Method of Assessing the Economic potential of Wind Energy in the Region (case study Syria)

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Abstract. Wind energy is one of the cheapest renewable energy sources. However, the problem of non-widespread of using wind energy turbines in the power sector is related to its economic efficiency and competitiveness compared to conventional systems. The purpose of this paper is to help the decision-maker and the investor in obtaining reliable information on how to calculate the basic approach to calculate the economic parameters of wind energy turbines involves determining the effectiveness of turbines in competition with the using traditional fuels. Thus, can be defined economic feasibility of using and economic potential of wind energy in specific region.

1. Introduction
In the early of 80s, when the world began the industrial using of wind energy turbines, the average cost of electricity produced was about 30 c/kWh, which was significantly higher than the average cost of electricity which was produced by using traditional sources - oil, coal and gas. For the past 15 years, the cost of electricity produced by turbines which was connected to power network, was reduced more than 6 times. In 2006, the average cost of electricity reached to less than 5 c/kWh and is comparable to the average cost of the electricity produced by using traditional fuel. During the same 15-year period, the cost of the installed capacity of wind energy turbines connected to the power network, was reduced more than 4 times from 4000 to 1000 dollars/kW [1,4-6,8-12].

The cost of installed capacity of renewable energy sources for a specific region including wind energy turbines, including the cost of equipment, the cost of transporting it to places of installation and the cost of construction. Determining the cost of turbines, as well as the resource of their work in natural conditions allows us to determine the cost of producing useful electricity and their effectiveness compared to other energy sources.

The basic approach to calculate the economic parameters of wind energy turbines involves determining the effectiveness of turbines in competition with the use of traditional fuel. Thus, can be defined economic feasibility of use and economic potential of wind energy in specific region.

2. Basics of the Methodology
The economic potential of wind energy is the annual revenues of electricity in the region that is produced by using wind energy turbines, the received electricity is economically justified for the region at the current price for production, transportation and consumption of energy and fuel, and compliance with environmental standards.

The economical potential of the region is the sum of the economic potential of its constituent areas. It should be taken into account that the number of zones in the region and their sizes when we
determine the technical potential do not coincide with the number of zones and their sizes when we determine the economic potential. In fact, under determining the technical potential, the number of zones and their sizes is determined by the similarity of annual average of wind speed and geographical conditions. While the number of zones and their sizes under determining the economical potential. In addition, separating signs for zones of technical potential should be determined based on actual needs of electricity for the areas and consistency in its adoption to calculate indicators of the cost. This is true especially for a specific cost of structures of a station of wind energy. It should be realized that when wind energy station is far away from the points of connection to the power network. Therefore, this increases the cost of construction of power lines, which should be taken into account of the cost of construction. In addition, it is meaningless to talk about the economic potential (as opposed to technical), when it comes to areas far away from the houses for hundreds of kilometers. In reference to the above stated facts, the economic potential of region is so smaller than the technical or, in other words, the area defines the economic potential is so smaller than the area defines technical potential [1-3, 7, 8, 10, 13].

The issue of cost-effectiveness of wind turbine is solved by the optimization parameters of wind energy turbines and find option that provides the minimum price of producing the electricity from wind turbine.

We further believe that during the lifetime $T_L$ and the annual discount rate $d$ is constant, $U_{WPU}^E = E_{WPU}^E = \text{const}$ and $E_{WPU}^G = \text{const}$. Under these assumptions, the cost of electricity produced by wind turbine can be written as [6, 10]:

$$z = \frac{K_{WPU} \cdot CRF(d, T_L) + U_{WPU}^E}{E_{WPU}^G} \quad (1)$$

where $CRF$ are the capital recovery factor, $U_{WPU}^E$ are the WPU operation and maintenance cost, $E_{WPU}^G$ - are the annual average of WPU electricity generated, $K_{WPU}$ - капитальные вложения в ВЭУ. The factor of using installed capacity of wind turbine is defined by the formula:

$$\theta = \frac{N_{ACWPU}}{N_{ICWPU}} \quad (2)$$

where $N_{ACWPU}$ are the annual average of capacity of WPU, $N_{ICWPU}$ are the installed capacity of WPU. The annual average of electricity generated can be written as:

$$E_{WPU}^G = N_{ACWPU} \cdot T = N_{ICWPU} \cdot T_U = \theta \cdot N_{ICWPU} \cdot T \quad (3)$$

where $T = 8760 \text{ hr}$, $T_U$ are the number of hours of using the installed capacity of WPU.

