Economic analysis of small wind turbines

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ABSTRACT: The paper analyzes the market of small wind turbines from the economic point of view. The analysis judges an investment in wind energy on the basis of different economic indicators, such as Simple Payback (SPB), Net Profit Value (NPV) and Internal Rate of Return (IRR). Selected turbines from the European and Polish market were picked. The rated power of a wind turbine up to 10 kW was established as the main criterion for the selection. Calculations of the tip-speed ratio and power coefficient and a comparison with the wind resource reference data are presented. On the basis of these considerations, economic effectiveness study is performed via an estimated profit income from the turbine purchase.

KEYWORDS: wind turbine, investment, Renewable Energy Source (RES), renewables, economic efficiency

1. Introduction

28 wind turbines available in the European Union were analyzed, each with a nominal power of up to 10 kW on the target market sector of micro to small wind turbines [1]. For each turbine, the following steps were performed:

- calculation of the turbine power coefficient and tip-speed ratio at nominal conditions,
- re-creation of the power curve,
- energy-based cost calculation according to the defined Weibull distribution of the wind.

In Table 1, values of the power coefficients $C_p = 2P_{rated}/(\rho v^3 \pi R^2)$ and the tip-speed ratios $\lambda = \Omega R/v$ for each analyzed turbine can be found (v – rated wind speed, P – rated power, ρ – air density, R – rotor radius, Ω – nominal rotational speed). The devices were divided into 3 groups: vertical axis wind turbines (VAWT), horizontal axis HAWT, and diffuser augmented turbines DAWT. The columns 'C_p' and 'λ' present the results of calculations based on rotor geometry, turbine rated power and rated wind speed.

2. Energy efficiency calculations

The obtained data were plotted in Fig. 1 to compare the performance. The most efficient VAWT turbines are as follows: Winddam 2 kW, Winddam 4 kW and Turby 2.5 kW. The first two turbines are produced in the United Kingdom and are examples of the modified H-rotor. Turbine Turby 2.5 kW, produced in the Netherlands, may be considered as a Darrieus type turbine. Among HAWTs, the ducted SMT3 turbine, made in Poland on the United States license, undeniably reached the best performance. Its high C_p is a consequence of the adopted formula, where the rotor swept area is used rather than the maximum cross-section of the diffuser outlet. The three-bladed turbine WES5 Tulipo is another notable device.

In the next step, the power curves allowed one to estimate the amount of electrical energy produced by the analyzed turbines during one year of operation. The results are based on the aggregated energy production obtained with Weibull's distribution for local wind speeds. The wind data set came from the meteorological station at the Lodz-Lublinek airport, located at the height of 10 m above the ground [2].

Table 1. Characteristics of the selected turbines [1]

Code	Type	# bld's	Name and nominal power (in kW)	C_p	λ
1V	VAWT	6	Venturi VAWT 0,5	0,166	2,72
2V	VAWT	2	Ropatec VAWT 0,75	0,199	1,96
3V	VAWT	2	Windside VAWT 1	0,071	1,16
4V	VAWT	5	Winddam DVAWT 2	0,377	1,21
5V	VAWT	3	Turby VAWT 2,5	0,287	0,265
6V	VAWT	6	WindWall VAWT 2,9	0,418	0,177
7V	VAWT	5	Ecofys VAWT 3	0,331	0,207
8V	VAWT	2	Ropatec VAWT 3	0,251	1,48
9V	VAWT	3	Winddam DVAWT 4	0,377	2,23
10V	VAWT	2	Ropatec VAWT 6	0,251	1,36
11V	VAWT	2	Windside VAWT 8	0,139	1,57
1H	HAWT	5	Eclectic HAWT 0,4	0,171	4,32
2H	HAWT	2	Fortis Espada HAWT 0,8	0,128	8,22
3H	HAWT	3	Sviab HAWT 0,75	0,147	10,47
4H	HAWT	2	Travere HAWT 0,9	0,332	9,42
5H	HAWT	3	Fortis Passaat HAWT 1,4	0,074	7,91
6H	HAWT	2	Travere HAWT 1,6	0,332	10,05
7H	HAWT	3	NHEOwind HAWT 2	0,311	2,14
8H	HAWT	2	Travere HAWT 2,1	0,242	17,3
9H	HAWT	3	Tulipower HAWT 2,5	0,213	3,66
10H	HAWT	3	WES HAWT 2,5	0,346	4,31
11H	HAWT	2	Travere HAWT 3	0,284	8,64
12H	HAWT	3	Iskra HAWT 5	0,273	5,14
13H	HAWT	2	Travere HAWT 5,5	0,324	7,54
14H	HAWT	3	Fortis Montana HAWT 5,6	0,097	6,93
15H	HAWT	3	Aircon HAWT 10	0,316	4,39
16H	HAWT	3	Fortis Alize HAWT 10	0,251	9,16
D	DAWT	3	SMT3 DAWT 3	0,697	3,53

