TECHNO-ECONOMIC ANALYSIS OF THE WIND PARK *BOGDANCI* IN THE REPUBLIC OF MACEDONIA

by

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Wind energy as a renewable energy source with the highest growth rate in the last two decades, is considered as a very important source of electricity for the future. The forecasts for development of wind energy are highly optimistic and state that this type of energy will be really important in the future. Following recent data and analysis from certain studies, the share of wind energy in the global world electricity generation in 2020 is estimated to reach 12%. In the same context, and in order to reduce high dependence on fossil fuels, Macedonian government took some steps to introduce and enforce utilization of renewable energy sources. First wind park with capacity of 36.8 MW, installed and operated by the state-owned electricity producing company (JSC Macedonian Power Plants – ELEM), started with operation in April 2014, on a location near Bogdanci. The techno-economic analysis regarding its performance in terms of investment costs, operation and maintenance costs, electricity production and return on investment period, considering valid feed-in tariffs for wind energy production in the country is also presented in the article.

Key words: *wind energy, investment costs, electricity production*

Introduction

Wind, or kinetic energy of air-flow, has been used in transport, industry or agriculture for thousands of years. The rise of modern wind turbines, which harness this energy and turns it into electricity, is a story of scientific and engineering skill coupled with strong entrepreneurial spirit. Wind power continues to expand worldwide, reflecting the reduced cost of turbines, expanding policy support and growing investor recognition of the positive characteristics of wind generation [1].

Global installed wind-generation capacity on-shore and off-shore has increased by a factor of more than 70 in the past two decades, jumping from 7.5 GW in 1997 to almost 540 GW by the end of 2017.

With its geographical location, Macedonia has plenty of Sun, wind and other natural resources needed to produce a renewable energy. In the eastern parts of the country, 130 to 170 days per year are windy, with wind speed averaging 3.5 m/s. Macedonia can theoretically secure 7% of its annual electricity needs by utilizing wind as a source. To reduce the high dependence on fossil fuels that reaches 80% of total electricity production in the country, as well

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as to reduce impact on climate change and prevent environmental pollution, Macedonian Government took some steps in the direction of renewable energy utilization. Based on the Preliminary Atlas of winds for Republic of Macedonia prepared by AWS Truewind in 2005 [2], four measuring stations with high-quality testing equipment at four different locations with sufficient wind energy potential were installed.

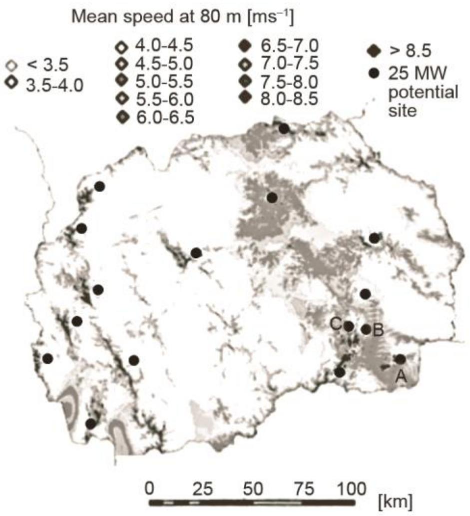


Figure 1. Map of most favorable locations for building of wind farms in the Republic of Macedonia; A – Bogdanci, B – Miravci, C – Davidovo [2]

With the preparation of the feasibility study completed in 2010, information on physical characteristics, economic and financial feasibility, environmental, social, and other impacts of the wind farm project were obtained [3].

In April 2014, the first wind park installed and operated by the state-owned electricity producing company (JSC Macedonian Power Plants – ELEM), started with operation on a location near the town of Bogdanci, location A in fig. 1.

