RENEWABLE ENERGY AS AN ALTERNATIVE OF THE DECENTRALIZATION ENERGY SUPPLY IN UKRAINE

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ABSTRACT

The scientific article considers the state of the energy sector of the Ukrainian economy and determines a high level of depreciation of equipment, as a result of which conclusions were drawn on the need for the speedy introduction of renewable energy, the main investor of this project is the business sector and the population of the country. An example we selected wind energy installation, for which the payback model equipment for the term of its operation. A key lever for the introduction of renewable energy is the ratio of feed-in and network tariffs, which should ensure the effectiveness of investment. In this model, the investor's income is calculated on the basis of the network tariff for own consumption and the feed-in tariff for the energy supply of the balances from consumption to the grid. It's proved that the development of renewable energy is important for the Ukrainian economy and business, both from the point of view of energy security, and the commissioning of new generating capacities, ensuring environmental compatibility, which, in particular, includes wind energy.

Introduction. In any country in the world, the development of the energy sector is a factor that largely determines the vector of economic development. Nowadays, significant changes are taking place in the world energy industry, conditioned by a change in public opinion regarding the basic life priorities of the overwhelming majority of the society. This is primarily an increase in the level of public requirements for the state of the environment. As a result, there is a significant restructuring of the world energy industry in favor of generations that do not worsen the state of the environment.

The main lever for the development of renewable energy in Ukraine is the introduction in 2008 of the feed-in tariff [2] where the balance from generated energy is supplied to the power grid. Since the introduction, the feed-in tariff for all types of generation (wind, solar and bioenergy) has been significantly reduced, but it is several times higher than the electricity grid tariff and will not change until 2035.

The introduction of the feed-in tariff, aims to support the process of investing the population in renewable energy. In the Energy Strategy of Ukraine [1], the main focus is on bioenergy, the main sources of which the country's forestry, by-products of agricultural production and household waste. However, the strategy did not take into account that the use of forest products in such huge volumes associated with huge investments in infrastructure and qualified personnel. In addition, a feature of bioenergy is that bioenergetic generators become cost-effective starting from a capacity of 1 megawatt.

Unlike bioenergy, solar and wind power are provided by a regular energy source of natural energy [9], and the capacity of windmills and solar cells starts from a unit of kilowatts and is therefore available for ordinary Ukrainian households. Therefore, a massive investment in solar and wind energy, can lead to a significant improvement in the state of the environment and reduce the risks and losses that accompany the use of traditional energy sources for Ukraine.

Materials. Poul-Erik Morthorst and Shimon Awerbuch in their report of the economics of wind energy [7] provide a systematic framework for the economic dimension of wind energy and of the energy policy debate during comparing different power generation technologies. They also prove the most important economic benefits of wind power such as reduction of exposure of our economies. Authors of the report demonstrate that global energy market can't solve its own problems itself because the market doesn't properly value the external effects of power generation. In the last chapter of the report the value of wind compared to gas generation is given so it demonstrates how wind energy can replace gas energy over a quite long period of time.

The Levelized cost of energy report [9] made by U. S. department of energy brought a lot of useful calculation, such as: upfront capital costs for renewable or simplified levelized cost of energy (LCOE) for different existing energy technology at this time. At the same time the simple LCOE concept is given which includes the calculation of initial costs, annual expenses and annual energy production. This report proves that initial capital cost and capacity factor are two critical drivers but discount rate (or so-called financing costs) and annual operating expenses can't be considered trivial factors during determining the wind LCOE sensitivity.

The aim of the article. The purpose of the article is to substantiate the feasibility of using wind generation at existing tariffs and the level of macroeconomic stability by a significant part of the population of Ukraine.

The results obtained. Considering the existing ratio of tariffs for electricity and feed-in tariffs [2, 6], we consider the investor's optimization tasks in solar and wind energy. If we consider only one from the energy sector, then it is necessary to take into account the time of effective generation. Therefore, for a wind turbine installed on land this time in a year does not exceed 2000 hours (the total number of hours is 365 · 24 = 8760 hours, which means that for 2000 hours it is necessary to generate the amount of electricity that is needed during the year). In this case, it is necessary to take into account the costs of equipment intended for conservation and transformation of energy, in the absence of generation. This equipment includes batteries and inverters.

