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TECHNO-ECONOMIC AND ENVIRONMENTAL ANALYSIS OF THE WIND POWER PLANT PROPOSAL AT THE UNIVERSITY CAMPUS

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Abstract: This paper presents in detail the proposal of the small wind power system as the initial part of the research and development concept of the idea project of a microgrid based on distributed energy resources. The paper describes the basic parts of the small wind power system, its technical characteristics and the technical aspects of its application. In order to prove the justification of the future exploitation of wind power and electricity generation at the micro-location of a small wind power system whose installation is planned on a flat roof of the Faculty of Technical Sciences, this study presents the potentials of wind energy in the territory of the Autonomous Province of Vojvodina with a special focus on annual average wind speed, technical data on annual average production of electricity from a small wind power system, economically feasible data on incentive measures for production of electricity from wind power system (Feed-In-Tariff), as well as environmental data on reduction of greenhouse gas emission, especially carbon dioxide (CO_2).

Key words: microgrid**;** distributed energy sources; renewable energy system; wind energy; power electronics; wind power plant; wind turbine; techno-economic and environmental analysis

ТЕХНО-ЕКОНОМСКА И ЕКОЛОШКА АНАЛИЗА НА ПРЕДЛОГОТ ЗА ИЗГРАДБА НА ВЕТЕРНА ЕЛЕКТРИЧНА ЦЕНТРАЛА ВО УНИВЕРЗИТЕТСКИ КАМПУС

Апстракт: Трудот детално го презентира предлогот за мала ветерна електрична централа, која е иницијален дел на проектот за развој на микро-електрична мрежа базирана на дистрибуирани енергетски ресурси. Трудот ги опишува основните делови на мала ветерна електрична централа, нејзините технички карактеристики и техничките аспекти на нејзината примена. Оваа мала ветерна централа е планирана да се постави на рамниот кров на Факултетот за технички науки во Нови Сад. Оваа студија го презентира потенцијалот на ветерната енергија во Автономната Покраина Војводина, ставајќи акцент на годишната просечна брзина на ветерот, годишното просечно производство на електрична енергија од мала ветерна централа, економските поттикнувачки мерки за производство на електрична енергија од ветерни централи (Feed-In-Tariff), како и податоци за намалување на емисијата на стакленички гасови, особено јаглерод диоксид (CO_2).

Клучни зборови: микромрежа; дистрибуирани извори на енергија; систем за обновлива енергија; енергија на ветер; енергетска електроника; мала турбина на ветер; техно-економска и еколошка анализа

1. INTRODUCTION

Wind power plants, wind farms and the conversion of wind energy into electricity represent one of the most effective and efficient solutions for the energy problems that humanity faces.

The dynamic growth of the human population, the process of overburdening of cities and the creation of megacities, the intensive development of the economy and industry at global level, the irrational and uneconomical attitude towards conventional energy sources (fossil fuels, primarily coal and oil) have led to an extremely serious problem of increasing consumption of all types energy. The problem of increasing the consumption of electricity and heat is the cause of the creation of new and very dramatic problems of greenhouse gas emissions, global warming and climate change on the planet Earth. In addition to these global problems, the traditional concepts of planning, design and realization of the construction of power systems and transmission of electricity at large geographical distances represent a complex, costly and time-consuming process that requires complicated laws, standards, rules, conditions and procedures in the field of construction, electrical engineering, environment, rights, etc.

All of the above problems have led to the development of renewable energy and energy efficiency, and the creation of a concept of local electricity production from renewable energy plants in the immediate vicinity of the electricity consumption site. In recent years, microscopes represent a new concept of energy systems based on the application of different types of distributed energy sources [1].

Within the areas and groups of different types of renewable energy, a special place is taken by the wind energy and the process of converting wind energy into electricity using wind power plants. At the end of 2016, more than 487 GW of installed capacity of wind turbines was installed in the world and in Europe, with the total number of direct and indirect jobs in the wind sector 1,155,000, which for today's economic opportunities is a respectable number with a rapid growth trend in the near future [2].

In terms of further development of the wind power industry, by 2022, it is planned to increase the capacity of 295 GW of wind power systems (80% increase in electricity production), and global cumulative offshore wind energy systems with a capacity of 41 GW (increase of full load hours of wind generators from 40% to 55%) [3].

The main goals of the development of the wind industry are directed in two key directions:

1) increase in power, and
2) increase in efficiency.

The increase in power is realized by increasing the diameter of the rotor (i.e. increasing the utilization of the kinetic energy of the wind), while the increase in efficiency is realized through the improvement of the construction and control of power electronics and energy converters, active speed regulation and operation at the point of maximum power (as in the case of photovoltaic panels in solar power plants).

