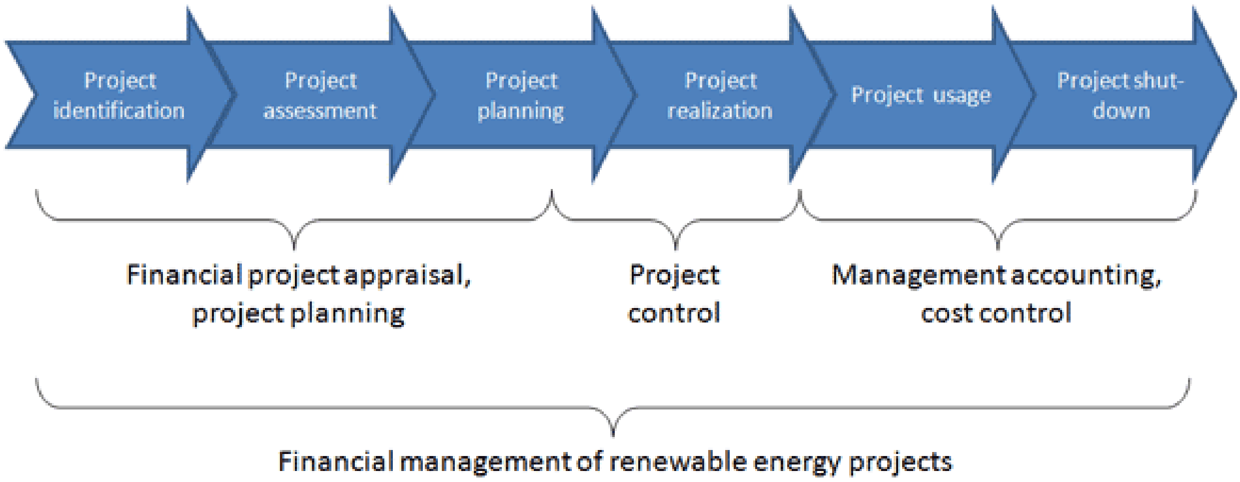


Figure 1. Evaluation process and financial management of renewable energy projects [2]

The evaluation measures the investment attractiveness of investment or potential project (here more specifically: a renewable energy project, wind onshore) for the investor and/or manager. A project is attractive, the consequences of that lead to the expected result of attractive economically, financially by the investor [3].
This paper discusses the main methods of economic evaluation applied to the energy industry with a discussion of the topics of greatest interest to economists, engineers and other professionals related to analysis of economic and financial viability of investments in power of decentralized production of electricity. However the issue is important: the economic and financial viability of the enterprises is a necessary condition for the gradual deployment of new energy technologies to do so solid and convincing.

2. Classification of costs categories

2.1 Cost structure of wind energy onshore

Although we have not made any distinction between different technologies in renewable energy, the cost structure of a renewable energy project is dependent on the technology used. The "Renewable Energy" covers a diverse set of technologies ranging from small photovoltaic solutions for roofs of individual houses to large wind farms onshore and offshore. All costs parameters and definitions used in this paper, are characterized only costs related to the onshore wind made the analysis from production to the mains distribution.
The following are the major cost components for onshore wind power are presented and briefly described (see Table 1). The emphasis is on description of these elements are not in exact figures. The cost values are dependent on circumstances of individual projects and are altered at a rapid pace due to technological advances and economies of scale. The main cost elements are proving to be quite stable in the technological nature of particular projects to produce electricity from wind, so you should be familiar with them, to make a complete and consistent assessment of attractiveness of the project [4, 5].
Depending on the nature and reflects the behavior of the final cost of power produced by wind farm, the typical elements of cost are grouped by cost category. The listing does not tend to be exhaustive, as wind power, by experience and technological maturity has become easier to identify these costs. It is important that classification of the cost structure to facilitate financial and economic analysis of projects [6]. A plant for producing electricity from wind energy uses the principle of conversion of kinetic energy[1] contained in flowing air masses (wind) into electrical energy [7]. The wind turbine consists of tower

[1] In Physics, the principle of converting kinetic energy is the amount of work that must make an object to change its speed (either from the rest - zero speed - either from an initial speed). For an object of mass (m) velocity (v) kinetic energy in an instant of time, is calculated as $Ec = \frac{mv^2}{2}$

equipped with rotor blades and (the concept of "windmill") connected to the electrical generator that converts rotational mechanical energy into electrical energy. Wind power can be used for both connected to the mains system (usually "wind farms"), as well as for applications independent of electrical grids [8]. According to IEA [9], NREL [2] and RETScreen® International Clean Energy Decision Support Centre [10], the individual elements of project costs of wind power for electricity production can be grouped into four distinct categories of costs (investment costs, operational costs, maintenance cost and financial cost.

Table 1. Classification of costs into categories for wind energy projects

Investment cost	Also called the "capital cost" or "initial investment", this group of costs reflect all cost elements that occur only once at the beginning of the project. Investment cost includes cost of purchase and installation of equipment, site preparation, acquisition of necessary licenses or permissions, planning and professional advice necessary to connect the wind farm system facilities or construction of public grids.
Operating cost	Refers to the cost elements that occur during regular operation mode of the system after being put into production. The operating cost can be cost of raw materials or operating personnel, as well tax payments and insurance, land lease, or cost to supply energy to the public network (access fee). Part of the cost of operations is independent of capacity utilization of the production system, so, they are fixed. Other operating costs vary with the load supplied to the grid. The split between fixed and variable operating costs differ among renewable energy technologies. The ratio of fixed operating costs to revenue (per period) is called “project self-financed". In a system with self-finance the project uses a greater proportion of revenue on systems with low self-financing. The self-finance the project reduces the flexibility of the cost of the system during operation.
Cost of O&M	It includes all cost elements that occur in order to maintain or ensure the productive capacity (system operational availability). Can be achieved through preventive maintenance (system check before being damaged) or repair (arranged in the system after it was damaged). Maintenance measures may be small and frequent (replacement of small parts such as lamps and air filters, periodic verification procedures), or large and infrequent (unscheduled repair of significant damage, change of principal components).
Financial cost	This category of costs is included in all financial expenditures caused by financing transactions within the lifetime of the project. The most important element of cost is the interest payment to lenders of the project. Other elements are typical costs resulting from banking to venture capital acquisition, construction consortium, the cost of financial guarantees. The financial cost can be cost elements related to a specific period during the life of the project (similar to the cost of capital) or elements of recurrent costs (similar to the operating cost). Different from the capital costs and operations, as are not due to technical or operational characteristics of the project, but are influenced by the nature of funding.

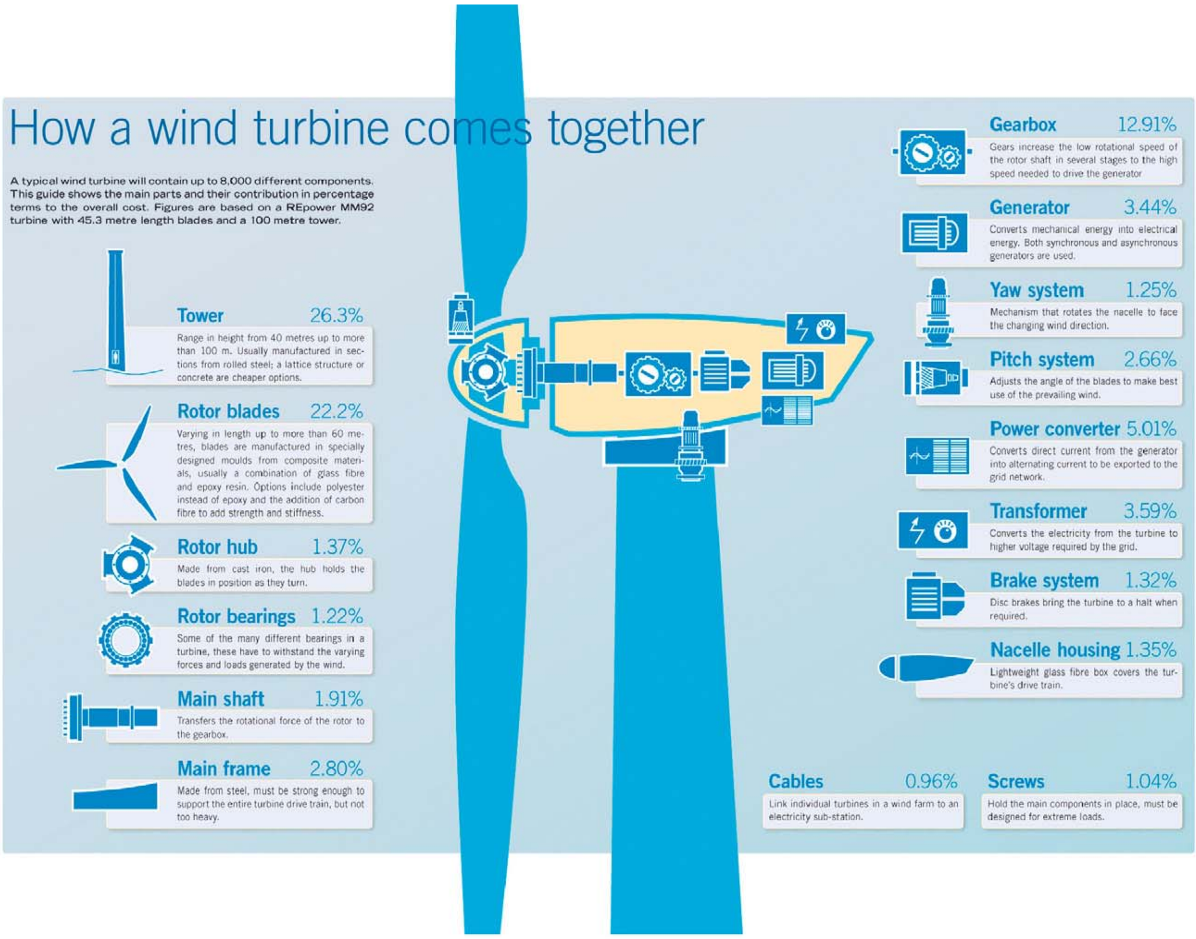
Source:[9]