A similar problem arises when using solar energy, which is not produced in the dark. Consider the index of attractiveness of investments in renewable energy. In order to increase investment attractiveness, a feed-in tariff introduced, in which surplus energy generated and supplied to the energy system (Table 1).

Table 1. Tariffs for electricity consumption and feed-in tariff in eurocents / kWh (cents USD / kWh as of December 20, 2017)

	Population	Industry	Feed-in tariff		
			Solar energy	Wind energy	Biomass energy
EU(28)	21(25)	12(14)	10(12)	16(19)	12(14)
Denmark	30(35)	9(11)			
Germany	29(34)	15(18)			
Bulgaria	7(8)	8(9)			
Ukraine	5(6)	7(8)	17(20)	11(13)	12(14)

Source: [6]

The table shows the diversity of incentive mechanisms for renewable energy used in the EU and Ukraine, if the EU encourages investors to have high tariffs for electricity consumption [6], in Ukraine it is high tariffs for the sale of energy balances in the system in relation to tariffs for consumption. Consequently, there is a difference in the results of use: in the EU, an increase in the share of renewable energy will lead to a reduction in tariffs in developed countries, while in Ukraine it will grow. In fact, this way, the public burden is evenly distributed, in the form of payment for improving the state of the external environment.

Consider the optimization task of autonomous power supply taking into account both the macroeconomic situation and the stimulus in the form of the feed-in tariff. Usually, with the existing ratio of tariffs, the optimal solution is own energy consumption due to the energy system and the total sale of the energies generated in the system. Considered options for the existence of risk-free returns should not exist (free lunch absence). Hence, this option is excluded at the legislative level and, first of all, autonomous generation must satisfy its own needs and only the residuals from generation can be supplied to the grid by the feed-in tariff [2]. In these conditions, the annual energy consumption of a potential investor is a key parameter of the task.

The scheme of autonomous power supply with the possibility of putting energy balances in the power system, besides the generator, includes a battery for saving energy for the absence of generation and an inverter for converting a DC to an alternating current. The cost of all equipment must be included in the costs.

We introduce the following notation:

E_y *(kWh)* – the amount of electricity consumed by a household per year;

$\tau_з$ – feed-in tariff;

τ_c – energy sales rate;

w_c – average power consumption;

$w_з$ – the average power supplied to the grid by the feed-in tariff and the total power generated is – $w = w_c + w_з$;

T_y – number of hours of generation per year;

$I(w) = \gamma \cdot w^{\alpha}$ - volume of investments in generation;

α, γ – parameters determined by econometric way to price indicators existing on the market;

$C(w) = c_1 \cdot w \cdot T_y$ – operating costs that are proportional to the energy generated during the year [15];

c_1 – coefficient of proportionality;

$\mu; r$ – discounting and lending rates to the investor;

$P_a \frac{E_y \cdot d_m}{365}$ – the purchase price to the battery, which will provide the household energy for the maximum number of days possible for the type of generation chosen (d_m);

P_a –cost of accumulation 1 kWh;

T – operating life of the generating set;

$I_a(w) = \eta \cdot w^{\psi}$ – amount of investments in the purchase of inverters;

η, ψ – parameters that determine in econometric way by market data.

We introduce the objective function, maximize the discount income on the acquisition of equipment. The service life of equipment for wind generation (T) is 20 years. The lifetime of the accumulation unit is 10 years. We believe that the objective function depends only on the capacity of the generating unit:

$$\max Z(w) = \sum_{t=1}^{T} \frac{\tau_c \cdot E_y + (w \cdot T_y - E_y) \cdot \tau_з - C(w)}{(1+\mu)^t} - I(w) - \left(P_a \frac{E_y \cdot d_m}{365} + I_a \ w \right) \cdot \frac{(1+\mu)^{10} + 1}{(1+\mu)^{10}} \qquad (1)$$

In addition, the amount of energy generated must exceed the amount of energy consumed:

$$wT_y \geq E_y \qquad (2)$$

Since the standard operating time of the generators is 20 years, and the batteries only work out 10 [16], the discount function takes into account the discount purchase of generators in 10 years.

