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Short Communication

Environmental and Economic Benefits of Using Kinetic Wind Energy to Generate Electricity

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Abstract

This paper examines the use of kinetic energy of the wind to generate electricity in Polish environmental conditions. The aim of the analysis is defining the correlation between chosen environmental and structural factors of a wind power station and the amount of the avoided emissions designated for greenhouse gases and planned economic benefits from realized investments. Wind power stations of the leading world producers were chosen and subsequently they were combined into groups of wind power stations with similar total power. The level and the extent of the noise occurring as a result of work of the complex of power station were calculated. The amount of energy produced in chosen locations was estimated and the avoided emissions of CO_2 were calculated. Considering prices of: tons of carbon dioxide emissions, energy on the market, and green certificates, an economic profitability of investment was calculated.

Keywords: environmental pollution, reduction of atmospheric pollution, renewable energy sources

Introduction

Renewable energy sources are solutions to hold back climate change, to provide global economic growth, and to ensure the security of the energy supply. Climate change can be analyzed by carbon dioxide concentration in the atmosphere, the anomaly of global surface temperature, September Arctic Sea ice extent, land ice variations, and sea level change [1]. According to monthly measurements of global distribution and variation of the concentration of mid-tropospheric carbon dioxide at an altitude range of 3-13 km, carbon dioxide concentration levels have increased by about 11.03 ppm in recent years (up to 395.94 in February 2013) and CO_2 concentrations are at their highest of the last 650,000 years. The global land-ocean temperature index points to a continuous increase in the global surface temperature relative to the base period 1951-80 average temperatures. The change in global surface temperature reached 0.56K (end 2012). Arctic summer sea ice is still declining at an average rate of decrease of 39,800 km^2 per year (more than 10 percent per decade) relative to the 1979 to 2000 average ($6.7\cdot10^6$ km^2). The change in arctic sea ice extent reached $3.61\cdot10^6$ km^2 (September 2012). The land ice mass-loss for the Greenland and Antarctic ice sheets during the last decade accelerated, entailing that the ice sheets share to a sea level increase with time. The sea level change is due to the addition of water from the melting ice and thermal expansion of water. The average sea level in 1993-2012 rose by about 68 mm. The estimated growth reached more than 3.18 mm per year.

In a world of increasing average temperatures, the tendency of escalating severe weather and climate events is expected to continue. Climate change affects human populations [2, 3], the natural environment, the global economy, and the global energy system. Wind energy is now regarded as a significant energy resource whose exploitation has a positive impact on sustainable economic growth throughout the world. The energy of the wind, as the combined kinetic energy of all of the air molecules, is a free and renewable energy resource.

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Table 1. Specifications of wind turbines.

Producer	Turbine Type	Rotor diameter [m]	Hub height [m]	Amount of wind turbines	Sound power [dB(A)]	Total power [MW]
GE Wind	GE 1.5 SL	77	100	7×1.5	103.5	10.5
Vestas	V80-2000	80	100	5×2.0	105.2	10.0
Siemens	SWT-3.6	120	80	3×3.6	106.4	10.8
Enercon	E82/2000	82	98	5×2.0	104.0	10.0
Suzlon Group	S.66/1250	66	74.5	8×1.25	104.9	10.0

Problem Formulation and Solution

Wind turbines (Table 1) impact the environment by polluting the landscape with inadequate locations, danger to birds, shadow casting, or unwanted sound. In the analysis the effect of unwanted sound on the environment was taken into account. Distance from the power station, in which the level of noise drops below the assumed maximum value, was counted. The equivalent continuous A-weighted downwind sound pressure level was calculated according to [4].

The quantities of energy produced for the entire scope of the speed in which analyzed wind power stations work were estimated. The power of each wind speed with the probability of each wind speed from the Weibull graph were multiplied and wind energy at different wind speeds was achieved. For the power station which out of chosen models got the maximum value of the energy production, the quantities of energy possible to get at the same average speed but other boundary layer were estimated [5]. Next, the annual gross avoided GHG emission for all analyzed power stations was estimated.

The ecological effect which was reducing the amount of pollutants released into the atmosphere during investments was described. Analyzing the power curves and the amount of energy produced annually in the given location, the power station that best adapted to the location was chosen [6, 7].

The economic effect for chosen location of wind power station, for chosen period of time based on the average hourly wind speed, and the quantity of generated energy was counted. Taking into account the market price of 1MWh, the profits from the sale of produced energy were counted and the additional advantages coming from discontinuing certificates of origin of the energy (green certificates) and from the sale of avoided CO_2 emissions were added.