The operation cost of WPU is defined by the formula:

$$U_{WPU}^E = b \cdot K_{WPU} = b \cdot k_{WPU} \cdot N_{ICWPU} = i \cdot N_{ICWPU} \quad (4)$$
where \( i = b \cdot k^{WPU} \) - fixed operation costs, $/kW per year. With regard to Eq. 2 – Eq. 4, the Eq. 1 can be written as [10]:

\[
z = \frac{1}{0 \cdot T} \left( \frac{k^{WPU} \cdot d}{1-(1+d)^{-1}} + i \right)
\]

(5)

From Eq. 5 it follows that there are two regional factors that affect the price of production of electricity from wind turbine, the factor of using installed capacity of wind turbine and the investment in wind turbine, which should be taken into account regional differences.

The capacity of wind turbine varies with time. For reliable and uninterrupted supply of electricity for consumers, other power stations must also work, such as fossil fuel. Therefore, when comparing competing options of price of electricity (Eq. 5) should be compared with the price production of electricity by using fossil fuel \( Z_f \), also the criterion of economic efficiency of wind turbine is given by the formula \( Z \sim Z_f \). It is also assumed that the work of wind turbine in the power system is organized in a way that all the electricity produced is used for consumers.

Revenue from the sale of electricity \( B_{E}^{WPU} \) and the total revenue, taking into account losses of shortages of electricity are determined by the formula [1, 10]:

\[
B_{E}^{WPU} = E_{G}^{WPU} \cdot C_{TF} - U_{E}^{WPU}
\]

(6)

\[
B_{EL}^{WPU} = B_{E}^{WPU} + Q \cdot (C_{C} - C_{TF})
\]

(7)

where \( Q \) kWh/year - the annual deficit of electricity that is covered by energy station, \( C_{C} \) Rub/kWh – unit's price of losses of energy shortages. \( Q \), \( C_{C} \) and may have a different meaning of that is suitable for any region. A namely \( Q \) kWh/year - the annual demand of industrial production in the region from electricity that is covered by the energy turbines; \( C_{C} \), Rub/kWh - the price of values or goods of industrial production in the region per unit of electricity consumed.

Simple payback of wind energy turbine \( T_{PB} \), will be:

\[
T_{PB} = \frac{K^{WPU}}{B_{E}^{WPU}}
\]

(8)

The economic effect of using wind turbine NPV is expressed in dollar or ruble and can be defined as the revenue, received from the use of wind turbine through time-life [6, 10]:

\[
NPV = \frac{B_{EL}^{WPU}}{CRF} - K^{WPU}
\]

(9)

From the condition \( NPV = 0 \) is the payment period \( T_{O} \) or payback discount. As can be seen, the economic indicators that determine the economic feasibility and effectiveness of using wind turbine, are strongly dependent on the cost of electricity \( C_{TF} \) produced by using traditional sources. In areas which
contains central power network, the cost is relatively low, which reduces the economic effect of using wind energy.

At the same time, the existence of power network is a favorable condition for connection to the wind energy turbines and ensure their stable operation. Some areas of Russia, are located in areas of power network are short supply. The existence of an energy deficit, as a rule, hides the development of production and leads to significant losses, including the material and financial.