To estimate the dependence of the price of the generating unit on its capacity, we use the following analytical expression:

$$I(w) = \gamma \cdot w^{\alpha} \qquad (3)$$

where $I(w)$ – the volume of investments in the acquisition of a generating unit;

w – installed power, kWh;

$\gamma; \cdot\alpha$ – coefficients of the equation, which are estimated econometrically and $(\alpha < 1)$.

Consider a quantitative example of determining the dependence of the price of setting the capacity (Table 2).

For the linearization of the dependence, we find the natural logarithm from both sides of equation (3):

$$\ln I = \ln \gamma + \alpha \ln w$$

On the basis of the obtained data set, we perform a regression analysis in which the logarithm of the cost of the wind turbine will act as an effective attribute (y), and the nominal power of the factor (x):

$$y = \beta_0 + \beta_1 x + \varepsilon$$

where $\beta_0 = \ln \gamma$ and $\beta_1 = \alpha$.

Table 2. The cost of wind turbines, depending on their rated power

Wind turbine model	Rated power, kW (X)	Cost, thous. USD (Y)	Ln(X)	Ln(Y)
C 300	0,3	0,63	-1,21	-0,51
M 300	0,09	0,24	-2,41	-1,41
EW 400	0,4	0,58	-0,91	-0,51
EW 600	0,6	0,75	-0,51	-0,31
EW 1000	1	1,09	-0,01	0,09
EW 2000	2	3,11	0,69	1,09
EW 3000	3	4,21	1,09	1,39
EW 5000	5	10,36	1,59	2,29
EW 10000	10	14,52	2,29	2,69
FD 10	10	17,66	2,29	2,89
FD 20	20	26,73	2,99	3,29
FD 30	30	40,86	3,39	3,69
FD 31	30	43,82	3,39	3,79
FD 50	50	94,23	3,89	4,59

Sources: own calculations, [13]

By a standard least squares approach, we obtain estimates of the coefficients $\beta_0 = 0,73$ and $\beta_1 = 0,96$. Thereby $\gamma = 2,1$ and $\alpha = 0,96 \approx 1$ (there remains the null hypothesis $\alpha = 1$). The dependence of the price of setting the capacity will take the form:

$$I(w) = 2,1w \tag{4}$$

Proportional dependence is shown, which means that the installation of an additional capacity of 1 kW is worth 2.1 thousand USD, which corresponds to the world statistics for wind generation (Table 2).

When constructing an optimization task, it is also necessary to take into account the variable costs associated with servicing the mill. Based on the world experience [9] it is known that the mill maintenance costs are 4 USD for every 1 MWh or 0.004 thousand USD for every 1 kW of produced energy. Dependence of annual maintenance costs in thousands of USD of installed capacity:

$$C(w) = c_1 w T_y \tag{5}$$

where – in case of wind generation.

Thus, from (5), it follows that each additional 1 kW of installed capacity increases the annual operating costs by 8 USD at 2000 hours worked per year, concerns the cost of the innovators, then according to the market data, the following dependence of the cost (thousand USD) on power (kW):

$$I_a(w) = \eta \cdot w^{\psi}; \eta = 0,15; \psi = 0,3 \tag{6}$$

As a result of the analysis of prices and battery capacity, it turned out that the cost of storing a unit of energy is a constant value equal to:

P_a = 0,2 thous. USD / kWh

Since the numerator of the first expression of the objective function (1) does not depend on time, it is taken out beyond the sum sign, and the sum of the discount factors is added as a geometric progression. As a result, we obtain an integrated discount on the interval *T*:

$$k_T(\mu) = \frac{1-(1+\mu)^{-T}}{\mu} \tag{7}$$

where T – number of years of operation; μ – discount rates.

In addition, we will designate the discounted indicator taking into account the cost of the inverter, will be implemented in 10 years:

$$k_{10+}(\mu) = \frac{(1+\mu)^{10}+1}{(1+\mu)^{10}} \tag{8}$$

The total discount factor for the 20-year life of the equipment at a 10 % discount rate is 8.5, with 5 % it is 12.59 (Fig.1).