It is important to differentiate the wind farm costs in terms of installed capacity (total capital costs and variable costs) and cost of wind energy per kWh produced. Fuel costs for wind farm cost is zero. This is the fundamental difference between electricity generated by wind power and other options of conventional power generation. For example, in a power plant to natural gas has been 40 to 60% of the costs related to fuel and O&M, compared with about 10% for onshore wind farm. Moreover, the fact that wind energy projects require substantial capital investment affects the financial viability of projects. Become essential to the investor or manager to have most of the funds needed at the time that the wind farm is built. To have access to the rest of the capital financed in good condition for a refund. Some projects cannot be executed due to the necessary funding during this initial phase, although, over time, may become a less expensive option [11].
The great advantage of wind power after the installation process and wind measurements calculated correctly, the production cost of this technology is predictable, which reduces the overall risk to the power company. The cost of capital projects for offshore wind power is higher than for onshore wind

energy projects [12]. The higher cost is due to increased investments (foundations of the tower under the sea) and transport costs, on the other hand the need for high reliability and low maintenance routine (accessibility of the wind farm). The additional protection to physical facilities more effectively against corrosion and accumulation of harmful materials is necessary for marine offshore installations. All these factors orientates the initial investment [13].

Wind energy is a capital intensive technology, so that majority of cash outflows occur in this phase. The cost of capital can reach 80% of the total cost of the project during its lifetime, with variations between models, and local markets. The wind turbine is the major cost component, followed by the network. Even after more than two decades of consistent reductions, the capital cost of proposed wind energy has increased by 20% over the past three years. The results show that in the range of 1100-1400 €/kW for new projects in Europe. The costs are smaller in some emerging markets, especially in China and the United States of America. There are also variations in the European Union [14].

The Figure 2 illustrates the complexity of sub-components that make up a wind turbine, and helps explain why these elements are higher costs of initial investment. Note that the value refers to the exceptionally large size in the current market (5 MW, as opposed to 2-3 MW machines being installed in most onshore wind farms). The relative weight of sub-components varies depending on model. Other elements of cost, besides the wind turbine, are needed at the beginning of the project and represent about 18 to 32% of the total capital cost for onshore wind energy projects.



Source: Wind Directions, January/February 2007.

Figure 2. Example of the main components of onshore wind turbine with distribution of the overall cost of the 5 MW REpower [11]

Variable costs of production in wind energy projects are directly related to the cost of annual operations and maintenance (O&M) that are relatively high, accounting for 5-8% of initial investment (capital cost). The cost of O&M is particularly high in offshore systems. A distinctive feature of wind energy is the importance of the cost of insurance due to increased risk of equipment damage, downtime and damage to third parties. Wind energy (offshore wind farms in particular) can also involve considerable repair costs. Although the overall lifetime of the project could be 20-25 years, major repairs may be needed after 10 years of operational wind farm [14]. Currently, one of the priorities for wind turbine manufacturers is to reduce variable costs, especially those related to operations and maintenance (O&M) through the development of new projects for wind turbines, which require less service visits, resulting in higher productivity of the turbine. It is important to note that the downtime of the turbines is less than 2% per year [15].

According to British Energy Wind Energy Association [16], Asociación Empresarial Eólica [17]; P.E. Morthoest [18]; Milborrow [14], DTI [19], a prudent level of variable costs would be between 1-2 c€/kWh over the life span of the wind turbine. Which would mean 10 to 20% of total costs (about 10% in O&M activities). As with other cost categories, the percentages are only indicative.

Finally, the future development of variable costs, should be careful when interpreting the results presented previously. First, wind turbines have economies of scale in terms of reducing the investment per kW with an increase in turbine capacity, economies of scale similar may happen with O & M. Secondly, new and larger wind turbines have reduced the requirements for O & M in relation to older turbines and smaller. Other costs, including replacement of components, monitoring and insurance may increase due to increases in material costs and risks associated with certain models of large capacity wind turbines [11].

The local wind resource is the most important factor affecting the profitability of investments in wind and also explains most of the differences in cost per kWh between countries and projects. Wind turbines are useless without adequate wind resource. The correct location of each individual wind turbine is crucial to the economy of any proposed wind energy. In fact, it is widely recognized that during the initial phase of the modern wind industry (1975-1985), the development of the European Wind Atlas Methodology[2] was more important to productivity gains that advances in design in wind turbines [20].

The size and characteristics of the turbines are adapted according to wind patterns observed, being located after careful computer modeling, based on local topography and meteorological measurements. The average number of hours of full load varies from place to place and from country to country[3]. The range of facilities for onshore wind farms ranges from 1700-3000 hours/ year (average of 2342 in Spain, 2300 in Denmark and in 2600 in the UK, to name a few in Europe). In general, good sites are first to be exploited, although they may be located in areas of difficult access [21].

The theoretical energy production, based on the power curves of wind turbines and wind regime estimates is reduced by a number of factors, including losses in matrix production (occurring due to wind turbines shadowed each other within the wind farm), losses due to dirt or freeze in spades, mechanical friction losses, losses in transformers and electrical cabling and downtime of wind turbines for scheduled maintenance or technical failure. The net energy output is usually estimated at 10-15% below the energy calculation based on power curves of wind turbines [22].

Wind turbines are designed to generate maximum power at certain wind speed. This power is known as the rated power and wind speed at which it is reached is called the rated speed of the wind. The speed is adjusted according to the local wind regime, with values common to find between 12 to 15 m.s^{-1}. For the same reason, to values above the rated wind speed is not increasing economic power, it would require the largest of all equipment with a corresponding increase in initial investment, which would draw only a few hours during the year, thus turbine is set at above nominal wind speed and operate at constant power, leading to artificially decrease the efficiency of conversion [23]. When the wind speed becomes dangerously high (above about 25-30 m.s^{-1}), the turbine is switched off for safety reasons (the aerodynamic loads increase with the square of wind speed). Today's turbines in the adaptation of the system of production to wind speed at each instant it is set by adjusting the angle of attack of the blades (pitch control) and solution set through mechanical or electrical that has in some cases associated solutions for electronic power control, as well as for controlling the rotation speed. However, in certain situations, is limited to the operating power of the wind turbine [24].

A variety of models that analyze the trend of long-term costs of wind and other renewable, have been developed over the last decade, many supported by the European Union[4]. The European Commission [21] in the 2007 Strategic Energy Review presents a set of key results, as part of the assessment of

[2] The European Wind Atlas Methodology developed by Erik Petersen and Troen Lundtang Erik which was later formalized in the WAsP software for wind resource assessment by Risø National Laboratory, Denmark. For more information, see http://www.wasp.dk/.

[3] The full load hours are calculated as average annual production of wind turbine, divided by the nominal power.

[4] For example, TEEM, SAPIENT, SAPIENTIA, CASCADE-MINTS, co-funded by DG Research.

impact on renewable energies. This shows that the capital cost of wind power will drop to around 826€/kW in 2020, 788 €/kW in 2030 and 762 €/kW in 2050. A similar pattern is expected for offshore wind energy, as shown in Table 2.

Table 2. Trends in the cost of capital assumed by PRIMES project for wind energy

	€/kW in2020	€/kW in 2030	€/kW in 2040	€/kW in 2050
Onshore	826	788	770	762
Offshore	1274	1206	1175	1161

Source: [21]

Likewise, the British Department for Business, Enterprise and Regulatory Reform [25] commissioned a study by Ernst & Young to examine current and future costs of renewable technologies. Wind energy onshore and offshore provide upward trend until 2010. This will be followed by a decrease, since bottlenecks in the supply chain are addressed. Using specific costs of energy as the basis (cost per kWh produced), the estimated rates of progress in specialized publications are between 0.83 to 0.91, corresponding to learning rates from 0.17 to 0.09. Then, when the total installed capacity of wind energy doubles, the cost per kWh for new turbines decrease between 9-17%. The recent study by the DTI [25] estimates the cost savings of 10% when the total installed capacity doubles. Tables 3 and 4, has been short of capital costs, energy production and variable costs with their studies and values.

Table 3. Summary of some sources about capital costs and production costs of wind power

Study	Capital cost per kW installed	Cost per kWh
P.E. Morthorst [18, 26]	900€/kW to 1,175€/kW	n.a
Milborrow [27]	869€/kW to 1,559 €/kW	n.a
AEE [17]	971.67€/kW to 1,175.10€/kW	n.a
EER for Vestas [28]	1,050€/kW to 1,350€/kW	n.a
BWEA [16]	1,520€/kW	n.a
IEA [29] projected costs of generating electricity, 2005 update, IEA publications	1,000–1,600US$ *onshore* (850–1,360€) and 1,600–2,600 US$ *offshore.*	n.a.
IEA [30] annual report, draft-data provided by Governments	1,365€/kW in Canada; 979€/kW in Denmark; 1,289€/kW in Germany; 1,050€/kW in Greece; 1,200€/kW in Italy; 1,209€/kW in Japan; 1,088€/kW in Mexico; 1100 €/kW in the Netherlands; 1,216€/kW in Norway; 1,170€/kW in Portugal; 1,220€/kW in Spain; 1,242€/kW in Switzerland; 1,261€/kW in the UK; 1,121€/kW in the U.S.	n.a.
UKERC [31]	n.a.	5.9 c€/kWh with a standard deviation of 2.5 c€/kWh
DTI [19]	1,633€/kW (medium scenario); 1,850€/kW (in the high scenario); 1,422€/kW (in the low scenario).	9.3–11.5c€/kWh (high and low)
DTI [25]	n.a.	8.1 c€/kWh to 15.9c€/kWh
Bano, Lorenzoni for APER [11]	1,400 €/kW	9.4 c€/kWh
Wiser, Bolinger for US DOE [11]	1,480 US$/kW (1,200 €/kW approximately) projects in 2006; 1680 US$/kW (1,428€/kW) for proposed in 2007.	n.a.