Greater economic effect is the creation of autonomous wind energy turbines in regions far away from power network, although this is subject to certain constraints to ensure their stable operation in a rapidly changing wind speed, as well as possible long periods of weak wind. Needs of the population and economy of these regions are very large of power, and the cost of conventional fuels is much higher than their value in the areas of distribution of power network due to transport costs and losses of fuel during transportation. On this basis, the price of electricity in the region includes the regional factor $r_p$ [1,10]:

$$C_{TFR} = r_p \cdot C_{TF}$$

(10)

Where $r_p > 1$ and for different regions can be changed its value. At the same time, the cost of the installed capacity is almost unchanged compared with $C_{TF}$. Therefore, replacement $C_{TF}$ with $C_{TFR}$ a Eq. 6 calculated payback autonomous wind energy turbines in areas remote from the networks decreases and the economic effect increases proportionally $r_p$.

In the presented expressions that determine the cost-effectiveness does not consider the effect on the environment, on social conditions and human activities. Renewable energy compared to traditional energy sources have an important advantage, concluded the possibility of saving environment, and in some cases the possibility of improving the environment.

One of the forms of effect of power plans on the environment of the region can be the cost of the energy produced regional environmental factor source $r_{ECOL}$, taking into account the relative costs of compensation for the harmful effects of each unit of energy. If $z$ - the unit's price of electricity produced by wind turbine, taking into account regional environmental factors.

$$z_{ECOL} = r_{ECOL} \cdot z$$

(11)

$r_{ECOL} > 1$ for the source, that leads to deterioration of the ecological situation in the region, and , $r_{ECOL} < 1$ for the source, that leads to improving the ecological situation in the region. $r_{ECOL}$ in different regions may change its amount and becomes greater than or less than unity. A similar expression exists for the cost of traditional fuels [1, 10]:

$$C_{TRF} = r_{ECOL} \cdot r_R \cdot U_{TF}$$

(12)

Thus, taking into account the regional factors in the cost of fuel and regional environmental factors, the payback period and the economic effect of using wind turbine is given by (Eq. 8) and (Eq. 9). By analogy with [1, 10] we obtain general formulas for the case of evaluating the effectiveness of wind turbine, but with the discount.

The economic potential of the region is the sum of the economic potential of its constituent areas and represents the energy $W_{ECON}$ (kWh/year), which can be generated for the year $M$ of the same type of wind turbine, provided that their total net present value is positive or zero [10]:
\[ \text{NPV} = \frac{\sum_{i=1}^{M} B_{ELi}^{WPU}}{\text{CRF}} - \sum_{i=1}^{M} K_{i}^{WPU} \geq 0 \]  

(13)

the variable that is associated with the ratio CRF:

\[ \alpha(d, T_L) = \text{CRF} \cdot T_L = \frac{d \cdot T_L}{1 - (1 + d)^{-T_L}} \]  

(14)

Obviously,  \( \alpha = 1 \) when  \( d = 0 \). Then

\[ \text{NPV} = \frac{M \cdot (E_G^{WPU} \cdot C_{TFR} - U_E^{WPU})}{\text{CRF}} + \frac{Q_I \cdot (C_{TF} - C_{TFR})}{\text{CRF}} - T_{PB} \cdot B_{E}^{WPU} \cdot M \geq 0 \]  

(15)

or:

\[ \text{NPV} = M \cdot B_{E}^{WPU} \cdot \left( \frac{T_L}{\alpha(d, T_L)} - T_{PB} \right) + \frac{T_L \cdot Q_I \cdot (C_{TF} - C_{TFR})}{\alpha(d, T_L)} \geq 0 \]  

(16)

If service life-time of wind power turbine is lower  \( T_L' \) is greater than or equal to the simple payback.

\[ T_L' = \frac{T_L}{\alpha(d, T_L)} \geq T_{PB} \]  

(17)

And  \( C_{TF} > C_{TFR} \) as the economic effect of using plants is positive for any of them. This means that in this case it is advisable to use the maximum possible power of station of wind energy so that the economic potential of wind energy is coincident with the technical capacity  \( W_{ECON} = W_T \). Payback period is associated with a payback ratio:

\[ T_O(d) = \beta(d) \cdot T_{PB} \]  

(18)

where  \( \beta(d) \geq 1 \) - a factor that depends only on the discount rate.  \( \beta = 1 \) when  \( d = 0 \).