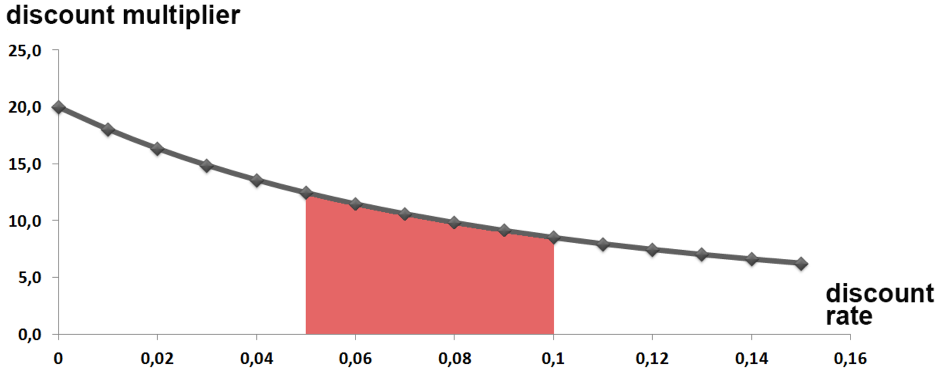

Fig. 1. The integrated discount, depending on the discount rate on the interval of 20 years and the zone of effective use of wind energy (0.05-0.1)
Source: own calculations

This means that the macroeconomic situation in the country significantly affects the performance indicators for local energy supply. If based on the standard definition of the discount rate as the rate of return of a financial instrument with a similar degree of risk, then due to the limited financial instruments on the national market, this can only be the deposit rate on foreign currency deposits, which at the beginning of 2018 belongs to a 2-5 % gap.

From the decision of the problem it follows that the effect of the scale of generation should positively affect the discount profit flow, is given by the objective function (1). A formal confirmation of this fact would be the fulfillment of the condition of growth of the objective function with the growth of production volumes:

$$\frac{dZ}{dw} > 0 \Rightarrow k_T(\mu)(T_y\tau_z - C'(w)) - I'(w) - k_{+10}(\mu)I'_a(w) > 0 \tag{9}$$

It follows that if condition:

$$w > \left(\frac{\eta\psi k_{+10}(\mu)}{k_T(\mu)T_y(\tau_з - c_1) - \gamma}\right)^{\frac{1}{1-\psi}} \tag{10}$$

where the economies of scale will operate and the discount income will grow with increasing capacity and generation volumes. Turning to the resolution of the optimization problem (1) and the constraints (2) the search for a solution, the investor should be satisfied by condition:

$$w > \max\left\{\frac{E_y}{T_y}; \left(\frac{\eta\psi k_{+10}(\mu)}{k_T(\mu)T_y(\tau_з - c_1) - \gamma}\right)^{\frac{1}{1-\psi}}\right\} \tag{11}$$

If the profit grows by the growth of the generation volumes, then there is such a generation volume when the objective function becomes a positive value. The last expression with a fixed green tariff imposes restrictions on the integrated discount and its rate:

$$k_T(\mu)T_y(\tau_з - c_1) - \gamma > 0 \Rightarrow k_T(\mu) > \frac{\gamma}{T_y(\tau_з - c_1)} \tag{12}$$

Substituting the quantitative values of the corresponding parameters in (12), we obtain the limiting value of the integrated discount 8.3 that corresponds to the discount rate of 10.04 % [17]. At a larger rate, the scale effect of generation does not work and investment is not advisable. This allows us to conclude that under the current conditions of macroeconomic instability, all settlements are best done in USD dollars or euros. For settlements in hryvnia, condition (12) will not be realized (the discount rate is significantly higher). Considering the definitions of the discount rate, as the profitability of a financial instrument with a similar degree of risk and the risks of investing in wind energy, the working range of the discount can be considered as an interval of 5 to 10 % [17].