According to the Strategy for utilization of renewable energy sources (RES) in Republic of Macedonia till the year 2020, Energy Law, and the Decision of the Energy Regulatory Commission of the Republic of Macedonia, projected installed capacity at four most favorable locations in the Republic of Macedonia varies from 20 MW to 30 MW per location, with the maximum planned installed capacity of wind power plants in the electric power system is from 150 to 180 MW, with expected annual electricity production ranging from 300 to 360 GWh [4, 5].

Installed wind power capacity in the world

The share of RES within the global power generation mix has been growing quickly since the end of the 2000s. In 2016, the share of wind and solar power electricity generation reached 5.66% of the world's electricity generation, representing 14.3% growth compared to 2015 [6].

In 2017, China led the expansion of new wind power installations with installed capacity additions of 19.5 GW, followed by the USA with 7.0 GW and Germany with 6.6 GW [7]. International Renewable Energy Agency in its report REmap 2030 has indicated that out of the total electricity production in 2030, estimated at 37 thousand TWh, wind energy will account for 12%, *i. e.* 4.4. thousand TWh [8].

Total cumulative wind power capacity installed in Europe by the end of 2017 was 178.096 GW with a share of EU-28 countries of about 168.7 GW (Germany – 56.132 GW, Spain – 23.170 GW, UK – 18.872 GW, France – 13.759 GW, Italy – 9.479 GW, Turkey – 6.857 GW, Sweden – 6.691 GW, Poland – 6.397 GW, Denmark – 5.476 GW, Portugal – 5.316 GW, The Netherlands – 4.341 GW, Ireland – 3.127 GW, Romania – 3.029 GW, Belgium – 2.843 GW, Austria – 2.828 GW, and the rest of Europe (Bulgaria, Cyprus, Czech Republic, Estonia, Finland, Faroe Islands, Macedonia, Hungary, Iceland, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Norway, Romania, Russia, Serbia, Switzerland, Slovakia, Slovenia, and Ukraine) – 9.786 GW. Wind energy covered 11.6% of EU electricity demand in year 2017 [7].

Total installed wind power capacity in the world, by the end of year 2017 was 539.581 GW. In fig. 2, global cumulative installed wind capacity in the world from 2001-2017 is shown.

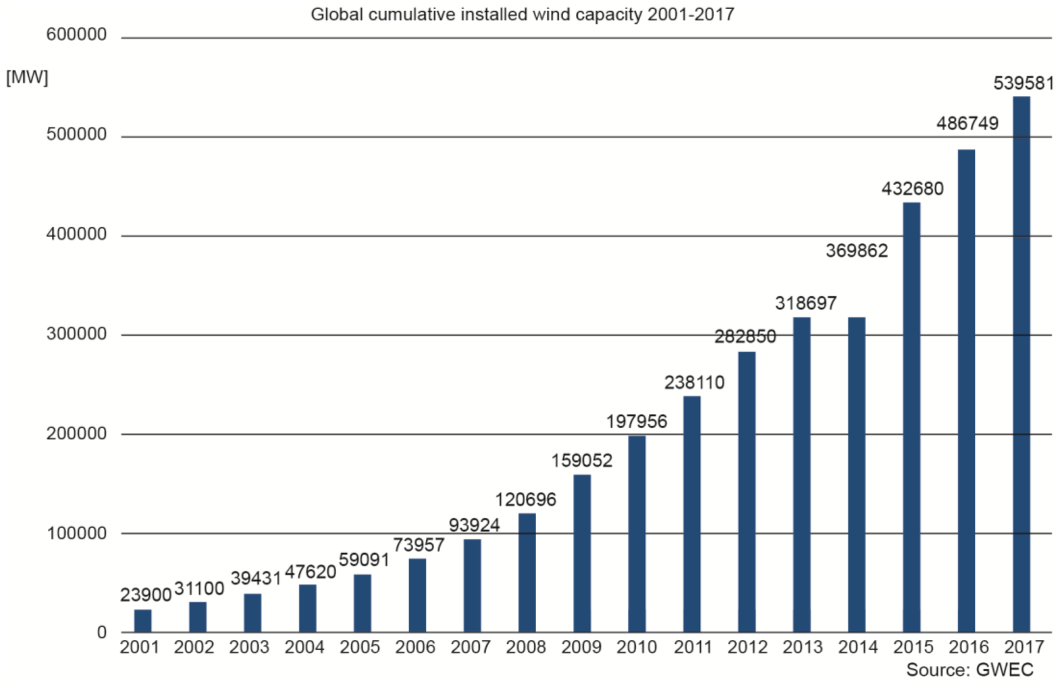
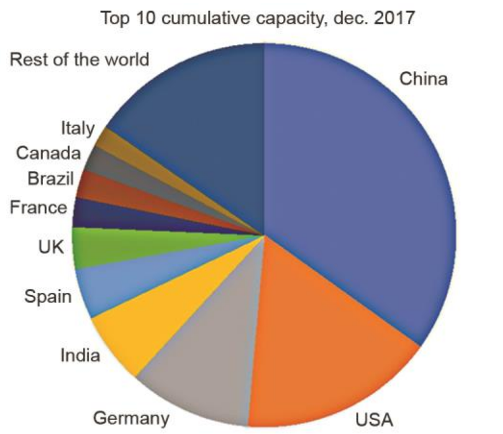