If lifetime of turbines is less than simple payback  \( T_L' < T_{PB} \), the condition (Eq. 16) corresponds to the following restrictions on the full capacity of wind power systems [1, 10]:

\[ \frac{E_G^{WPU} \cdot C_{TFR} - U_E^{WPU}}{C_{TFR}} \cdot M \leq \frac{T_L' \cdot Q_I \cdot (C_{TF} - C_{TFR})}{T_{PB} - T_L'} \cdot C_{TFR} \]  

(19)

In the same time, of course, have the relation  \( E_G^{WPU} \cdot M \geq Q_I \). If the difference between the lifetime and payback period is significant, the economic potential is given by:
In various areas of the region for wind turbine, even of the same type may have different conditions for determining the economic potential that is largely dependent on wind conditions.

Analysis of data on payback period wind turbine shows that the condition $W_{ECON} = W_T$ in real cases can be performed, depending on the value of factor of using installed capacity of wind turbine $\theta$ and the cost of traditional fuel $C_{TFR}$. Condition (Eq. 15) can be written as:

$$1 > \theta \geq \theta_{ECON} = \frac{k_E^{WPU} \cdot (\alpha(d,T_L) + b \cdot T_L)}{C_{TFR} \cdot T \cdot T_L}$$

(21)

where $\theta_{ECON}$ - coefficient that defines the area of economic efficiency of plant; $T = 8760$ hr/year. Regions in which the condition (Eq. 21), have economic potential of wind energy equal to their technical potential. While taking into account the restriction $\theta < 1$ and $\theta_{ECON} > 1$ condition (Eq. 21) is not satisfied.

If condition (Eq. 21) is not satisfied, and $\theta < \theta_{ECON}$, then the economic potential of wind energy saves the value $W_{ECON} = W_T$ for sufficiently large $\theta$ [1, 10]:

$$\theta \geq \frac{\theta_{ECON}}{1 + \frac{Q_L}{W_T} \cdot \left(\frac{C_{TF}}{C_{TFR}} - 1\right)}$$

(22)

In the intermediate range of values $\theta$:

$$\theta_{ECON} \cdot \frac{C_{TFR}}{C_{TF}} \leq \theta < \frac{\theta_{ECON}}{1 + \frac{Q_L}{W_T} \cdot \left(\frac{C_{TF}}{C_{TFR}} - 1\right)}$$

(23)

Economic potential is

$$W_{ECON} = Q_L \cdot \left(\frac{C_{TF}}{C_{TFR}} - 1\right) \cdot \frac{\theta}{\theta_{ECON} - \theta}.$$  

(24)

$\theta < \frac{C_{TFR}}{C_{TF}} \cdot \theta_{ECON}$, economic potential is zero $W_{ECON} = 0$.

Thus, the economic potential of wind energy in the region $W_{ECON}$ has a growing dependence on the use of installed capacity $\theta$, is determined by three parameters: the ratio of the economic feasibility of wind energy plant $\theta_{ECON}$, economic parameter needs of industry in the region, energy
$Q_1 / W_T$, and pricing of industrial production $C_{TF} / C_{TRF}$. Specific calculations of technical potential were carried out for the two territories.

Economic potential was taken to 16% of the technical, depending on the annual average of wind speed and density of the population in Syria. The potential of wind energy is distributed unevenly on the territory of Syria. There are many areas where the annual average of wind speed exceeds (6 m/s). The highest average of wind speeds are found in Katina (7.8 m/s), Qonaitra (6.2 m/s). Other areas with relatively high wind speeds (5-6 m/s) include: Ghabagheb (5.6 m/s) and Alharah (5.4 m/s).

3. Conclusion

We have developed a methodology for assessing the economic potential of wind energy in specific Region and build upon to better assess the profitability of a wind energy site. We examine the fixed and variable cost components of wind power and provide estimates of the level of cost of electricity from wind power. This up-to-date analysis of the costs of generating electricity from wind will allow a fair comparison with other generating technologies.

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