Economic evaluation applied to wind energy projects

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***Abstract*—Financial and economic evaluations are the main features of a feasibility study. Financial evaluation would look mainly into the money aspects of the project and its rewards and financial profitability to the investors. Whereas a financial study can usually be undertaken by a financial analyst(s) and engineers, an economic evaluation study demands the involvement of economic and environmental disciplines and analysis that is beyond the proficiency of most engineers, accountants and financial analysts. In this paper 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.**

***Index Terms*—Economic evaluation, Wind energy projects, Onshore wind energy.**

I. INTRODUCTION

Opportunities to explore 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 Fig. 1.

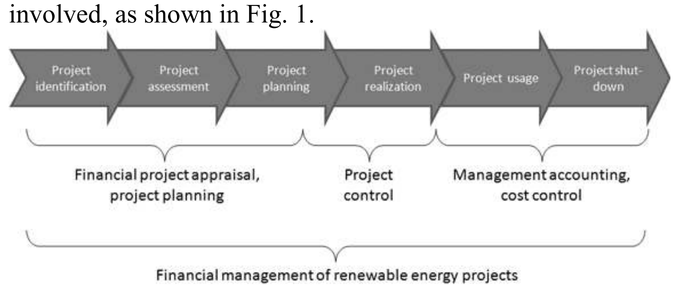

Fig. 1. Evaluation process and financial management of renewable energy projects [3].

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 [4].

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.

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II. Classification of Costs Categories

A. 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.

In the following the main cost elements of the most common wind energy technology 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 [5]-[6].

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 [7]. 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. The wind turbine consists of tower 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 [9].

According to IEA [2], NREL [3] 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.

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 have 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.

TABLE I
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: [2]

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

[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 $Ec = \frac{mv^2}{2}$ 8. Rosa, A.V., *Fundamentals of Renewable Energy Processes*. 2nd ed2009, UK: Elsevier.

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 drive 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].

Fig. 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.

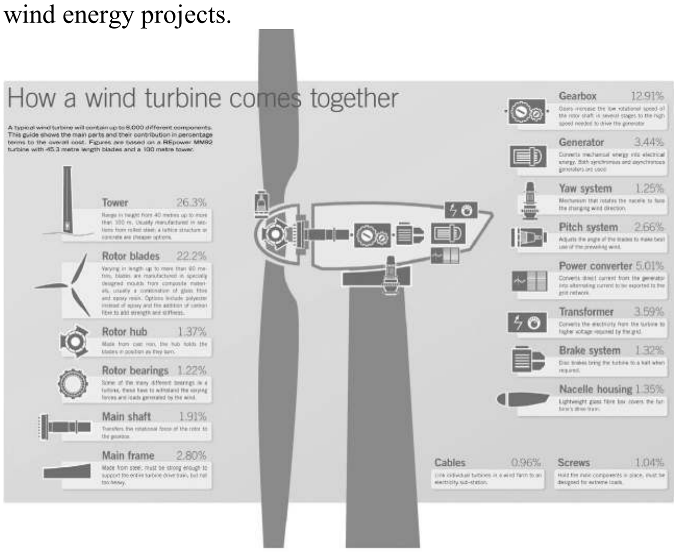

Fig. 2. Example of the main components of onshore wind turbine with distribution of the overall cost of the 5 MW Repower [11].

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

[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.

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 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.

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 II
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]

TABLE III
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.

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

TABLE IV
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.

III. MODELS OF PROJECTS ECONOMIC EVALUATION

A. *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]:

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

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:

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

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 [3]. 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.

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:

[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 ed1997, Lisboa: McGraw-Hill.

$$(Ci-Co)_{1}+(Ci-Co)_{2+...+}(Ci-Co)_{t}=\sum(Ci-Co)_{t}\geq Co_{0} \quad (3)$$

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

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

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:

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.

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]:

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

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]:

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

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.

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 [6]:

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

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 [6]. 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.

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

[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.

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 [6].

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

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.

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 [3].

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

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):

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

Where: $UCRF \equiv$ *Uniform Capital Recovery Factor;* and $n \equiv$ *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.

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 [3]:

If $PV_{ci} = \sum \frac{Ci_t}{(1+i)^t}$ and $PV_{co} = \sum \frac{Co_t}{(1+i)^t}$, so

$$B/C = \sum \frac{\sum \frac{Ci_t}{(1+i)^t}}{\sum \frac{Co_t}{(1+i)^t}} \quad (20)$$

Where: $PV_{ci} \equiv$ *Present Value of Cash Inflows* and $PV_{co} \equiv$ *Present Value of Cash Outflows.*

TABLE V
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: [3]

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.

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.

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

B. 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 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.

IV. 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 paper, 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

TABLE VI
Overview of Economic Measures Applying to Specific Investment Features and Decisions

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

Source: Adapted from [2]

[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 ed2001: John Wiley and Sons Ltd,. 1000.

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 paper, 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.

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. It is comparative analysis of methodologies studied in Table 6, considering the main aspects that impact on economic assessment of wind energy projects.

The methodologies for economic evaluation of projects are summarized in Table 6. 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. It is applied to projects of all types and especially for onshore wind energy projects [39].

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