With regard to the power of the wind turbine (WT), at the end of the last century, the wind industry marked small power units of several tenths of output power with a symbolic amount of electricity production and an influence on the electricity system, at the beginning of this century, the wind power was marked by wind power generators of several MW output power. Nowadays, WTs generate 7.5 MW output power in the wind power market, with a development plan between 15 MW (practical) and 20 MW (theoretical) [4]. An illustrative depiction of the diameter of the rotor diameter from the output power of the WT is shown in Figure 1.

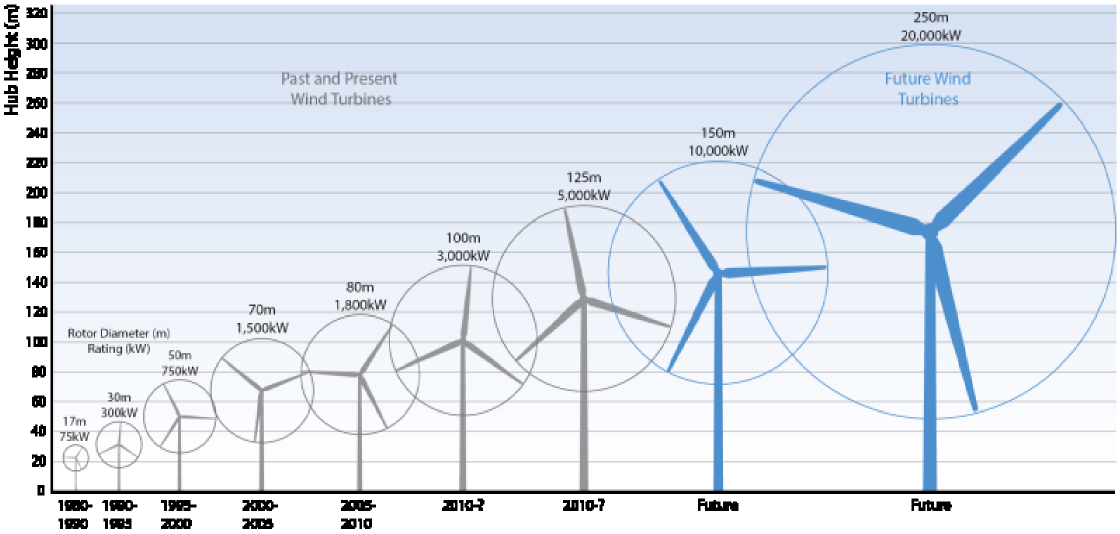

Fig. 1. Dependence of the rotor diameter on the installed power (Source: SBC Energy Institute)

Based on the growth of the rotor diameter of the WT shown in Figure 1, it can be concluded that wind power plants represent colossal construction objects of height being above 100 meters in diameter and dimensions of rotor wingers (blades) larger than the dimensions of the football field and the largest passenger airplane Airbus A380 with a wing span of 80 meters.

Regarding the efficiency of wind power conversion in electricity, the efficiency depends on the type of WT used. In terms of classification, WTs can be divided into two main types: fixed speed WTs and regulated speed WTs [5].

Fixed speed WTs is a concept used at the beginning of the development of wind power industry for low-power WTs, characterized by technical limitations in terms of grid requirements, while speed-controlled WTs allow and provide better power utilization and are more easily adapted to the demands of the transmission and/or distribution grid.

The partial-speed control is achieved using an asynchronous slip-ring generator with a regulator of the external resistance of the rotor and a double-feeded generator, while the full control is achieved by low-voltage asynchronous and synchronous electric generators in the Squirell Cage Induction Generator/Synchronous Generator (SCIG/SG) configuration with the Back-to-Back (B2B) converter and converter configuration assemblies with a diode rectifier, a power lifter and a voltage rectifier [6].

In order to realize the planned intensive growth, it is necessary to further improve wind generation technologies, with a special focus on the efficiency of conversion and production through the development of power electronic converters as an interface between the generator and the transmission and/or distribution grid, reducing the costs of construction and maintenance through research and development of new materials, increasing individualstrength through the development of new technologies.

Considering the very significant potentials of wind energy in the territory of the Republic of Serbia, following the modern trends of dynamic research, development and promotion of wind power systems, the Faculty of Technical Sciences Novi Sad ("FTN") has made the project of the wind power plant (WPP) “FTN” and its integration within the planned microgrid “FTN“ based on the application of different types of distributed energy resources.

The main aim of this paper is to assess the feasibility of the implementation of the WPP at the FTN in the university campus, through the preparation of a techno-economic and ecological analysis of the aspects of the application.