Figure 2. Cumulative wind power installations in the world from 2001-2017 [7]

By the end of 2017, China remained in the world with the largest cumulative capacity of 188.232 GW or share of 34.9%, followed by the USA with 89.077 GW (16.5%), Germany with 56.132 GW (10.4%), India – 32.848 GW (6.1%), Spain – 23.170 GW (4.3%), the UK – 18.872 GW (3.5%), France – 13.759 GW (2.5%), Brazil – 12.763 GW (2.4%), Canada – 12.239 GW (2.2%), Italy 9.479 GW (1.8%), and the rest of the world with 83.008 GW or share of 15.4%, fig. 3. It can be concluded that the cumulative capacity of top ten countries by the end of December 2017 reached share of about 85% (or 456.572 GW) of the total installed wind capacity in the world. At the same time, top ten countries participated with approximately 89% in the new wind power installations in the world for year 2017. Europe installed 16.8 GW (15.6 GW in the EU) of additional wind power capacity in year 2017, marking a record year on annual installations. With a total net installed capacity of 169 GW, wind energy remains the second largest form of power generation capacity in Europe, closely approaching gas installations [9].

If we consider wind power installations in the region, Turkey has, by far, largest installed cumulative capacity of 6.857 GW followed by Romania with 3.029 GW, Greece with 2.651 GW, Bulgaria and Croatia with 691 MW and 613 MW, respectively. In this regard, Macedonia with its wind power installations of 36.8 MW stands better than its neighbors (Serbia – 18 MW; Albania and Kosovo without any installations) and manages to cover 1.6% of its average annual electricity demand [9].



Source: GWEC

Country	MW	%Share
China	188232	34.9
USA	89077	16.5
Germany	56132	10.4
India	32848	6.1
Spain	23170	4.3
UK	18872	3.5
France	13759	2.5
Brazil	12763	2.4
Canada	12239	2.2
Italy	9479	1.8
Rest of the world	83008	15.4
Total top 10	456572	85
World total	539581	100

Figure 3. Top ten cumulative installed capacities by December 2017, worldwide [7]
(*for color image see journal web site*)

Installation, operation and maintenance costs of wind power

Installation costs together with operation and maintenance (O&M) costs are the main elements of electricity production cost from wind energy. For onshore wind, turbine costs dominate, while the rotor blades and tower account for nearly half of the total cost of a turbine. Major factors in reducing the levelized cost of electricity (LCOE) for wind power are larger turbines and large-scale installation of wind farms. The LCOE, also known as levelized energy cost, is the net present value (NPV) of the unit-cost of electricity over the lifetime of a generating asset [10]. Since larger turbines harness strong wind at higher altitudes, they produce more electricity per unit of installation area, thereby reducing both the number of turbines and the land area needed per unit of output. Large-scale installation of wind farms increases the economies of scale and reduces costs for transport, installation and O&M. For onshore wind, the regional weighted average installed cost in 2014 was between 1128 € per kW and 2018 € per kW. The O&M costs typically account for 20-25% of the LCOE for onshore wind, ranging from 0.0044 € per kWh to 0.022 € per produced kWh*, tab. 1, [1].