Table 4. Summary of some sources about variable costs in producing wind energy

Study	O&M costs	Other variable costs
P.E. Morthorst [18, 26]	1.2 to 1.5c€/kWh	n.a. (not clear)
Milborrow [27]	15 to 40c€/kW; 1 to 1.5c€/kWh	n.a. (not clear)
AEE [17]	1.02c€/kWh	1.03 c€/kWh
EER for Vestas [28]	2.5 to 4c€/kWh; 0.25 to 0.40c€/kWh	n.a
BWEA [16]	23.25c€/MWh	(check)
IEA [29]	12.50 to 33.8c€/kW	n.a.
DTI [25]	61.5c€/kW	n.a.
Bano, Lorenzoni for APER [11]	1.8c€/kWh	n.a.
Wiser, Bolinger for US DOE [11]	Partial data; 0.68c€/kWh for the most recent projects; 1.7 c€/kWh for older projects.	n.a.

3. Models of projects economic evaluation

3.1 Economic basics of projects evaluation

An "investment" in the broadest sense is any occasion where financial resources (capital) are put to productive purposes. This money could then be invested in new product development, acquisition of a competitor or to build new plant to produce electricity. In a narrower sense, an investment is limited to cases where financial resources are applied to acquire or build tangible capital assets ("capital cost"). The purchase of government securities (investments) or project financing to develop new products (intangible investment) is not characterized as an investment in this sense. Renewable energy projects are typically capital-intensive investments, as mentioned earlier [32].

The investments have important consequences for the investor, because a considerable amount of capital is needed and is linked to long and not available for other purposes, equally attractive, if applied (time of operation or life of the project). The consequences of a wrong investment decision can be large, and endangering the investor. It is natural that investment decisions are preceded by long and extensive analysis of the potential attractiveness of investment. The analysis of investment attractiveness are called "economic evaluation of investment" [33].

Appropriate setting for the opportunity cost of investment (discount rate or cost of capital), the cost of capital is an appropriate discount rate to be applied in the economic evaluation of projects. Note that in business practice, often we use the average cost of capital (measured in all forms of capital currently used). The most appropriate measure would be the marginal cost of capital (cost of additional capital investment in employee analysis). The marginal cost and average cost are not equal. However, the most common is the "Weighted Average Cost of Capital or WACC. It is calculated using the following formula [32]:

$$r_{WACC} = (1 - W_D) r_E + W_D r_D (1 - t) \qquad (1)$$

where, r_{WACC} ≡ Weighted Average Cost of Capital; W_D≡ Capital Structure; r_E ≡ Equit cost; r_D ≡ Debt cost before tax and t ≡ taxes.

The assets of a project are financed by debt and equity. The WACC allows calculation of weighted average cost of funding sources, in which the weight of each is considered in each funding position. This weight is defined as the ratio:

$$W_D = \frac{Equity}{(Equity + Debt)} \qquad (2)$$

The interest rate for working capital loan is simple (since it is known from the interest payment to creditors). The interest rate to be applied to equity is less obvious. In finance theory suggests alternative methods for estimating the cost of equity, the most prominent are the opportunity cost methods, methods based on discounted cash flow (DCF - Discounted Cash Flows) and methods based on model pricing of capital assets (CAPM - Capital Asset Pricing Model). Both approaches have a disadvantage because they are applicable in open capital markets (sale of shares through stock exchanges). In these cases, the

opportunity cost approach must be taken when the investor is evaluating alternative investment options with equity and / or oblivious to the expected return on investment as "cost of capital" for the planned project.
An analysis or economic evaluation of investment involves activities undertaken before an investment decision in order to assess the potential of attracting investment by the investor. These evaluations may be limited to purely monetary parameters, which in most cases also include non-monetary parameters [2]. This section only discusses about economic evaluations methods for renewable energy projects, especially onshore wind farms in order to meet the objectives of this paper.

3.1.1 Simple payback
The simple payback (SPB) is defined as the time (number of periods) required for the project's cash flow[5] refinance the initial investment. In other words, the SPB is required to recover the initial investment through positive cash flows of the project. Before that moment, the project has recovered all the initial investment or at least part of the invested capital is still at risk (if the project fails).
The SPB is used as a measure of project risk: the higher the return time, the greater the risk for investors, because (in part) the invested capital cannot be recovered. In a typical project, the negative cash flow early in the project (initial investment) is followed by positive cash flows (return) in subsequent periods. Mathematically, SPB can be expressed as the smallest *t* that satisfies the condition:

$$(Ci - Co)_{1+}(Ci - Co)_{2+....+}(Ci - Co)_t = \sum(Ci - Co)_t \geq Co_0 \quad (3)$$

where: C_i ≡ Cash inflows; C_o ≡ Cash outflows; C_{o0} ≡ Initial Investment and t ≡ Number of periods.
Since t is an integer, the sum (equation 5) is likely to be lower or higher than the initial investment (C_{o0}), but not exactly equal to C_{o0}. The value (decimal) exactly the SPB (where the sum corresponds exactly to the initial investment) can be calculated by linear approximation by using the following formula [34]:

$$t' = t - \sum(Ci - Co)_t \times \frac{1}{\sum(Ci - Co)_{t+1} - \sum(Ci - Co)_t} \quad (4)$$

With

$$\sum(Ci - Co)_t < Co_0 \text{ and } \sum(Ci - Co)_t > Co_0 \quad (5)$$

For investment projects in renewable energy, wind energy onshore case, to determine the best project is necessary to consider the cash inflows or revenues uniform (which actually does not happen) during the lifetime of the project. For energy projects, the SPB must be calculated using the following equation [35]:

$$SPB = \frac{ICC}{AAR} \quad (6)$$

where: ICC ≡ Initial Capital Cost and AAR ≡ Average Annual Revenue based on hourly production.
Importantly, this model assumes that the wind farm (project) will produce the same amount of electricity per year to the same sales price during the years of operation under review. As a result, this analysis assumes constant revenue stream. This method does not consider the discount rate or life of the project, so, the analysis of the Simple Payback is not dependent on these values. The SPB is often preferred as a measure of investment merit due to its simplicity. However, there are several other aspects of economic merit. These methods are discussed and compared below, the discussion is in relation to the needs of this particular study. There is a general discussion on the economic values of merit.
Before the occurrence of the SPB, the project has not recovered all the initial investment, or at least part of the capital invested is still at risk (if the project fails). The SPB has disadvantages that limit its use in business practice in renewable energy:

[5] In finance, cash flow (known in English as "cash flow "), refers to the amount of cash received and spent by a company during a period, sometimes linked to a specific project. There are two types of streams: - outflow exit, which represents cash outflows, underlying the investment costs - inflow of entry, which is the result of the investment. The value that balances with the outputs and translates into increased sales or represents a reduction of production costs, among others. (34. Brealey, R.A. and S.C. Myers, *Princípios de Finanças Empresariais*. 5a ed. 1997, Lisboa: McGraw-Hill.)

1. SPB ignores the value of economic resources over time. The positive net cash flows for subsequent periods are treated as if they were carried out at present. Future cash flows are as overweight which leads to SPBs too optimistic.
2. SPB ignores cash flows that occur after the recovery period. It may be that a project has shorter payback, but smaller NPV (Net Present Value) over the life of the entire project. Decide based solely on the SPB, the investor chooses the wrong alternative.

3.1.2 Discounted payback

The discounted payback (DPB) considers the value of capital over time by discounting net cash flows of each period before sum them and compare them with the initial investment. BDP, therefore, can be expressed by the following formula [34]:

$$\frac{(Ci-Co)_1}{(1+i)^1}+\frac{(Ci-Co)_2}{(1+i)^2}+.....+\frac{(Ci-Co)t}{(1+i)^t}=\sum\left(\frac{(Ci-Co)t}{(1+i)^t}\right)\geq Co_0 \tag{7}$$

where: C_i ≡ Cash inflows; C_o ≡ Cash outflows; C_{o0} ≡ Initial Investment and i ≡ Discount rate.

When investment projects relate to renewable energy, wind energy onshore case, to determine the time of return on investment of the project is necessary to consider the cash inflows or revenues uniform (which actually does not happen) during the period project life. For energy projects, the DPB should be calculated using the following equation [35]:

$$DPB=\frac{ICC}{[AAR-(O\,\&\,M+LLC)]} \tag{8}$$

where: ICC ≡ Initial Capital Cost; AAR ≡ Average Annual Revenue based on hourly production; O&M ≡ Operations and Maintenance cost and LLC ≡ Land Lease Cost.

As DPB is discounting the future cash flows (positive), this takes longer periods of recovery that the SPB. For any project will exceed the typical SPB. Linear interpolation can be used to determine the exact decimal value of BDP. According to equations 4 and 5. Unlike PBS, which is simplified, the BDP believes the discount rate (interest rate) and the fact that not always the expected flows are constant.

The project of producing electricity from renewable primary energy sources, wind energy onshore case highlights the importance given to the costs of operations and maintenance as well as lease cost of the land where the wind farm is deployed, if leased. Thus the analysis of investment risk is minimal considering the changing market. This method reveals some weaknesses among other models of investment appraisal. The main limitations of this method are:

1. It has total focus on the variable time, not worrying about possible cash flows after the payback time.
2. Does not discount cash flows properly, because it considers "surplus" of investment.
3. Determine the payback period is somewhat arbitrary, because the BDP can be expected to take interest or discount rates that are not practiced by the financial market.