We turn the objective function (1) into a more convenient form, which allows us to distinguish separate components of profit and expenses:

$$Z(w) = -E_y \cdot k_{20}(\mu)(\tau_з - \tau_c) - k_{10+}P_a \frac{E_y d_m}{365} + w(k_{20}(\mu)T_y(\tau_з - \tau_c) - \gamma) - k_{10+}(\mu) \cdot \eta \cdot w^{\psi}$$

If we draw analogies with the equation of a straight line with some slight nonlinearity:

$$Z(w) = \beta_0 + \beta_1 \cdot w + \varepsilon(w) \tag{13}$$

where $\beta_0 = -E_y \cdot k_{20}(\mu)(\tau_з - \tau_c) - k_{10+}P_a \frac{E_y d_m}{365}$,

$$\beta_1 = k_{20}(\mu)T_y(\tau_з - \tau_c) - \gamma$$

$$\varepsilon(w) = -k_{10+}(\mu) \cdot \eta \cdot w^{\psi}$$

A free member β_0 is determined by the cost of acquiring batteries, and fictitious losses due to the fact that own consumption is paid for by a mudflow, not a feed-in tariff. Marginal profit β_1 is determined by the difference between feed-in and network tariffs and an integrated discount. The slight nonlinearity of $\varepsilon(w)$ is determined by the costs of acquiring the inverter, which grow nonlinearity (with a power of 0.3) with an increase in generation power.

To obtain quantitative estimates of the objective function (discount income), we need to determine all the quantitative parameters (13) for the case of wind generation:

$$\begin{gathered} \eta = 0{,}15; \psi = 0{,}3; T_y = 2000; \tau_з = 13 \cdot 10^{-5}; c_1 = 0{,}4 \cdot 10^{-5}; \\ \gamma = 2{,}1; k_{20}(0{,}1) = 8{,}5; k_{20}(0{,}05) = 12{,}5; \\ k_{10+}(0{,}1) = 1{,}39; k_{10+}(0{,}05) = 1{,}61; \tau_c = 6 \cdot 10^{-5}; P_a = 0{,}2; d_m = 5. \end{gathered} \tag{14}$$

As a result of the calculations performed at a 5 % discount rate, we obtain the dependence of the profit on the generation capacity for the indicated annual level of own energy consumption (Fig. 2). Due to the fact that all angles of inclination are the same (independent of their own energy consumption), an illusion of collinearity is created.

The first point of each of the graphs represents losses from local energy supply in the case when the power is sufficient only for own needs. It is not difficult to calculate that, for example, with a consumption of 5000 kWh per year, the discount rate at a tariff of 0.06 USD/kWh will be 3.75 thousand USD for 20 years, while losses from own power supply will amount to approximately 25 thousand. USD The same situation with its own energy consumption of 1000 kWh per year, where the payment for electricity for 20 years is 750 USD, while losses as a result of own power supply are about 4 thousand USD.

That why, without using a green tariff, under current conditions it is hardly worth investing in an autonomous power supply. However, as the generation volumes grow according to the conditions (9.10), the profit increases and at the points of intersection of the X-axis the investor starts to make a profit, is formed due to the absence of expenses for paying for electricity and putting the remainders in the energy system according to the green tariff. At the same time, if a person consuming 1000 kWh invests in a power of 30 kW, then as a result of the operation of the equipment within 20 years, it will receive a profit of 25 thousand USD.

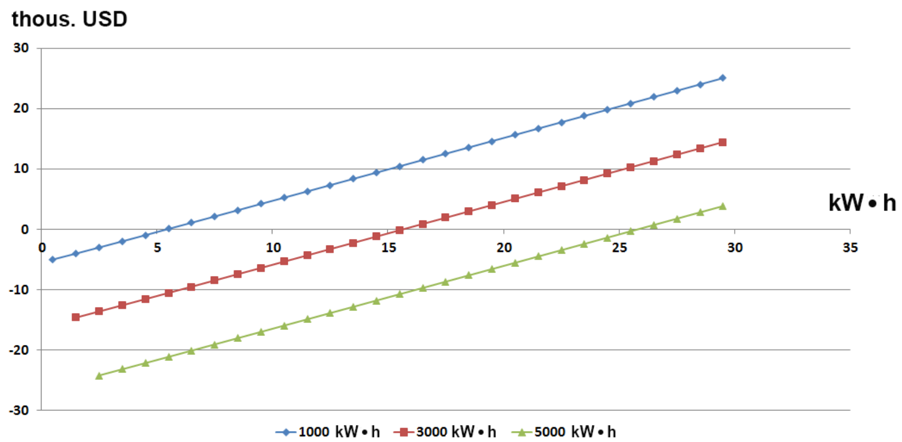

Fig. 2. Revenues from electricity generation over 20 years in case of different levels of own energy consumption (discount rate 5 %)
Source: own calculations

With a maximum generation capacity of 30 kW, the investment volume is from 65 to 75 thousand USD. However, in order to reach the payback level with an annual consumption of 1,000 kWh per year, it is enough to invest 5 thousand USD. When consuming 3 thousand kWh, it is necessary to invest 40 thousand USD, while consuming 5 thousand kWh for 68 thousand USD.