Table 1. Capital cost for onshore wind power systems

Cost share	On shore [%]
Wind turbine	64-84
Grid connection	9-14
Construction	4-10
Other capital	4-10

Techno-economic analysis of operation of the first wind park in the Republic of Macedonia

In order to obtain more realistic picture of the true wind energy potential, and also to stimulate broader support for the development and use of the RES in the Republic of Mace-

* Calculations are made in accordance with average exchange list of $ *vs.* € at National Bank of the Republic of Macedonia on 23.03.2018.

donia, further research and measurements on determined locations are required [11]. Thorough financial analysis is also required in order to estimate profitability of such locations in terms of wind power utilization [12].

Preliminary Atlas of winds determined that the best wind resources in Macedonia are on the mountain tops, whereas on the plains and in the valleys, wind has lower average velocity. Nevertheless, the hills along the river Vardar, in the area between the towns of Kavadarci and Gevgelija (southeastern and south-central part of Macedonia), prove that even areas with lower altitude have potential for wind resources. The average velocity of the wind in this area is 7-7.5 m/s on an altitude of 500-800 meters above sea level. Considering the measurements performed and previous meteorological data regarding winds blowing in this area, including wind rose, fig. 4, location for the first wind park was determined.

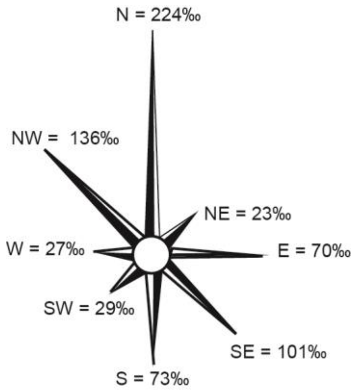


Figure 4. Wind rose for the chosen location [3]

In 2013, state owned electricity production company ELEM, started to build the first wind farm near the city of Bogdanci.

Considering the available financial resources of the company, it was agreed that the wind park will be installed in two phases:
- first phase with installed capacity of 36.8 MW and net annual production of 90 GWh and
- second phase with additional capacity of 13.8 MW and additional net annual production of 33 GWh.

For this purpose, a total of 16 wind turbines, each with installed capacity of 2.3 MW were installed, in order to achieve a total nominal capacity of 36.8 MW, which was expected to generate a total of 90 GWh per year. The layout of the wind farm consists of a total of 22 wind turbines which are oriented in one line, following the highest parts of the ridge. The layout of the complete wind park (with 22 turbines) is shown in figs. 5 and 6 [3].

Most important technical characteristics of installed wind turbines, type Siemens 2.3 MW-Mk II are shown in tab. 2. Each turbine is mounted on conical steel pillar, 80 m high, fig. 6.

According to the wind map and measured values of wind speed at four locations, projected installed capacity by location, varies from 20 MW to 30 MW. On the other site, measured data in Macedonia shows that the effective factor of wind farm with installed capacity of 30 MW is between 0.13-0.25. This means that expected annual generation of wind power-park with average installed capacity of 25 MW ranges from 30 GWh to 55 GWh [4, 13]. It should be emphasized that from the beginning of the operation of wind park *Bogdanci* (excluding the trial year 2014), estimated production of electricity was exceeded by 12.5% on average, thus providing justification for the realization of the second phase, but also for implementation of similar projects near Bogdanci or other areas with wind abundance in Macedonia. In meantime, ELEM acquired software for wind energy project design and planning windPRO [14], for analysis of data regarding wind direction and speed, obtained from measuring stations .