3.1.3 Net present value

The Net Present Value (NPV) is a method of economic evaluation of projects very well known also. The NPV takes into account the capital value over time. The value of capital in time refers to the fact that this value is now worth more than the present in time future. This is because an amount placed in time may be invested and getting a return above the rate of inflation. Therefore, future earnings should be discounted. The NPV has become more widespread and accepted as a measure of financial performance of the project [34].

The NPV is the direct application of the concept of present value[6] and the difference of present value of cash inflows (inflows) between the present values of cash outflows (outflows). The NPV is the sum of all discounted cash flows associated with the project. The general equation can be written as [5]:

[6] It denotes the number of periods elapsing between now and when the payment occurs *i* denotes interest rate or discount period, then the general formula to discount future cash flow is given as: $K_0=\frac{K_t}{(1+i)^1}=K_t\times(1+i)^{-t}$, and K_0 is called *"present value"* of future payment K_t. 34.Ibid.

$$NPV = (Ci_0 - Co_0) + \frac{(Ci_1 - Co_1)}{(1+i)} + .\frac{(Ci_2 - Co_2)}{(1+i)^2} + ... + \frac{(Ci_t - Co_t)}{(1+i)^T} = \Sigma\left(\frac{(Ci_t - Co_t)}{(1+i)^t}\right) \quad (9)$$

where: C_i ≡ Cash inflows; C_o ≡ Cash outflows; C_{o0} ≡ Initial Investment, i ≡ Discount rate and T ≡ Number of periods.

When investment projects refer to projects for onshore wind, to determine the time for return on investment of the project is necessary to consider the entries of cash receipts as uniforms (which actually does not happen) during the lifetime of the project .

For energy projects, the NPV, is defined as the present value of benefits less the present value of costs. The present value of costs is the cost of initial capital, *ICC*. It is assumed that the distribution of wind speed remains constant from year to year, resulting in uniform amount of electricity produced from year to year [5]. It is assumed that the annual revenue would be uniform. This cash flow uniform must be discounted, since it occurs in the future. The NPV of a uniform cash flow is given by equation 10.

$$NPV = AAR\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] - ICC \quad (10)$$

where: AAR ≡ Average Annual Revenue based on hourly production; i ≡ Discount rate; N ≡ Lifetime of wind farm and ICC ≡ Initial Capital Cost.

For independent projects, the investment decision occurs when the NPV is greater than zero. If the investor decides between two mutually exclusive projects, then the project with higher NPV should be chosen. In optimization analysis, the choice is mutually exclusive. It is important to remember that, unlike the Simple Payback, the financial assumptions that count in determining the discount rate and lifetime for the NPV of the investment can change engineering aspects of the wind farm under consideration.

Once the rotor diameter is the single parameter of the project to be variable, *AAR* and *ICC* can be generalized as functions of rotor diameter, *i* and *N* are chosen, the value of the term $\left[\frac{(1+i)^N - 1}{i(1+1)^N}\right]$ will remain constant and then equation 10 can be generalized as:

$$NPV = C \times AAR(D) - ICC(D) \quad (11)$$

where *C* is a constant. The maximum NPV is found by differentiating equation 11 with respect to the rotor diameter, *D*, and equating to zero, as shown below.

$$\frac{dNPV}{dD} = C\frac{dAAR(D)}{dD} - \frac{dICC(D)}{dD} = 0 \quad (12)$$

Rearranging the equation 12, we have:

$$C\frac{dAAR(D)}{dD} = -\frac{dICC(D)}{dD} = 0 \quad (13)$$

The equation 13 shows that the constant, *C*, has no effect on the rotor diameter that maximizes the NPV. The financial assumptions that go into determining the discount rate and lifetime of the investment will change the optimal design of engineering of the wind farm.

The NPV has disadvantages that may limit the use in the evaluation and management of projects in renewable energy, particularly in wind energy projects:

1. The need to know the actual capital cost of the project. As the interest rate that measures the cost of capital for an investment should include the risk of the project, the task of defining the real value of capital cost is not always easy to accomplish.
2. The discount rate or cost of capital remains unchanged throughout the period under review the project, which is not as fixed as well as the cost of capital depends on financial market behavior and risk of new developments in the analysis.

3. The type of response in money instead of being a percentage, for the assessment of monetary values incurs no assessment of the real purchasing power, if it were in percentage terms; it would make it easier to compare projects in different currencies.

3.1.4 Internal rate of return

The method of Internal Rate of Return (IRR) is to calculate the rate that cancels the net present value of cash flow in investment analysis. Investment which will be attractive internal rate of return is greater than or equal to the rate expected by the investor attractiveness. In comparisons of investment, the best is one that has the highest internal rate of return [36].
According to Newnan & Jerome [37] the rate is not easily calculated, since it must be determined by trial and error or the least squares method. We try to rate a likely value and thereafter to make successive approximations. The level of precision in the result of IRR is 0.01%, and should be obtained for a maximum of 10 000 interactions. As the calculations of present value, IRR is used to bring the current date all the cash flows of the project, according to equation 14.

$$NPV = \sum\left(\frac{(Ci_t - Co_t)}{(1+i)^t}\right) = 0 \Rightarrow i = ? = IRR \tag{14}$$

where: NPV ≡ Net Present Value; C_{it} ≡ Cash inflows in period t; C_{ot} ≡ Cash outflows in period t; i ≡ Discount rate and t ≡ Number of periods.
In most cases, this equation is a polynomial of degree t that cannot be solved in closed form. Instead, different types of successive approximation should be applied to solve i. The software (MS Excel and RETScreen) offer this functionality as a modern tool inserted in their functions.
The IRR is expressed as a percentage ("return") and is easily interpreted as "return of a project". The IRR represents the maximum rate of interest that *i* can still take the project to create the NPV equals zero. If the NPV is zero means that the project finances the capital invested, plus interest, an IRR of 10% means that the project could re-finance the capital invested, plus interest at a maximum of 10% of this capital. At any rate above 10%, the same project creates surplus value (NPV> 0) for the investor. At any interest rate below 10%, the project would not be able to refinance the capital invested and pay interest. The investor would have to add extra capital to pay the amount invested, plus interest, and thus reduces your assets. Only 10% would be indifferent to the investor, and neither gain nor loses from the project [33].
The IRR)is the discount rate that sets the NPV equal to zero [37]. The IRR of a wind energy project, with uniform revenue is found by solving the equation for the IRR. The project IRR is greater chosen as best. If the IRR is maximized, the financial assumptions required to determine the duration of the project, *N*, have no effect on the ideal project. Maximize the IRR result in the same design when SPB is minimized. This is shown below [5].

$$NPV = AAR\left[\frac{(1+IRR)^N - 1}{IRR(1+IRR)^N}\right] - ICC = 0 \tag{15}$$

where: IRR ≡ Internal Rate of Return; AAR ≡ Average Annual Revenue based on hourly production; N ≡ Lifetime of wind farm and ICC ≡ Initial Capital Cost.
This equation can be rearranged to:

$$\left[\frac{(1+IRR)^N - 1}{IRR(1+IRR)^N}\right] = \frac{ICC}{AAR} = SPB \tag{16}$$

By increasing the IRR, the left side of the above equation decreases for any *N* value. The relationship *ICC/AAR*, which is equivalent to SPB, it must also decrease with the increase in IRR. This proves that maximize the IRR have the same effect of minimizing SPB, no matter what is assumed for the lifetime of the project.
Despite its intuitive nature, the IRR has some drawbacks, therefore, must be applied with care:

1. Depending on the structure of cash flows of the project, a project can have more than one IRR. The equation to be solved generates multiple solutions (for example, depending on the value from the iterative approach). So, no clear decision can be made.

2. The IRR implicitly assumes that all cash flows can be reinvested at the IRR. NPV does not have this disadvantage, since it assumes that cash flows are reinvested in the *i* defined as the discount rate (which is the average cost of capital and represents a more realistic assumption for reinvestment).
3. The IRR does not take into account the different sizes of investment. An alternative could provide an internal rate of return, but with a smaller initial investment. The absolute gain in wealth for the investor may still be more different with IRR that offers a slightly lower IRR. NPV does not have this limitation.

3.1.5 Required revenues

Required Revenues (RR) is the appropriate concept and applies only to regulated sectors (consumers and producers of electricity are regulated by specific taxes or burdens of government action). The renewable energy projects can fit into this profile, because the market power electrical distribution system in a certain region (for large wind farms onshore and offshore), which access to the public grids is regulated by tariffs.

The method RR is the analysis of total receipts (cash inflows), the project received from clients to compensate for all costs associated with the project during its lifetime [2].

$$RR = TLCC = \sum\left(\frac{Co_t}{(1+i)^t}\right) \quad (17)$$

where: RR ≡ Required Revenues; TLCC ≡ Total Life-Cycle Cost; C_{ot} ≡ Cash outflows in period t; i ≡ Discount rate and t ≡ Number of outflows periods.

This comparison is not made with absolute (nominal), but with discounted values. The method determines the level annual returns required to cover the cost of the entire project (with discount):

$$LevelizedRR = TLCC \times UCRF = \sum\frac{Co_t}{(1+i)^t}\times\frac{i(1+i)^n}{(1+i)^n-1} \quad (18)$$

where: UCRF ≡ Uniform Capital Recovery Factor; and n ≡ Number of periods.