Research Results

As the analysis shows (Figs. 1 a and b), at a distance above 350 m the maximum noise level from wind turbines in general is below 45 dB(A) (41.6-44.5 dB(A)) outdoors, which is comparable to noise of normal living with radio in a background 45 dB(A) or bird calls 44 dB(A). Comparing the noise level for two power stations with 5 rotor diameters between one another, the noise level between them does not decrease below the noise of normal living; however, at a distance of 400 m from the side power station calculated sound pressure levels reach the value of 40 dB(A), which may be compared to a quiet library or to urban ambient sound (Fig. 1c).

An important element of selection of the complex of power stations is the analysis of local climate conditions. Taking into consideration this parameter and comparing it with the power station characteristic, it was found that the quantity of energy produced from different types of power stations for identical wind conditions vary up to about 20% (Fig. 1e). The average wind speed in areas with different surface shape indicates the possibilities to produce energy. For the same average wind speed about 50% energy more can be obtained on the urban areas than on the flat areas (Fig. 1f). Analyzing gross avoided GHG emission conducted for a Rayleigh distribution it was noticed that depending on the power plants adjustment to wind conditions the gross avoided GHG emission may vary up to 20% (Fig. 1d).

Analyzing the power graph, the shape of a curve was noticed. The curve prefers power stations obtaining higher powers at lower wind speeds for analyzed location (Fig. 2b). Analyzing the amount of energy produced annually, it may vary by as much as 20% in extreme cases of analyzed plants (Fig. 2c). Gross avoided GHG emissions were compared for various eliminated non-renewable energy sources. For the conversion of coal $9.2\times10^3 t_{CO_2}$ was obtained, while for the CHP $8.9\times10^3 t_{CO_2}$ was obtained, which is a measurable environmental effect of a functioning system (Fig. 2a).

The type of wind turbine, wind turbine working conditions, and energy price influence the economy of investment. For:

- Average wind speed distribution for chosen locations for a select period of time (Fig. 2e)
- Price of energy on energy stock exchange (Fig. 2f)
- Price of CO_2 allowances (CO_2e-reduction certificates) on the spot market equals 4,52€/t_{CO_2} (April 2, 2013, KOBiZE–PL)
- Price of green certificates that are traded separately from the energy produced, equal 29,07€/MWh (April 9, 2013, PMOZE_A)

the analyses were conducted (Fig. 2d). Almost 73% of energy was obtained from 9 a.m. to 6 p.m., which corresponds with the highest prices for energy on the energy market. The total economical effect in the most beneficial power station working hour, which is best suited to wind conditions, is 68.5€, while the total economic effect for 24 hours work of the power station complex is up to 700 €.

Results and Discussion

World energy production, as well as consumption in the last decades, have been growing rapidly but supplies of fossil fuels are diminishing. Such circumstances have led to exploration of renewable energy sources and, as a result, caused the development of new technological processes of energy production [8, 9]. A vital issue was evaluating the suitability of renewable energy production with respect to various principles [10, 11]. On a global scale, the criterion might be greenhouse gas emissions and temperature changes in the atmosphere. On a local scale, the impact of noise pollution and the economic viability of the project could be indicated. Climate and temperature are often omitted in the analysis because of the difficulty in assessing their influence on the quality of life. However, issues related to climate change are worth studying, especially at the local level, where one can see their impact on quality of life of inhabitants [12-14]. The amount of greenhouse gases and temperature are interrelated. The phenomenon of rise in temperature is a factor that should be carefully monitored and taken into account in the overall assessment of living conditions of the population. The increased temperature and areas in which the negative influence of people is more noticeable affects negatively on the functioning of society [15]. Thus, a lower quality of life, and increased mortality is expected in areas of higher temperature. This is confirmed by a study on the quality of life in higher temperature conditions [16-18]. The results presented in publication show that there is a correlation between the use of renewable energy sources and avoided GHG emissions into the atmosphere, which could affect climate change, as well. A wind turbine properly fitted to the local climate conditions can reduce local CO_2 emissions up to 25% in comparison to worse solutions [19, 20].

Electricity production is associated with impurities delivered to the water, soil, and air. Furthermore, areas of abandoned exploitation of energy resources are recovered for the society for years [21]. Any activities in a number of cases are negative [22-25], especially in the initial phase of their implementation. Therefore, the main priority should be rational use of brownfield sites as new spatial and environmental elements [26]. In order to prevent the need for restoration of areas degraded by the energy industry, a good practice is to use non-invasive environmental sources of renewable energy [19, 20].