Investment costs and financial analysis of the project

Instead of the planned 95.544 GWh, electricity generation reached 120.768 GWh in 2015, which is 26.40% more than planned. In 2016, electricity production was 109.483 GWh, *i. e.* 5.43% more than planned 103.848 GWh for that year [15]. Electricity production from the wind park reached 110.480 GWh in 2017 surpassing the planned 104.528 GWh for around 5.69%, tab. 3, fig. 7, [16].

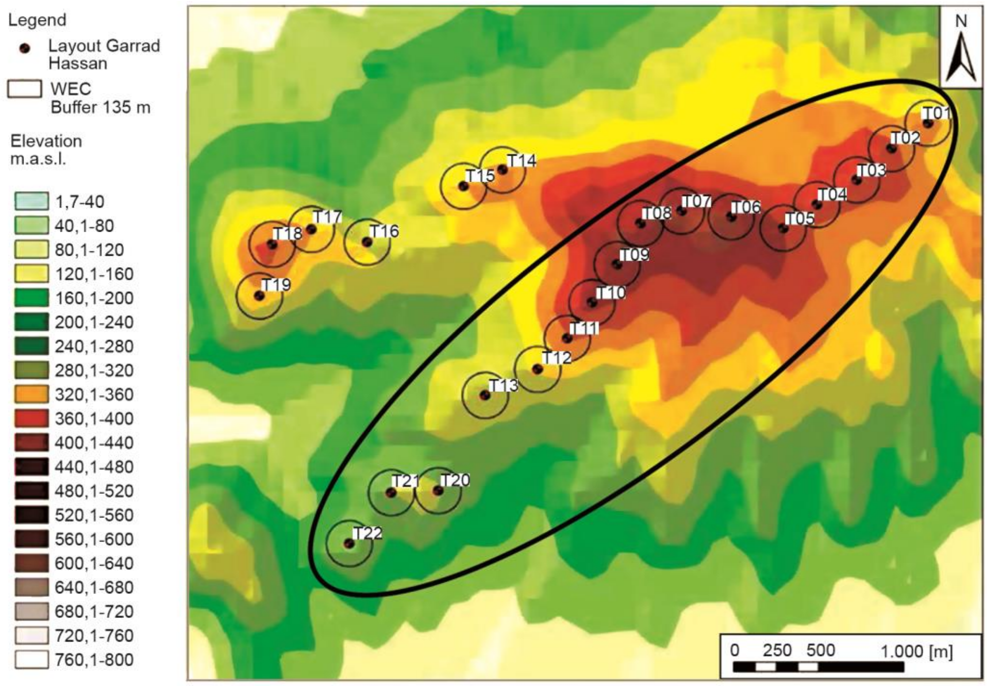


Figure 5. Layout of turbines for the complete wind park (marked locations show installed turbines in first phase) (*for color image see journal web site*)

Table 2. Technical specifications of Siemens 2.3 MW-Mk II wind turbine

Rotor		Blade	
Type	3 bladed, horiz. axis	Type	Self-supporting
Position	Upwind	Blade length	45 m
Diameter	93 m	Tip chord	0.8 m
Swept area	6800 m^2	Root chord	3.5 m
Synchronous rotor speed	6-16 rpm	Material	GRE
Power regulation	Pitch regulation	Surface gloss	Semi-matt, <30/ISO 2813
Rotor tilt	6°	Surface color	Light grey, RAL 7035
Generator		Operational data	
Type	Asynchronous	Cut-in wind speed	4 m/s
Nominal power	2300 kW	Nominal power at approx.	13-14 m/s
Synchronous speed	1500 rpm	Cut-out wind speed	25 m/s
Voltage	690 V	Maximum 2s gust	55 m/s (standard version)
Frequency	50 Hz		60 m/s (special version)
Protection	IP54		