On the basis of the measurements conducted between 01/2010 and 09/2015, daily from 7am to 7pm, an averaged wind speed was 3.6 m/s. The value was cross-checked against source [3], where 3.4 m/s was reported. As a result, the arithmetic mean of 3.5 m/s was used.

The data helped to draw a wind histogram, next approximated by the Weibull distribution function [4]:

$$f(v, A, k) = \frac{k}{A}\left(\frac{v}{A}\right)^{k-1} - e^{-\left(\frac{v}{A}\right)^{k}} \quad (1)$$

where f(v, A, k) – wind speed probability, v – wind speed, A – scale parameter, k – shape coefficient. As a result, the following values were determined: k = 2 and A = 3.95.

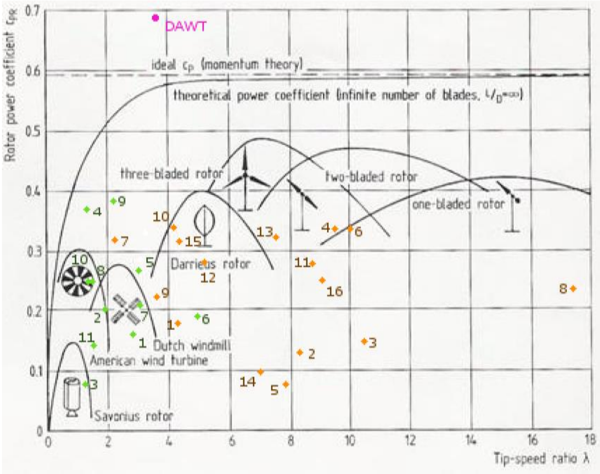


Fig. 1. C_p=f(λ), graph for turbines from [1]

A detailed economic analysis was conducted only for 7 selected turbines (D, 2H, 10H, 12H, 1V, 5V, 8V, ref. to Tab.1). They vary in design, price and performance. In order to enrich the investment analysis, also wind turbines available on the Polish market were added: Aerocopter 450, HWT3000, Zefir D7-P5-T10, SWT-7-pro.

3. Economic Profitability Calculations

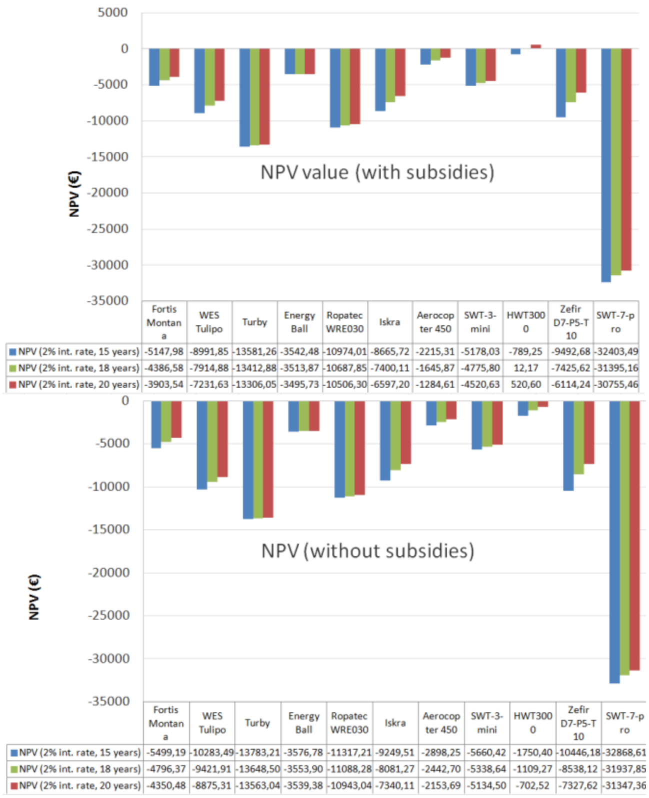
The analysis is conducted for an investment considered by an energy consumer who wants to produce electricity from wind energy to supply own household and/or sell generated electrical energy to a wholesaler. The consumer accepts initial costs connected with the purchase and installation of the turbine, but later, during its operation time, only small repairs or an inverter replacement are permissible (the O&M costs are accumulated yearly).