Areas where energy demand is observed are mainly regions where industry is rapidly growing. Industrial processes, fuels used for heating, and power plants are the

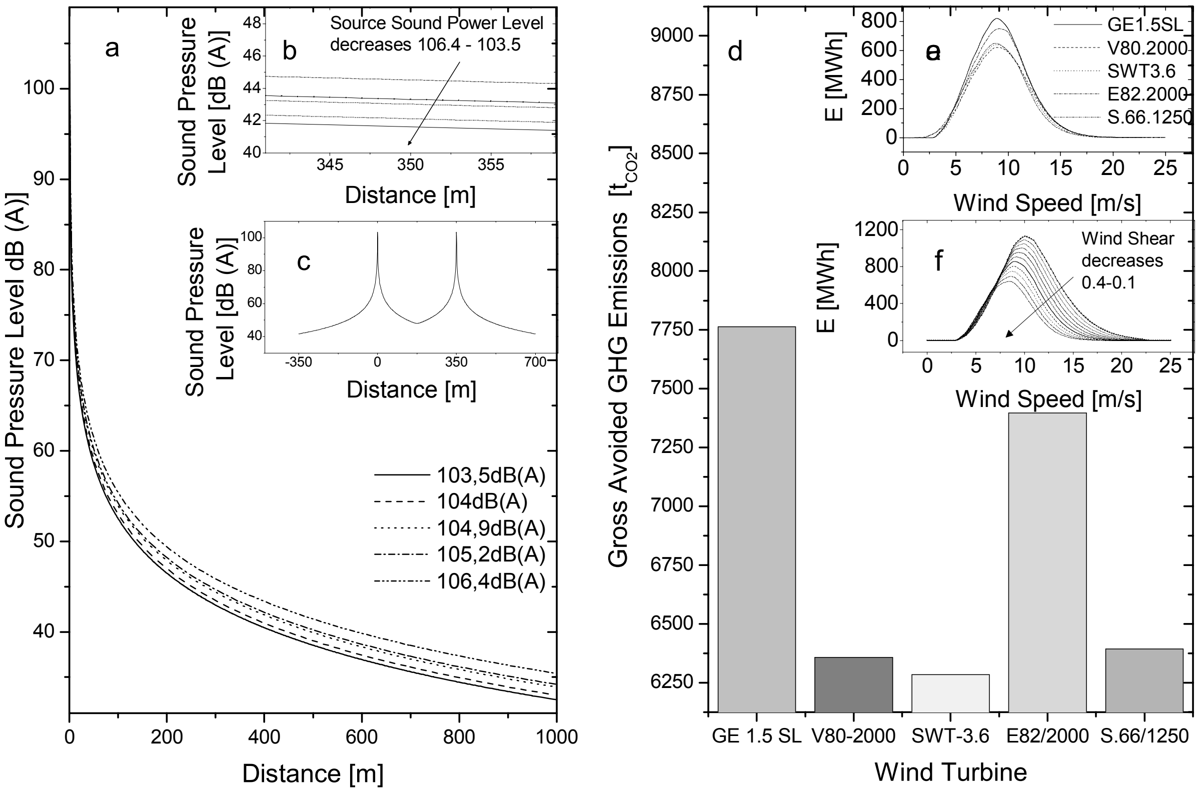

Fig. 1. Damping of sound pressure level with distance for analyzed wind turbines (a). Decrease of sound pressure level with distance in a free field at range of distance 340-360 m (b). Changing of sound pressure level vs. distance between two wind turbines (c). The gross avoided GHG emission for various wind power plants (d). The quantity of energy produced from different types of wind turbines for identical wind conditions (e). The quantity of energy produced for a wind shear range 0.1-0.4 (f).

primary source of sulphur oxides (SO_x) [27]. Sulphur dioxide (SO_2) represents an important share of the oxides of sulphur, which relate to the burning of fossil fuels [28-30]. Other most common air pollutants (carbon monoxide (CO), nitrogen oxides (NO_x), hydrogen sulphide (H_2S), and ozone) in addition to effects related to human impacts on the natural environment are often assessed for their impact on public health, as well [31-33]. Epidemiological research highlights relationships between exposure to air pollution and cardiovascular disease [34, 35]. There are biological mechanisms linking air pollution with cardiac disease [36, 37] and pregnancy-induced high blood pressure, which is a major cause of maternal mortality [38, 39]. Therefore, the use of wind turbines is an ideal alternative to avoid locally introducing contaminants into the atmosphere and thus prevent presented hazards [7, 20].

Noise is an important ecological problem for society. Compared to other pollutants, control of environmental noise levels was not implemented for a long time because of the lack of adequate knowledge about its impact on people [14]. Noise negatively affects children's learning and memory. A higher incidence of ischemic heart disease is the effect of noise pollution [40], the impact of noise on the quality of sleep is a major cause of headaches, high blood pressure, dizziness, and somnolence [41]. Assessment of noise pollution is so important that it has become an international issue [42] and in recent years the problem of noise pollution has gained worldwide attention [43]. Considering the results of the study on noise pollution effects, it seems that noise pollution is related mostly to construction parameters of wind turbines. The diameter of a wind turbine rotor and height of tower of the wind turbine, which are generally connected with nominal power and energy produced by a wind power plant, were predominantly the reasons for noise production in the surroundings of a wind farm. Fortunately, the noisier power plants are typically characterized by higher power, so in order to obtain the desired power produced by a group of wind turbines, noisier wind turbines are fewer and occupy less space. Furthermore, old construction, poor maintenance, and bad service habits might contribute to increased noise pollution, as well [7].