Figure 6. Aerial view of the location of the wind park

Table 3. Comparison between planned and realized electricity production from the wind park for the period 2015-2017

Year	Planned	Produced	Difference	
	MWh		MWh	[%]
2015	95544	120768	25224	26.40
2016	103848	109483	5635	5.43
2017	104528	110480	5952	5.69
Average	101307	113577	12270	12.51

Investment for the first phase totals 55.5 million euros, out of which 47.9 million euros were provided by a loan from Germany's KfW bank, while the rest were funded by JSC ELEM. Investment of 24 million euros is necessary for the realization of second phase, out of which 18 million euros will be credited by a bank, and the rest will be funded from company's own resources. The entire administrative and logistical support for the second phase of the wind park *Bogdanci* is already completed, including economic analysis, adopted investment decision on the continuation of the project, Ministry of finance has been addressed with a request for borrowing and also KfW bank already committed a mission [17].

In accordance with the Energy Regulatory Commission of the Republic of Macedonia that has implemented a feed-in tariff of 89 €/MWh for buying and selling of electric energy produced and supplied by wind stations [18], the profitability of this kind of projects and further development of this very important part of country's energy sector must be considered.

In this context, gross annual income from wind electricity production for 2015 was 10.75 million euros, for 2016 – 9.74 million euros, and 9.83 million euros for 2017. Annual net income from wind electricity production (gross annual income minus the O&M costs) for this period was 8.091 million euros in 2015, 7.335 million euros in 2016 and 7.402 million euros in 2017, fig. 8.

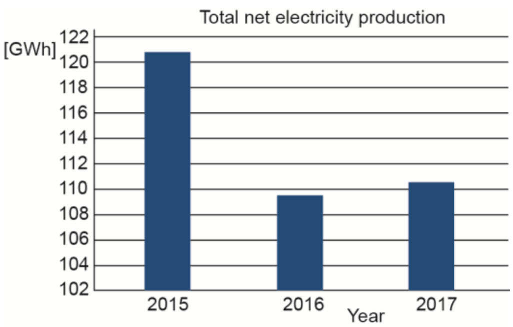


Figure 7. Total net electricity production from wind park for the period 2015 -2017

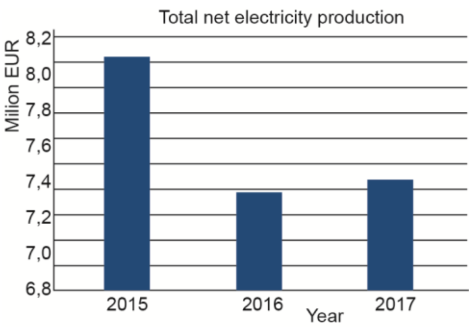


Figure 8. Annual net income from wind electricity production in the Republic of Macedonia for the period 2015-2017

If we consider that the regional weighted average installed cost in 2014 which was about 1589 € per kW or 1.589 million euros per MW [10], it is obvious that the average installed cost for 36.8 MW from the first phase is about 58.4752 million euros.

On the other side, O&M for onshore wind, ranging about 0.022 € per produced kWh or 22 € per produced MWh, so weighted average O&M cost for this period ranged from 2.4 to 2.65 million euros per year. This leads to a calculated average net income for the considered period of 7.609 million euros.

The payback period, also called simple payback (SP) of the project is calculated as (58.475 million euros)/(7.61 million euros) = 7.7 years. This is the length of time it takes for the initial investment to be repaid out of the net cash inflows from the wind farm installation.

The NPV is the difference between the present value of cash inflows and the present value of cash outflows. It is calculated by the following formula:

$$NPV=\sum_{t=1}^{T}\frac{C_t}{(1+r)^t}-C_0 \tag{1}$$

where C_t is the net cash inflow during the period t, C_0 – the total initial investment costs, r – the discount rate, and t – the number of time periods.