The UCRF converts the current value in the flow of equal annual payments over a specified period of time t, i the rate specified discount (interest). The formula 19 shows UCRF calculation, where i = discount rate and t = number of time periods in years.

$$UCRF = \left[\frac{i(1+i)^t}{(1+i)^t-1}\right] \quad (19)$$

This is an inverse measure: the lower level RR is the project more attractive because it can cover costs of the project (including interest), with lower incomes. When revenues are fixed (i.e., defined by the regulator), the investor or manager of the project (i.e., wind farm manager) will choose an alternative that can maximize the difference between RR level per unit of energy and administered prices per unit produced and marketed the electrical distribution network needed to ensure the smallest level of income required. The RR has disadvantages that limit their application in the evaluation and management of projects in renewable energy, particularly in wind energy projects:

1. The capacity factor is considered constant throughout the life of the project. In wind energy projects this may fluctuate resulting in annual electricity production variable, so revenue and costs also vary.
2. The financial indicators considered over the life of the project (inflation, discount rate, taxes) also remain constant throughout the analysis period of life of the project.
3. Costs are projected to lifetime of the project, which makes the financial cycle equal to the operational cycle of investment, a fact that the classical rules of accounting does not always coincide.

3.1.6 Benefit-to-cost ratio

The Benefit-to-Cost Ratio (BCR) of a project is another application of the principle of the capital in time. BCR analyzes the discounted cash flows. Unlike the NPV, cash flows are positive ("benefits" of the project) and negative cash flows (cost of the project) are discounted and accumulated separately. The sum of the discounted cash flow positive is placed over the sum of all negative cash flows discounted [2]:

$$\text{If } PV_{ci} = \sum \frac{Ci_t}{(1+i)^t} \text{ and } PV_{co} = \sum \frac{Co_t}{(1+i)^t} \text{ , so } B/C = \sum \frac{\sum \frac{Ci_t}{(1+i)^t}}{\sum \frac{Co_t}{(1+i)^t}} \quad (20)$$

where: PV_{ci} ≡ Present Value of Cash Inflows and PV_{co} ≡ Present Value of Cash Outflows.
In order to better illustrate the application of this method, using a discount rate of 8% per annum returns the discounted cash flow or updated, according to Table 5.

Table 5. Example of typical cash flow for BCR analysis

In “000 USD”, interest rate = 8%/year	Period (years)				Total
	0	1	2	3	
Cash outflows (-)	-100,0	-30,0	-30,0	-30,0	
Cash inflows (+)	0,0	80,0	80,0	80,0	
Discounted cash outflows	-100	-27,8	-25,7	-23,8	-177,3
Discounted cash inflows	0,0	74,1	68,6	63,5	206,2

Source:[2]

The BCR analysis is 206.2/177.3 = 1.16. Each currency (at current values) generates returns of 1.16 currency units (at current values). The relation B/C above 1 represents attractive investment options in absolute terms. The BCR analysis is not a useful measure to compare mutually exclusive alternatives; since the ratio does not measure the relative attractiveness can be misleading the decision maker. Not necessarily lead to the same result when assessing the attractiveness of a project because the NPV is not a widely used measure.
The BCR analysis is the ratio of current value of the sum of benefits divided by present value of the sum of costs. It is used as a selection criterion for all eligible projects that have independent cost-benefit ratio, calculated the relevant discount rate (opportunity cost of capital) equal to or greater than unity. Cannot be used to choose between mutually exclusive alternatives [38].
The BCR has disadvantages that limit its application in the evaluation and management of projects in renewable energy, particularly in wind energy projects:

1. The main disadvantage of ratings based on BCR is that ignoring non-monetary impacts. Attempts were made to mitigate these limitations through a combination of BCR with information regarding these impacts are not likely to denomination, as the approach proposed by the New Approach to Appraisal, used in the UK[7].
2. Another difficulty refers to the BCR precise definition of benefits and costs, due to variability in the criteria for more realistic analysis is required a distinction between perfect and total operating costs and investment.
3. The pre-operational wind energy project, (studies, construction and equipment installation, testing and technical adjustments) and the fact considers the costs of O&M constant over the lifetime of the project makes the phase of exploration / production project is different from the life of the project. This interferes with the production time and consequently the entrances and exits of cash flow, which makes the analysis imprecise BCR in terms of monetary values.

3.2 Peculiarities in the investment analysis of wind energy projects
The investment analysis can be considered as a set of techniques that allow the comparison between the results of making decisions regarding the different alternatives in a scientific manner. In these comparisons, the differences that mark the alternatives should be expressed in quantitative terms. To

[7] For further information, see on www.environment-agency.gov.uk.

express in quantitative terms the differences between the alternatives for decision-making uses economic engineering principles.
The IRR and NPV based on the same principles of equity capital[8] and lead to the same decision. The key difference among the two techniques is that the NPV assumes reinvestment at the same cost of capital (discount rate), while the IRR assumes reinvestment will be the actual internal rate of return of the project.
In the case of wind energy projects NPV is a function of *AAR* and the *ICC*. As a result, to maximize the NPV also maximizes the absolute wealth created by investment. Because of this, the NPV is biased toward larger investments. While on return is greater than the discount rate. The analysis of the NPV will push the decision to bigger projects, even if the relative profitability is smaller.
The SPB, DPB and IRR are functions of *ICC/AAR*. Minimizing *ICC/AAR* will maximize the wealth of the equity invested. For the optimization of wind farm, should be determined to maximize the wealth obtained from the absolute wind farm or to maximize the relative wealth generated by the project. As the wind turbine is modular, it is more convenient to choose the size of the rotor, which maximizes the relative ability of the wind turbine to generate wealth. In case you decide to minimize the SPB because of the method is simpler as shown before, to minimize SPB will result in the same optimal design to maximize the IRR. An example is when you want to maximize absolute wealth would be if the land available for development of wind farms were limited. In this case, the absolute wealth generated by the wind farm can be maximized by selecting a turbine capable of producing greater.

4. Models for costs evaluation

4.1 Specific measures of economic performance for energy projects

The costs levelized (or revenue → revenues levelized) is a technique to compare investment alternatives (such as renewable energy projects), involving different amounts of capital (i.e., different sizes) and/or different time periods with different life-cycles. Applying the NPV method is done implicitly on assumptions necessary reinvestment in renewable energy projects. These implicit assumptions can be avoided by smoothing of cash flows: even involves the calculation of steady cash flow, net present value (NPV) is equal to a given cash flow variable [39]. Suppose that two investment alternatives for renewable energy projects have the following net cash flow per period, as shown in Table 6.

Table 6. Example of net cash flow for economic performance in energy projects (NPV method)

Cash Flows	Period (years)						NPV_{years}
	0	1	2	3	4	5	
Alternative 1 Net Cash Flow	-100	20	40	30	50	10	14,1
Alternative 2 Net Cash Flow	-50	20	25	30	-	-	11,4

Source: [2]

The alternative 1 implies a higher initial investment (capital requirements) and provides higher absolute return than alternative 2. Alternative 2 has only a small initial investment, but also shorter lifetime (3 versus 5 years). It is difficult to make a direct comparison between the two projects. In calculating the NPV of the project (with a discount rate of 10%) results in NPV = 14.1 for an alternative 1 and NPV = 11.4 to alternative 2. For the NPV rule suggests that an alternative 1 is chosen. The levelizing of cash flows (net) is to find a constant amount *g* during the life of the project NPV with this flow in equal amounts *g* to become equal to the NPV of the original project, as shown in Figure 3.
This amount g (also called "annuity") is calculated using the formula below:

$$g = NPV \times UCRF = NPV \times \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right] \qquad (21)$$

[8] The principle of equity capital is the financial situation at that given rate of return of capital or update makes a series of future values, regardless of their nominal values and terms, when the current values are equal. Thus, to effect any transactions involving securities held in the future you need to know how much currently worth, or what are the current values 32. Damodaran, A., *Corporate Finance: Theory and Practice*. 2nd ed. 2001: John Wiley and Sons Ltd,. 1000.

The UCRF (Uniform Capital Recovery Factor), is the factor by which the NPV must be multiplied to reach the constant value *g* given discount rate *i* for a series of *n* periods. In the example in Table 6, the alternative creates an annuity of 3.73 (in monetary units). The five cash inflows of 3.73 are equal to a NPV of 14.1, exactly equal to the NPV of cash flows of the project plan (including initial investment). Alternative 2 generates annuity of 4.58 (in monetary units). By comparing the potential of their projects to generate stable cash flows, the alternative 2 should be higher than the alternative 1.
Annuities are not specific to renewable energy projects. The concept LCOE is used to compare the different alternatives of energy production. Revenues are fixed and equal between these alternatives (e.g., because the price is set by the regulator and does not depend on the technology used to produce energy, then the alternatives differ only in their costs (cash flows of revenues are equal to all alternatives) [2].
The above concept is applied only to cash outflows (costs). The sum of all costs involved in the project during its full life cycle (Total Life Cycle Cost - TLCC) are discounted to present value and converted into a stream of equal cash outflows for each year of the project ("annuity negative") . If the value is divided by the annual amount of energy produced, the result is called the *Levelized Cost of Energy* (LCOE - Levelezed Cost of Energy). The LCOE is assigned each unit of energy produced (or saved) by the project during the analysis period is equal to the TLCC when discounted to the base year (period 0). The LCOE can be used to rank different alternatives for production (or consumption) of energy, as shown in Figure 4.