One of the most important factors in energy production is economic efficiency, which depends on investment costs, costs of operating a plant, and optimum energy production. For the analyzed location and period of time, the useful wind conditions corresponded with the high energy price on the marketplace [7, 20].

Conclusion

Getting the right place for the location of wind turbines can result in success or failure of the investment. Larger turbine spacing produces more energy, but also comes with a wider range of noise. Noise pollution is emerging as an environmental problem in locations close to wind turbines. It can cause negative impact on public health and welfare. For the analyzed wind power stations the noise pollution to the level of quiet rural residential area with no activity (about 45 dB(A)) reaches the distance of about 350 m from the furthest power station, regardless of the type and amount of power station.

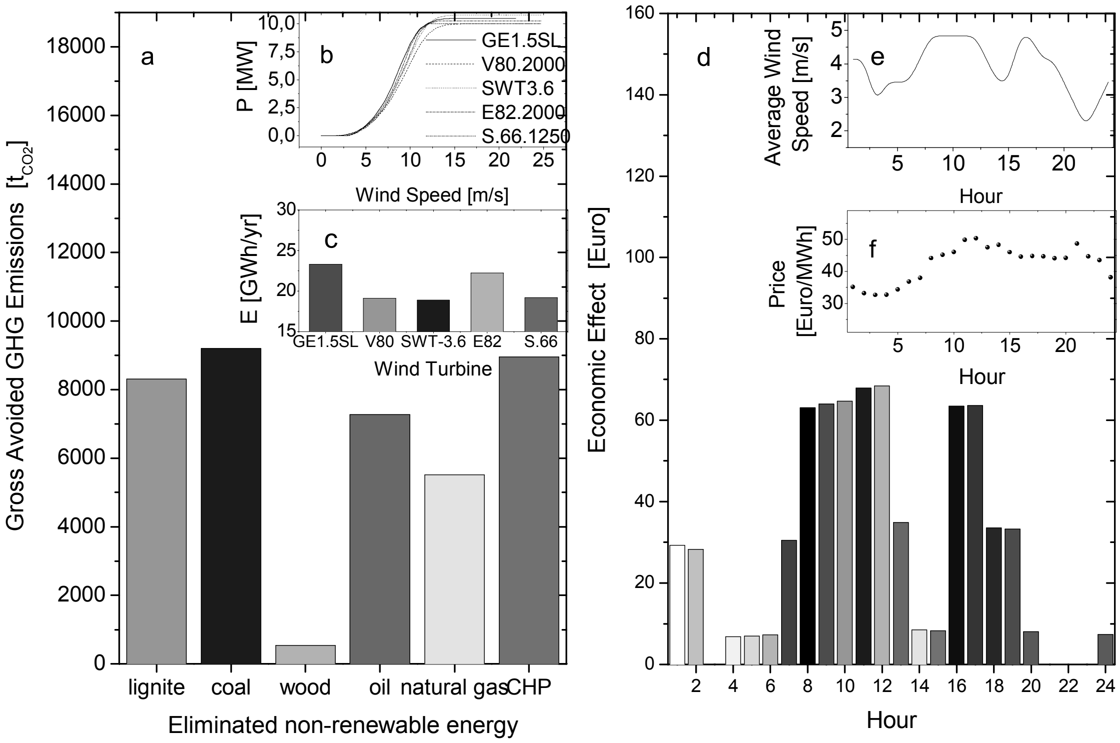

Fig. 2. Environmental effects of a functioning system (a). Power curve of analyzed wind power plants (b). The amount of energy produced annually by power plants (c). Economic effect of a wind turbine for a select period of time (d). Average wind speed distribution for chosen location (e). Price of energy on energy stock (f).

Improvement in air quality associated with increasing the use of renewable energy sources results in a reduced amount of GHG in the atmosphere. The ecological effect, assigned to the projects connected with the use of renewable energy, is the amount of avoided emission that was calculated in relation to one year on the base of annual amounts and types of eliminated renewable energies and adopted respectively for their emission rates associated with the type of energy. The calculations clearly show the measurable benefits for the environment.

The economic effect is dependent on energy prices and wind conditions. For an analyzed location of a power plant the analyzed period of time and beneficial wind conditions coincide with the high energy prices on the market.

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