This paper is organized in the following manner: Chapter II gives a brief description of the process of determining the potential of wind energy at a particular microlocation and choice of micro-location, the potentials of wind energy in the territory of the Autonomous Province of Vojvodina (APV) in the Republic of Serbia (RS), the way of determining power and energy content of the wind, methods for approximating wind power density, electricity generation, and turbulence intensity. Chapter III analyzes and processes the definition of different types of costs and revenues and mathematical models in the framework of the techno-economic and environmental analysis of the aspects of justification of the application of WPPs. Chapter IV provides a proposal and a description of the micro-location where the installation of the proposed WPP "FTN" and the detailed technical characteristics of the WPP "FTN", results of a techno-economic and environmental analysis of the aspects of the WPP "FTN" implementation, Discussion analyzes and processes obtained results, after which Chapter V summarizes and gives the necessary conclusions.

2. DETERMINING OF THE WIND ENERGY POTENTIAL ON A MICROLOCATION

Within the process of planning, designing and designing a wind power plant, and/or wind farm, the two main techno-economic and environmental factors used to assess the feasibility of a wind power system at a particular location are:

1) the potential of wind energy and the choice of wind power plant microlocation, and

2) characteristics and selection of wind turbines.

2.1. *Potentials of wind energy and choice of microlocation*

Given the favorable geographical location, the RS has significant potentials for different types of renewable energy sources.

Annually, the total technically available potential of all types of renewable energy sources in the RS is estimated at 5.65 million tons of equivalent oil, with a share of technically available wind power potential estimated at 0.103 million tons of equivalent oil [7].

Regarding the potential of wind power, the territory of the APV of the RS, where the microlocation of the planned WPP "FTN", is characterized by extremely high wind speeds with a long duration, especially during the winter period.

The territory of the APV in the RS is classified in the zone with an average wind speed in the range between 3.5 m/s and 4.5 m/s, where wind speeds ranged from 4.5 m/s to 6 m/s at the location of the Fruška Gora Mountain and southern Banat, and on the plateau Vršački Breg wind speed above 6 m/s, while the annual potential of wind power is 80 m in the range between 1,700 kWh/m^2 and 4,300 kWh/m^2 [8, 9]. The average annual wind speed of 100 meters on the territory of the APV in the RS is shown in Figure 2.

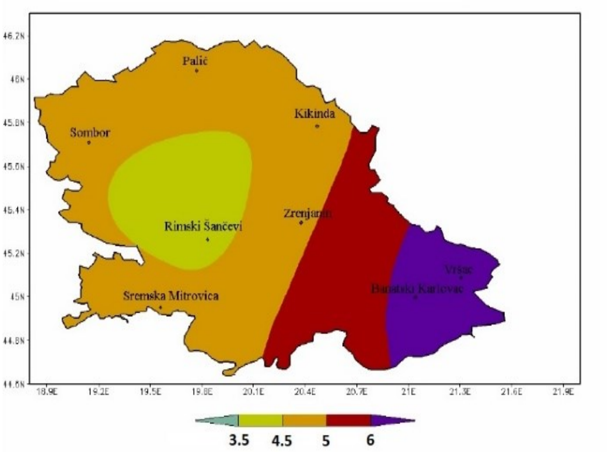

Fig. 2. Annual average wind speed at a height of 100 m [9]. (Source: Provincial Secretariat for Energy, Construction and Transport of the Autonomous Province of Vojvodina)

2.2. *Energy and power content of the wind*

Within the first major step of choosing the appropriate WT, in the process of planning, designing and making the preliminary and main project it is necessary to calculate the annual wind power, wind power density, turbulence coefficient and wind power generation.

The output power of the wind (P_W) is calculated on the basis of the following mathematical equation [10]:

$$P_w = \frac{1}{2} \cdot \rho \cdot A \cdot c_p \cdot v^3, \tag{1}$$

where ρ represents air density (kg/m^3((at a temperature of 20 °C and the at zero altitude ρ is about 1.225 kg/m^3), A represents the area (surface) of the circle formed by the blades of the WT (rotor diameter) [m^2], c_p represents coefficient of power that depends on speed and turbulence, and v represents average wind speed.

The wind power density (WPD) is obtained by dividing the power with the surface of the rotor and can be represented by the following mathematical equation:

$$\frac{W_w}{A} = WPD = \frac{1}{2} \cdot \rho \cdot v^3. \tag{2}$$

The dependence of the height on the average wind speed ($v(h)$) can be shown by the following mathematical relation [10]:

$$v(h) = v(h_r) \cdot \left[\frac{\ln(\frac{h}{z_0})}{\ln(\frac{h_r}{z_0})}\right]^m, \tag{3}$$

where h represents height at which the WT of the WPP is installed, h_r represents reference height (10 m), z_0 represents roughness lenghts, and m represents exponential coefficient that depends on roughness of the microlocation.