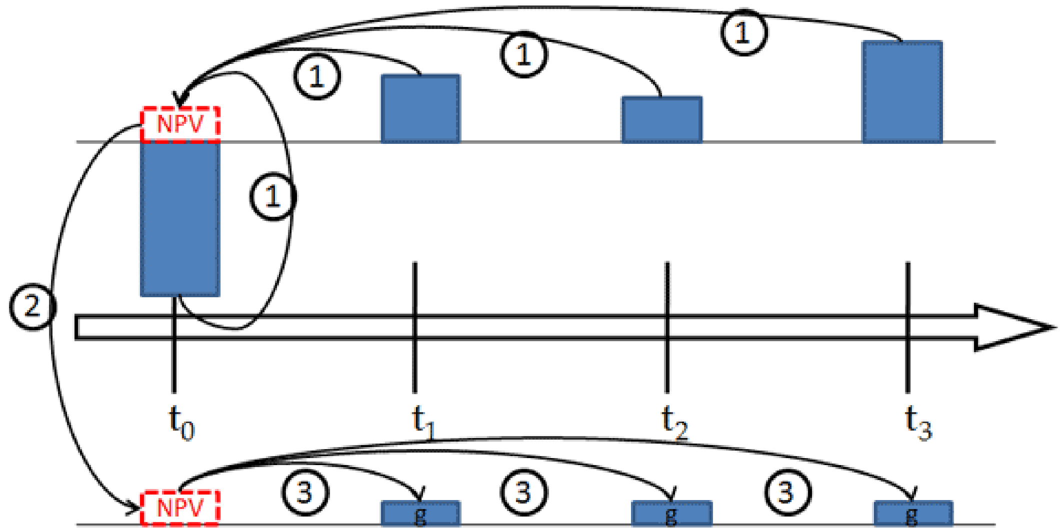


Figure 3. Schematic of the cash flows levelizing process for renewable energy projects [9]

Technology	LCOE, in 2005 $/kWh
Wind	$.028
Landfill Gas	$.030
Advanced Nuclear	$.035
Scrubbed Coal	$.044
Conventional Combined Cycle (CC) Gas/Oil	$.050
Biomass	$.050
Advanced CC with Carbon Sequestration	$.069
Conventional Combustion Turbine	$.077
Solar, PV (30%)	$.235
Solar, PV (10%)	$.310

Figure 4. Values in $/kWh LCOE (Levelezed Cost of Energy) in 2005 for various conventional and renewable technologies [2]

4.1.1 Levelezed cost of energy

The levelezed cost of energy (LCOE) is the real cost of production of kilowatt-hours (kWh) of electricity. Includes the total construction, central production costs of the power station during its economic lifetime, financing costs, return on capital and depreciation. Costs are leveled in current monetary values, or adjusted to eliminate the impact of inflation. The LCOE is what it would cost the owner of the facility to produce one kWh of energy. For electricity production, the LCOE is a method to compare renewable energy technologies adopted to produce electricity. The model LCOE most known and used in energy projects by the National Renewable Energy Laboratory [40]. The calculation method is defined below.

$$LCOE = \frac{FCR \times ICC + LRC}{AEP_{net}} + O\,\&\,M + PTC \quad (22)$$

where: FCR ≡ Fixed Charge Rate; ICC ≡ Initial Capital Cost; LRC ≡ Levelezed Replacement Cost; O&M ≡ Operations and Maintenance; PTC ≡ Production Tax Credit and AEP_{net} ≡ Net Annual Energy Production. The calculation of LRC can be accomplished with the equation 23, where MR ≡ Machine Rating [2].

$$LRC = \frac{\$}{kW} \times MR \quad (23)$$

For correct analysis of the leveled cost of energy, the net annual energy production of the wind farm is given by equation 24. The *availability* is defined as the ratio of hours the wind system is capable of producing energy relative to the number of hours during the study period and losses represent loss of matrix, dirt on the blades and ice formation, the central production downtime for maintenance and miscellaneous system losses in production and distribution of energy to the electric grid [10].

$$AEP_{net} = AEP_{gross} \times \text{Availability} \times (1 - losses) \quad (24)$$

where: AEP_{gross} ≡ Annual Energy Production.

The LCOE was adopted by the United States Department of Energy in the Low Speed Wind Turbine Program (LWST) and makes reasonable approximation of the COE (Cost of Energy), which is estimated by the potential investor to consider the reliability of the equipment to determine AEP (Annual Energy Production), O&M (Operations and Maintenance) and LRC (Levelezed Replacement Cost). The AEP is affected by the availability of equipment due to the shutdown of wind turbines due to scheduled and unscheduled maintenance. The costs of O&M consist of programmed costs (preventive) and costs unscheduled (repair) maintenance, including costs for replacement parts, supplies, manpower, leases (royalties) of land, among other expenses arising from the operation of a wind farm.

4.1.1.1 Fixed charge rate

The capital cost component of COE is determined by the spread of installed capital cost over the lifetime of the project done in a linear basis over the years through the FCR (Fixed Charge Rate). The FCR is a percentage of the cost of installed capital costs including debt service (financing costs) allocated to each year of the project. The component of the cost of capital is analogous to a payment of fixed rate mortgage of a house, or fixed amount per pay period during the term of the debt. The analysis period may be the life of a physical plant for the production or lifetime for accounting purposes. The lifetime of a wind farm ranges from 20 to 30 years, while lifetime used for financial accounting purposes may be smaller [2, 41]. The FCR is the annual value for each monetary unit of initial capital cost needed to fully cover the initial capital cost, return on equity and debt, and other overheads. The fee is charged from a hypothetical project, spread over cash flow. The current base model, FCR must include funding for construction, financing rates, return on equity and debt, amortization of equipment and facilities, tax revenue and profits all on an annual basis [40].

4.1.1.2 Initial capital cost

The initial capital cost (ICC) is the sum of the cost of wind power system and the cost structure of the wind farm. Not included is cost of financing the construction or financing rates, as they are calculated and added separately through the FCR. Nor does it include the costs of the reserve fund for debt service (charges for financing costs). This cost measure includes all the planning, equipment acquisition, construction and installation costs of the wind system, leaving the wind farm ready to operate. This cost includes wind turbine towers and delivered and installed on site along with all maintenance, electrical system and other infrastructure support. For a wind farm, the cost of installed capital should include the system of collection of electricity which extends from each wind turbine to the substation and point of interconnection with the grid. Depending on the policy and practice of grid administrator and distributor, the electrical system may or may not be included in the cost of capital [2]. The ICC includes costs for buildings to support the operation and maintenance, the initial stock of spare parts and maintenance of diagnostic equipment. Other costs should be included as costs of pre-construction planning, including assessment and analysis of wind resources, surveying, and consultancy for obtaining financing. The installed capital cost of a wind farm includes the following elements [39]:

1. Assessment and analysis of wind resources;
2. Construction of service roads;
3. Construction of foundations for wind turbines, infrastructure to mount transformers and substations;
4. Purchase of wind turbines and towers with local delivery and installation;
5. Construction and installation of wind sensors, able to communicate wind turbine units for controls;
6. Construction of the power reception system, including wiring of each wind turbine for the mounting of the transformer and deck mount transformers for the substation;
7. Construction of facilities needed for operations and maintenance during the regular operation of the wind farm;
8. Construction and installation of the communication system of wind farms to support the command and control data flow from each wind turbine to a central facility operations;
9. Integration and verification of all systems for proper operation of the wind farm;
10. Commissioning for wind farm period of decommissioning.

4.1.1.3 Levelezed replacement cost

Depending on the details of the project, the major review of the wind turbine occurs every 5, 10 or 15 years. The review focuses on the large gears, bearings, seals and other moving parts. Usually the nacelle and its machinery are removed from the tower and transported to the plant maintenance garage of the wind farm. Often, removal of the nacelle and equipment is replaced immediately by all already rebuilt [2]. The replacement of the blades of wind turbines is an example of this category of frequent replacement of subsystems. Since these costs occur at intervals of several years and infrequent during each year, correct accounting for these costs requires annual exercise of funds (working capital). The aim is to make funds available when needed to repair or total replacement of occurrence. The exercise involves calculating the net present value or even to allocate costs for review and replacement on an annualized basis consistent with other cost elements [39].

4.1.1.4 Operations and maintenance cost

The costs of operations and maintenance (O&M) include costs normally associated with recurrent routine operation of the plant installed. The O&M costs do not include overtime worked or infrequently, such as major repairs of wind turbines and other systems. These costs are included in the cost component LRC (Levelezed Repalcement Costs). Most of the O&M costs is associated with maintenance and generally grouped into three categories (Christopher, 2003):

1. Cost of unscheduled visits, but statistically predictable, routine maintenance visits to troubleshoot the operation of wind turbines;
2. Scheduled preventive maintenance costs for wind turbines and energy collection system;
3. Costs of major repairs and replacements scheduled subsystems of wind turbines.

The first two costs occur during the course of a year in operation and are included in the cost component of O&M. The third occurs at intervals of 5, 10 or 15 years and involves financial year over the next few years, therefore, is included in the cost component LRC. The purpose of preventive maintenance is to replace components and reform systems that have finite lifetime, generally smaller than the projected life of the turbine. Tasks include periodic inspections of equipment, lubricating oil and filter changes, calibration and adjustment of sensors and controllers, replacement of consumables such as brake pads. The cleaning of the blades in general, fits into this category. The specific tasks and frequency are usually explicitly defined in the maintenance manuals provided by the manufacturer of the turbine. The costs associated with planned maintenance can be estimated with reasonable accuracy, but may vary according to labor costs location, location and accessibility. The scheduled maintenance costs also depend on the type and cost of consumables used [29]. The unscheduled maintenance should be anticipated in any proposed wind energy production. Commercial wind turbines contain a variety of complex systems that must function correctly for the turbine work and get best possible performance. Failure or malfunction of the smaller component (subsystem), it often shuts down the turbine and require the attention of maintenance professionals. Unplanned costs can be separated into direct and indirect costs. Direct costs associated with labor and equipment needed for repair or replacement and consumables used in the process. The result of the indirect costs associated with the revenue lost due to stop the turbine. Depending on the details of ownership and location of the wind farm, there may also be costs associated with negotiating land use agreements, contracts, power purchase agreements and access to transmission and distribution of energy produced [11]. Besides the cost of operations and maintenance, spare parts and other maintenance items in the cost element of O&M may also include:

1. Taxes on property where the wind farm operates;
2. Payment of land use;
3. Miscellaneous insurance;
4. Access to transmission and distribution rates;
5. Management fees and general and administrative expenses.