A positive NPV indicates that the projected earnings generated by a project or investment (in present euros) exceeds the anticipated costs (also in present euros). Generally, an investment with a positive NPV will be a profitable one and one with a negative NPV will result in a net loss.

In our case, if we assume discount rate of 6% [19] and average annual cash-flow of 7.609 million euros for time period of 20 years, the NPV for the project is calculated as 28.81 million euros. It means that the projected cash flows are worth 87.72 million euros, which is greater than the initial 58.4752 million euros paid. This summates all the cost and benefits over the twenty-year period of the project. This period corresponds to the duration of concession for feed-in tariff.

Another economic parameter for valuation of profitability of potential investments is the internal rate of return (IRR). The IRR is a discount rate that makes the NPV of all cash flows from a particular project equal to zero. The IRR calculations rely on the same formula as NPV does. In theory, any project with an IRR greater than its capital cost is considered profitable. Usually, IRR is used with conjunction with NPV for a clearer picture of the value represented by a potential project a company may undertake. Since IRR cannot be calculated analytically, programmed Excel function was used to obtain this value. The same values for investment costs and annual net income as in the calculation of NPV were used. The IRR for this project was calculated to be 5.729% over 20 years' time period.

Conclusions

The RES became very important and attractive in the last two decades. Power generation from renewable sources is growing from year to year and will continue to grow in the coming years. Republic of Macedonia is trying to attend this process and makes big efforts to increase production of electricity from RES. In this direction, the first wind park installed and operated by the state-owned electricity producing company ELEM, started with operation in April 2014, on a location near the town of Bogdanci. Considering the available financial resources, it was agreed that the wind park will be installed in two phases: the first phase with installed capacity of 36.8 MW (estimated net annual electricity production of 90 GWh), and the second phase with 13.8 MW (estimated net annual electricity production of 33 GWh). When completed, this wind park will have total installed capacity of 50.6 MW and estimated annual electricity production of approximately 120 GWh. Initial experiences from the operation of the wind park show that this was a good investment. If we exclude the first year of operation (2014 – trial period of operation), realized electricity production was, in average, around 12.5% higher than planned. Accordingly, the wind park has a status of privileged electricity producer from RES and uses feed-in tariff of 89 € per produced MWh of electricity. The SP of the project, with the average electricity production from the first three operational years is 7.7 years, while the NPV of the project over time period of 20 years is positive, calculated at over 28.8 million euros, indicating that the risks associated with the investment were worth taking. Calculated IRR of 5.729%, in conjunction with relatively high NPV means that while the pace at which the company sees returns on the project may be slow, the project is adding a great deal of overall value to the company.

Furthermore, four measuring stations with high-quality testing equipment are installed in additional pre-determined locations across the river Vardar, in the areas of villages Miravci and Davidovo. Realization of another wind park in some of these locations is even more feasible with the construction of the new highway section Demir Kapija – Smokvica, part of the pan-European corridor 10, thus making these remote locations more accessible. Electric power company already announced tender procedure for *Preparation of a preliminary project for the wind power farm Miravci* earlier this year. This project should give preliminary technical parameters and feasibility of installation of wind farm with total installed capacity of 50 MW and nominal annual electricity production of 127 GWh. Project should be implemented in two phases: first phase with total installed capacity of 14 MW and second phase with total installed capacity of up to 50 MW [20]. Potential for installation of another 100 MW of wind turbines is already in feasibility study stage for these locations, if the results are similar to those obtained with measurements at the wind park *Bogdanci* [21].

Installation of new wind parks would have positive implications for the Macedonian electric power sector, business climate, foreign investments, and local economy. Measurements should also provide justification for the realization of the second phase of the first wind park in the country and for implementation of similar projects near Bogdanci. As far as Republic of Macedonia is concerned, having in mind positive experiences from the operation of the first wind park, it is necessary to continue and expand the exploitation of wind energy.

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