All the above calculations were made at a discount rate of 5 %, but the range of rates at which it makes sense to invest belongs to the 5-10 % gap (Figure 1). Therefore, in order to consider the impact of the discount rate on the payback period of the equipment, we will calculate the objective function with our own annual consumption of 1000 kWh for 5 and 10 % of the discount. The calculations show that for 5 % of the discount enough power of 5.5 kW to the project was profitable, for 10 % of the discount the project does not become profitable when the maximum possible capacity according to the current legislation is 30 kW, that is, the range of discount rates should be reduced to 5-7 %. Of course, it can be approached downward, but with the current macroeconomic situation and the presence of a significant level of corruption, this is hardly possible.

For that reason, it should be concluded that the discount rate has a significant effect on the final result. Since the discount rate depends on the degree of risk of the investment project, the state should first create a condition for reducing the uncertainty of the environment in which the investor operates.

This is primarily a reduction of corruption risks, which is created by local authorities for agreeing on the possibility of energy supply at a green tariff and providing qualified consultations on the specific features of certain types of energy generation. Usually, the level of macroeconomic stability in the country influences the discount rate and although the tariffs are defined in euros, still we receive hryvnia incomes, therefore devaluation processes also affect the risks of investing in renewable energy.

However, already with the Energy Strategy [1] it follows that they will increase, in favor of this is shown by the deplorable state of traditional Ukrainian energy, for example, a significant portion of the nuclear power capacity has already fulfilled its service life and this period has been extended to a maximum of 50 years. No better position for heat and hydropower engineering. Therefore, the increase in tariffs in the future is an inevitable process. The case of the evaluation of the objective function is considered when the tariffs for the population are equal to the European ones; moreover, the investment attractiveness of the project was compared with the usual placement of funds on the deposit.

At first glance, the project guarantees an insignificant annual rate of return: 1.3 % at current tariffs and 1.6 % for European ones, however, if they are compared by the yield generated by the banking system (deposits) at current interest rates (3 % and 4 %) and a discount rate of 5 %, it turns out that the annual return on deposits is negative. Consequently, under current conditions, investing in renewable energy can be considered a financial instrument more effective than saving currency funds on deposits. As for the use of long-term hryvnia investments, there may be a result of devaluation risks (subject to evaluation of the objective function in foreign currency), the discount rate is probably higher than the deposit rate.

The statement of the problem of solar generation is not much different from the presented resolution, it is necessary to make corrections in the number of hours worked, the cost of setting the power, operating costs. Perspective is the direction of diversification of energy supply at the expense of independent sources, which include solar and wind energy. In this case, most likely, the lack of generation will significantly decrease, the project may be cheaper.

Conclusions. Ukrainian energy is in serious condition as a result of almost complete depreciation of equipment of the main sources of electricity supply: nuclear, thermal and hydropower. The main source of electricity in the near future should be renewable energy.

The creation of national renewable energy with a scale of generation of tens of megatons of oil equivalent is possible only at the expense of the country's main investment resource - the money savings of the population.

The created model of the investment project payback in wind energy determines the existence of a sustainable energy efficiency growth scale, depending on the generation volume. At the same time, the range of the discount rate in which investment can result in a positive effect (return on investment in equipment and operating costs) is obtained.

Taking into account the legislative certain maximum generation capacity of 30 kW, it is determined that the maximum own energy consumption at which the payback of the project at 5 % discount is possible is 5.5 thousand kWh, and at 8 % only 2 thousand kWh. This confirms the tremendous impact of macroeconomic stabilization on the efficiency of introducing renewable energy, and perhaps not the advisability of limiting power at 30 kW.

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