The values of cost of operations vary with the situation. The tax structure is where the wind farm contract, land use, insurance rates and other fees vary from location to location and installation of wind farms to another. In comparison to maintenance costs, operating costs are typically very small relative to the cost of production of a central power generation [42].

4.1.1.5 Production tax credit

The Production Tax Credit (PTC) is a type of public incentive, usually granted by the Federal Government for the renewable energy sector. This incentive is offered in the form of tax credits for producing energy for a certain period of operation of the central production of energy. The PTC is adjusted for inflation rate prevailing in the country concerned, within 10 to 15 years, falling on each MWh of renewable energy produced and sold to the distribution grid. For the production of wind power in Portugal, Decree-Law No. 33-A/2005[9] stipulates that farms that have already obtained permission to establish the date of entry into force of the law or they may obtain the license for establishment within one year after the entry into force, maintaining the current tariff of 88.20€/MWh from 2005, progressing at the rate of inflation, for a period of 15 years from the date of entry into force of that legislation. At the end of this period, the rate will converge to market price plus the premium for the sale of green certificates.

The Levelezed Cost of Energy method has drawbacks that limit its application in the assessment and management of projects in renewable energy, particularly in wind energy projects:

1. The technical and economic parameters directly impact the method LCOE and should be carefully considered in the analysis of the final cost of energy produced. The dramatic reductions in LCOE occur when the wind farm wind resource is above average, or when we obtain improvements in capacity factor. This suggests that the increase in capacity factor from values below the levels of average capacity factor can lead mainly to large reductions in LCOE [43].
2. The LRC that matches the costs for equipment replacement in the long term, it has been reported to be increasingly significant component to the annual cost of wind power and if it is overvalued, can inflate the cost of energy currently produced. The technological improvement in wind power can make the cost of capital is smaller in the coming years.
3. The LCOE is a methodology for determining and analyzing the cost of energy production restricted to certain period of time. The fact that the analysis is for one year of production (a single unit of time) ignores gains economies of scale throughout the project life.

4.1.2 Total life-cycle cost

The evaluation method Total Life-Cycle Cost (TLCC) method is derived from the NPV, as it takes into account only items of costs (cash outflows). The TLCC evaluates the differences in cost (and time of occurrence of costs) between project alternatives over the life cycle. Cash outflows associated with the

[9] Available in http://www.edpdistribuicao.pt/pt/produtor/renovaveis/EDP%20Documents/DL33A-2005.pdf.

project (alternatives) are evaluated for each period and are then discounted to present value using a discount rate as defined in the NPV approach [36]. The TLCC calculate the present value of all cash outflows (cost items), but no cash inflows (revenues). This only makes sense if:

1. There is no revenue generated by the project (Note that the cost saved are recorded as revenue) or,
2. Revenues are independent of the investment decision (e.g., because revenues are fixed, no matter what the investment decision is chosen).

The analysis may focus only on cash outflows. Soon the TLCC takes no account of the project income, which makes this indicator not adequate to evaluate absolute attractiveness of an investment alternative. It can be used to evaluate the relative attractiveness of alternative investments when considering the cost per unit of output as a factor of choice. By definition, the calculation of TLCC is defined by the following formula [43]:

$$TLCC = \frac{Co_1}{(1+i)} + .\frac{Co_2}{(1+i)^2} + ... + \frac{Co_t}{(1+i)^t} = \sum\left(\frac{Co_t}{(1+i)^t}\right) \quad (25)$$

where: TLCC ≡ Total Life-Cycle Cost; C_{ot} ≡ Cash outflows in period t; i ≡ Discount rate and t ≡ Number of periods.

The TLCC has disadvantages that limit its application in assessing and managing projects in wind energy projects:

1. The need to know the actual capital cost of the project. As the interest rate that measures the cost of capital for an investment should include the risk of the project, the task of defining the real value of capital cost is not always easy to accomplish.
2. The failure to consider the project's revenues, there is interference by the revenue costs, because there are costs that are directly influenced by income, as is the case of taxes on income in energy projects that may or may not be supported by incentive programs governments on renewable energy.
3. Costs are projected for the life of the project, which makes the financial cycle equal to the operating cycle of the investment, which by classical rules of accounting does not always coincide.

4.1.3 Net present cost

The Net Present Cost (NPC) of a renewable energy project is the sum of the current value of all costs during the project's interest period (generally considered its lifetime), including residual values[10] as costs. The net present cost of a project is the sum of all cost components, including [44]:

1. The investment of capital or initial capital cost;
2. O&M costs, excluding fuel (in case of wind);
3. Costs of major replacements;
4. Energy costs (fuel costs, including other associated costs);
5. Any other costs such as fees and legal fees, among others.

If a series of projects or investment options are being considered, the lowest net present cost will be the best option. By definition, the formula for calculating the NPC is defined as [2, 15]:

$$NPC = \frac{Co_1}{(1+i)} + .\frac{Co_2}{(1+i)^2} + ... + \frac{Co_t}{(1+i)^t} + \frac{D_v}{(1+i)^N} = \sum\left(\frac{Co_t}{(1+i)^t} + \frac{D_v}{(1+i)^N}\right) \quad (26)$$

where: NPC ≡ Net Present Cost; C_{ot} ≡ Cash outflows in period t; i ≡ Discount rate; t ≡ Number of periods of outflows; N ≡ Lifetime of wind park and D_v ≡ disinvestment value.

The NPC has disadvantages that limit their application in the evaluation and management of wind energy projects:

[10] It is understood by residual values, the difference between the book value of the commercial value of a fixed asset after the project lifetime. 37. Newnan, D.G. and Jerome P. Lavelle., *Engineering Economic Analysis*. 1998, Austin, TX.: Engineering Press.

1. The discount rate or cost of capital remains unchanged throughout the period under review the project because the cost of capital depends on the behavior of the risk of the activity that tends to be decreasing with the years of operation and technological maturity.
2. The financial indicators considered over the life of the project (inflation, discount rate, insurance, taxes, among others) also remain constant throughout the period analyzed what makes the NPC not to be influenced by the uncertainties of the economic scenario where the projects are inserted.
3. The fact of considering the value of disinvestment, especially for wind energy projects, because it is capital intensive project, makes the value of the divestment is high compared to other renewable technologies. In the case of wind energy projects return higher net present cost.

4.1.4 Levelized electricity generation cost

The Levelized Electricity Gereration Cost (LEGC) per kW is the proportion of the total cost over the lifetime of the project from anticipated results expressed in equivalent terms by the current value. This cost is equivalent to the average cost being paid by consumers to cover production costs included capital costs, operations and maintenance, fuel, rate of return equivalent to the discount rate. The formula used for calculating the LEGC for one unit of electricity generation is defined by IEA [9]:

$$LEGC = \frac{\sum\left[\left(I_t + M_t + F_f\right)\left(1+r\right)^{-t}\right]}{\sum\left[AAR\left(1+r\right)^{-t}\right]} \quad (27)$$

where: LEGC ≡ Levelized Electricity Generation Cost; I_t ≡ Investment expenditures in the year t; M_t ≡ Operations and maintenance expenditures in the year t; F_t ≡ Fuel expenditures in the year t; AAR ≡ Average Annual Revenue based on hourly production and r ≡ Discount rate; t ≡ Number of outflows periods.

By comparing LEGC for wind energy projects in different sites, it is important to define the limits of "production system" and costs that are included in it. For example, transmission lines and distribution systems should be included in the cost? Usually only connection costs to the production source for the transmission system is included as cost of production. One must be careful to delimit the border of cost analysis, what should or should not be included in the cost of energy [29]. The LEGC has disadvantages that limit application in the assessment and management of projects in wind energy projects:

1. The discount rate or cost of capital remains unchanged throughout the period under review the project because the cost of capital depends on the behavior of the risk of the activity that tends to be decreasing with the years of operation and technological maturity.
2. Capital costs are regarded as a lump sum at the beginning of the analysis; however there are other capital costs as major equipment installations and replacements that occur in other periods of the plant's lifetime production.
3. All recurrent costs begin to accumulate from the first period and are grouped together and considered to occur at the end of the current period. By using the discount rate to update and add costs in different periods, one runs the risk of this rate is different from the rate at which raise costs and other current expenditure over the life of the project.

4.1.5 Unitary present average cost

The Unitary Present Average Cost (UPAC) is significant for each year. However it is less meaningful if the evaluation period extends from the investment decision until the end of the lifetime of the plant production. The average annual cost per unit calculated for the two solutions, both technically and financially different, may be the same and be different than the interest of such solutions. To obtain the average unit cost updated, update separately charges (investment, operations and maintenance, fuel, and others) and total output during the lifetime of the plant production. Assigning charges generally updated by PV_{Co} and annual accumulated and updated by PV_{sAEP}, UPAC (€/kW), is given by [2]:

$$UPAC = \frac{\sum PV_{\mathrm{Co}}}{PVs_{AEP}} \quad (28)$$

where: PV_{Co} ≡ Present value of cash outflows and PVs_{AEP} ≡ Present value of cumulated annual energy production.

The update is to calculate the amount as payments and receipts made on various dates if made at time $t = 0$. To set the model to consider is necessary to establish precisely what is expected escalation for the exits and entries for cash. A fairly general model can admit that both the inputs (energy sales) and cash outflows (investment, operating costs) are irregularly spread over a period of n years of life. Although payments and receipts are distributed more or less irregularity over time, can be assumed:

1. Expenditure is done on the first day of the year during which they pay,
2. Revenues go into the last day of the year in which they actually receive it.