The turbine lifespan is an important factor to consider. Many sources estimate it to be 20 years, on the condition that routine maintenance would be provided every six months. For this analysis, also other scenarios: 18 and 15 years were assumed.

All prices of non-domestic wind turbines come from the report prepared by an international consortium [5]. Prices of wind turbines available in Poland come from the companies' websites or from direct contact with their distributors. In order to make such an analysis possible, all prices were recalculated into Euro, basing on the average rate of exchange (1€ = 4.20 PLN) relevant as of Nov. 2015.

SPB calculations required the cost of the electrical energy in Poland. These data were taken from the Eurostat database: retail price of electrical energy in 2014 was 0.1428 €/kWh. A variant with subsidized help was also prepared on the basis of the Polish Government bill *Law on Renewable Energy Sources* [6]. It assumes that electricity wholesalers in Poland are forced to buy electrical energy from the prosumers at the prices predetermined by the regulatory office. The legislator established two groups of wind energy installations: up to 3 kW with subsidies reaching 0.1786 €/kWh and installations from 3 to 10 kW with subsidies up to 0.1548 €/kWh.

To conserve space, only the results of NPV analysis are presented in Fig. 2. The calculations are based on the realistic 2% discount rate, understood as a factor by which the value of the invested money will change yearly during the investment horizon.



	Fortis Montana	WES Tulipo	Turby	Energy Ball	Ropatec WRE030	Iskra	Aerocopter 450	SWT-3-mini	HWT3000	Zefir D7-P5-T10	SWT-7-pro
NPV (2% int. rate, 15 years)	-5147,98	-8991,85	-13581,26	-3542,48	-10974,01	-8665,72	-2215,31	-5178,03	-789,25	-9492,68	-32403,49
NPV (2% int. rate, 18 years)	-4386,58	-7914,88	-13412,88	-3513,87	-10687,85	-7400,11	-1645,87	-4775,80	12,17	-7425,62	-31395,16
NPV (2% int. rate, 20 years)	-3903,54	-7231,63	-13306,05	-3495,73	-10506,30	-6597,20	-1284,61	-4520,63	520,60	-6114,24	-30755,46

	Fortis Montana	WES Tulipo	Turby	Energy Ball	Ropatec WRE030	Iskra	Aerocopter 450	SWT-3-mini	HWT3000	Zefir D7-P5-T10	SWT-7-pro
NPV (2% int. rate, 15 years)	-5499,19	-10283,49	-13783,21	-3576,78	-11317,21	-9249,51	-2898,25	-5660,42	-1750,40	-10446,18	-32868,61
NPV (2% int. rate, 18 years)	-4796,37	-9421,91	-13648,50	-3553,90	-11088,28	-8081,27	-2442,70	-5338,64	-1109,27	-8538,12	-31937,85
NPV (2% int. rate, 20 years)	-4350,48	-8875,31	-13563,04	-3539,38	-10943,04	-7340,11	-2153,69	-5134,50	-702,52	-7327,62	-31347,36

Fig. 2. NPV values of the wind turbine investments

4. Summary

To ensure profit, the NPV should be higher than zero and higher than NPVs of other competing projects. None of the non-subsidised investments fulfils this basic criterion. On the other hand, when the electricity production is subsidised, only one investment turns profitable (the purchase of HWT3000). However, it is waived only for 18 and 20 years of turbine lifespan. Shall the discount rate be increased, the NPV will be lower. This effect can be technically leveraged by increasing grid energy prices in the analysed time horizon. In the calculations presented herein this was not taken into account, thus presenting a rather conservative look on the issue. SPB and IRR simulations have proved to give similar results.

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