The interest and depreciation depend on the conditions of financing, accepted the same for all projects being compared. The following calculation is the average cost to date, considers itself neither interest nor amortization. Invested capital and its depreciation could never be considered simultaneously, it would be a duplication [32]. In this model of assessment of costs, cash outflows are classified as investment costs and operating expenses. The investment costs include all cash outflows arising from the physical structure of the central production (machinery and equipment, civil works, roads and access, control systems, among other things of that nature). As for operating costs shall include O&M costs, fuel and other charges related to the regular functioning of the power plant. The calculation of the UPAC, starting of the equation 28, it is assumed the following parameters:

1. Investment (ICC) focuses on the initial moment of the project (t = 0).
2. The annual use of power (capacity factor for wind projects) installed is constant throughout the lifetime of the project.
3. The O&M costs are constant over the useful lifetime and equal to $C_{O\&M.}$
4. There are no charges for fuel, will be the case of small hydroelectric plants, wind farms and photovoltaic cells.
5. The various charges are void or may be included in the O&M costs.

Accordingly, the UPAC is defined by:

$$UPAC = \frac{ICC(1 + C_{O\&M} \times \alpha)}{(AEP \times \alpha)} = \frac{ICC(\beta + C_{O\&M})}{AEP_s} \tag{29}$$

where: UPAC ≡ Unitary Present Average Cost; ICC ≡ Initial Capital Cost; $C_{O\&M}$ ≡ Operations and Maintenance costs and AEP_s ≡ Cumulated annual energy production.

For those factors $\alpha = \left[\frac{(1+i)^t - 1}{i(1+i)^t}\right]$ and $\beta = UCRF = \left[\frac{i(1+i)^t}{(1+i)^t - 1}\right]$, where: i = interest rate and t = number of outflows or lifetime of the project.

The UPAC has disadvantages that limit its use in evaluating and managing projects in wind energy:

1. Capital costs (ICC) are considered as a fixed sum at the beginning of the project; however there are other capital costs as major equipment installations and replacements that occur in other periods of the plant's lifetime production.
2. The capacity factor is not fixed throughout the period of operation of the project (lifetime), which makes the wind production variable over the years. By oscillating energy production, there is also fluctuation in wind energy revenues and costs.
3. The O&M costs are not fixed over the lifetime of the project. The maintenance contracts for wind farms are defined according to the warranty period given by equipment manufacturers. The duration of maintenance contract outside the manufacturer's warranty is 5 to 12 years, yet the life of the wind farms are for at least 20 years.

4.2 Peculiarities in the cost analysis of wind energy projects

The adoption of standardized methodology for calculating the cost of wind energy projects is necessary in the efficient management of a wind farm. Some approaches can be used for economic assessment in various contexts, to reflect the criteria and priorities of different economic agents involved in the venture.

For the correct definition and calculation of the cost of one unit of energy produced by a central production is essential to characterize the boundaries of the project under study. It is important to compare the power plants meet the cost of energy produced in isolation, but may not reflect the total economic impact of new power when connected to the network within an existing electrical system. It is important from the standpoint of the producer to estimate the cost of producing one unit of energy for the management and evaluation of the project as a business unit must ensure that economic return for the investor/manager [45]. The average cash cost methodology for the series of costs to present values at a given base year by applying the discount rate. The discount rate considered appropriate for the energy sector may differ from country to country, and in the same country, from technology to technology. Applying the discount rate takes into account the time value of money, or an amount earned or spent in the past or future, has the same value as the same amount (in real terms) gained or spent on this. The discount rate may be related to rates of returns that can be earned on investments typical, which may be a fee required by regulators incorporating the provision for financial risks and /or derived from national macroeconomic analysis. Despite the investment option not to depend entirely on how it is financed, as it should be profitable by itself, funding may influence the attractiveness of the project. This is especially true for renewable energy projects. How often is very capital intensive and require large amount of initial debt and equity. The financial conditions for such a loan, becoming an important factor in the project evaluation [41].

5. Summary and conclusions

As far as investment decisions when dealing with uncertainty of future events that may not be totally avoided. The decision is based on estimates and assumptions about future developments and future states (prices, volumes, market sizes, regulations, etc.). The reality may eventually be less favorable than the original estimate of project. It is not a productive strategy for evaluating investments working hypotheses, very negative. The objective of the investment should not be too pessimistic, but to evaluate adequately the uncertainties involved in analyzing and quantifying this uncertainty in some analytical way. One rule applies to all methods of economic evaluation of projects and costs for the private view, if two projects generate the same results in the future, but are associated with different degrees of uncertainty, the more uncertain project will be considered less attractive. There is an inverse relationship between uncertainty and attractiveness of the project. Like any other project, the renewable energy projects should ensure financial returns to investors and managers. The evaluation is not limited to assessment of financial attractiveness, but should include several other factors.

As explained in this chapter, the attractiveness of an investment project should be quantified in an analytical way. Methodologically, to arrive at this result it is necessary to sort and organize items in the project cost. In the case of wind energy projects, the costs are classified and structured investment costs, operating costs, maintenance costs and financial costs. All these classes and cost structure have their own characteristics depending on the location, size, types of financing and regulations. These costs behave differently from project to project, from country to country (region), from author to author, in summary, we present estimates for these costs, as shown in Tables 3 and 4.

Although it is of fundamental importance to classification and structuring of the cost of wind energy projects is of great importance to proper application of existing models for economic evaluation of projects, considering the objectives of the evaluation itself. For this dissertation, the purpose and scope of the theme, we studied the main methods of economic evaluation of projects and their applicability in wind energy projects. The indicators studied were SPB, DPB, NPV, NPV, IRR, RR and BCR.

The SPB and DPB measure the return time of investment, although the BDP discounting project costs (usually operating costs). The NPV analysis measures the level of wealth that the investor receives the bet on any one project with its own capital and/or others. In the IRR analysis, which refers specifically rate the investment can pay for the capital (the higher the rate, the better the project). For models of economic evaluation of projects studied were identified limitations or weaknesses of each.

However, for sectors where there is strong government regulation of economic activity, if the renewable energy sector, we need to analyze, also what level of minimum income that the project in question needs. This response is given by the RR analysis. For a RR analysis, the smaller the need for revenue, better the project is. The analysis of BCR is the ratio of the current value of the sum of the project benefits divided by present value of the sum of project costs. BCR analysis is used as a criterion for selection of independent projects that have benefit-cost ratio greater than or equal to unity. It cannot be used to choose between mutually exclusive alternatives.

For onshore wind energy projects, methodologies were also analyzed with emphasis on analysis of the cost production per MWh. Among the indicators studied were LCOE, TLCC, NPC, LEGC and UPAC. These indicators of attractiveness and cost of projects are for specific renewable energy projects. Together with other indicators of financial attractiveness of the project is a set of tools that can be used selectively to evaluate and project management. They were also pointed out factors that limit each type of cost analysis. It is comparative analysis of methodologies studied in Table 7, considering the main aspects that impact on economic assessment of wind energy projects and their costs.

Table 7. Overview of economic measures applying to specific investment features and decision

	Methods of economic evaluation of projects and costs								
	NPV	IRR	TLCC	SPB	DPB	BCR	LCOE	RR	UPAC
Significant investments (negative net cash flow) after first return	Posible	Not useful	Posible	Posible	Posible	Posible	Posible	Posible	Not useful
Investment subject to regulation	Posible	Posible	Posible	Posible	Posible	Posible	Posible	Preferred	Posible
Project-specific debt-financing needed	Posible	Posible	Posible	Not useful	Not useful	Posible	Posible	Posible	Not useful
Social costs (externalities)	Preferred	Posible	Posible	Posible	Posible	Preferred	Posible	Posible	Posible
Taxes	Posible	Posible	Posible	Not useful	Not useful	Posible	Posible	Posible	Posible
Select from mutually exclusive alternatives	Preferred	Not useful	Posible	Not useful	Not useful	Not useful	Not useful	Posible	Posible
Ranking (Limited budget)	Posible	Posible	Posible	Not useful	Not useful	Preferred	Preferred	Posible	Posible
Risks	Posible	Posible	Posible	Preferred	Preferred	Posible	Posible	Posible	Posible

Source: [9]

The methodologies for economic evaluation of projects and costs are summarized in Table 7. Economic measures are suggested which better suited for each specific analysis. Different economic measures apply to different situations and it is believed to be preferable to use several methodologies to evaluate an investment project in the energy area. Sometimes the objective of economic evaluation is to find the most appropriate combination of each method available in engineering economics.

After analysis of these models applied to renewable energy, include:

1. The attractiveness of the proposed wind energy can vary considerably between evaluation of the private and public sector. The public sector takes into account additional factors such as externalities, public authorities for tax purposes or long-term effects that are beyond the horizon of private investors.
2. The financing structure is very important influencing factor for the attractiveness of wind energy project. In many cases, economic agents practice their actions by means of financing the project in order to earn sufficient income to meet the demands from investors and other economic agents involved.
3. The project's economic attractiveness of wind energy is influenced by government intervention through regulatory actions. Common tools of public intervention are tax incentives, direct subsidies, regulated tariffs (revenue) or subsidized loans (low interest loans).

The renewable energy projects can be analyzed using essentially the *"tool kit"*, presented in this paper. The financial attractiveness is an integral part of any project. The economic agents involved must offer sufficient guarantees to the financial return in order to make it attractive. There are a number of other factors and peculiarities that make the evaluation of renewable energy projects little more difficult than in "normal" projects. So far, possible investments in renewable energy projects have been treated as if the consequences were entirely predictable. In reality, the consequences are still very uncertain. This applies to projects of all types and especially for onshore wind energy projects [46].

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