The dependence of the roughness length z_0 and the exponential coefficient m on the type of terrain on the microlocation of the WPP is given in Table 1.

Table 1.

Dependence of the roughness length $\mathbf{z_0}$ *and the exponential coefficient* $\mathbf{m}$ *of the type of terrain on the microlocation of the WPP*

Type of terrain on the microlocation	z_0 (m)	m
Water	0.0001	0.01
Fire-swept zone	0.02	0.12
Arable land with a rare plant	0.05	0.16
Arable land with dense plant, forests, inhabited areas	0.3	0.928

The turbulence intensity (TI) can be calculated by following equation [11]:

$$TI = \frac{\sigma_u}{U}, \tag{4}$$

where σ_u represents standard deviation of the horizontal wind speed, and U represents horizontal mean wind speed.

2.3. *Characteristics and choice of wind turbine type*

In the framework of the process of planning, designing and projecting of the WPP, in addition to the first main factor for choosing the appropriate microlocation at which the realization of the construction of the WPP and its integration into the main distribution grid will be realized, the second main factor is the choice of the appropriate type of WTs.

The choice of a specific and appropriate type of WT turbine to be used in the WPP depends on various factors of microlocation (on land, at sea, in/out of the city center), the size of electricity consumers, available funds, etc.

Nowadays, in the field of wind and wind energy systems, a large number of software programs, packages and tools [12, 13, 14] have been developed for checking and selecting microlocation with the best potential for the realization of the construction of the WPP and its integration into the main distribution grid, design, design and planning [15, 16, 17], as well as the choice of a particular WT type wind power plant/wind farm with the best technical characteristics and is the most effective and most effective technical solution [18].

3. TECHNICAL-ECONOMIC AND ENVIRONMENTAL ASPECTS OF WIND PLANT APPLICATION

After determining the potential of wind energy at a particular location and choosing the appropriate WT, it is necessary to carry out a detailed techno-economic and ecological analysis of the justification of the realization of the wind power system at the desired microlocation.

The techno-economic and ecological analysis of justification of the realization of the wind power system at a certain microlocation involves the calculation of the following parameters:

- total costs, and
- total revenues.

The total costs of the realization of the project for the construction of a WPP at a certain microlocation consist of:

- investment costs,
- operation and maintenance costs, and
- decomissioning costs.

The total costs of the realization of the construction of a WPP at a particular microlocation are calculated on the basis of the following mathematical formula:

$$C_T = C_I + C_{O\&M} + C_D, \tag{5}$$

where C_T represents the total investment costs of the realization of the construction of a wind power system [€], $C_{O\&M}$ represents operation and maintenance costs [€], and C_D represents decomissioning costs of a wind power system [€].

Investment costs for the construction of WPP include the costs of developing project documentation (design and main project) and the necessary construction, energy and environmental permits from competent institutions, the costs of procurement and transport of main and accompanying parts of the WPP, as well as the costs of building a WPP.

Operation and maintenance costs include regular annual service costs, as well as repairs of existing and/or replacement and installation of new main/auxiliary parts of the wind power system in case of failure (planned and/or unplanned interventions).

Decommissioning costs include the costs of reuse, recycling and re-installation of main/auxiliary mechanical and electrical parts and components of a WPP after closing the project at the end of the life of the wind power system.

The total revenues of the realization of the project for the construction of a wind power system at a certain microlocation consist of:

- revenues from electricity generation through economic compensation for incentive measures, and
- revenues from avoiding emissions of greenhouse gases through ecological and economic incentives.

The total revenues of realization of the construction of a wind power system at a certain microlocation are calculated on the basis of the following mathematical formula:

$$R_T = R_{IM} + R_{GHG}, \tag{6}$$

where R_T represents total revenues of the realization of the project for the construction of a WPP [€], R_{IM} represents revenues from incentive measures for the production of electricity from the WPP [€], and R_{GHG} represents revenues from incentive measures to avoid greenhouse gas emissions through the use of a WPP [€].

Revenues from incentive measures for the production of electricity from WPPs as a type of power plant for renewable energy sources and are realized in accordance with the energy policy of the state and the competent institutions.

In the world and in Europe, several types of economic mechanisms are used to encourage the production of electricity from renewable energy sources such as Net-metering, Feed-In-Tariffs (FIT), Renewable Energy Certificates ("Green Tags"), Value Added Tax (VAT), tax credits, energy and environmental credits, government (state) economic-ecological subsidies, etc., where the Republic of Serbia uses the model of economic fees (Feed-In-Tariff) [19, 20].

Revenues from incentive measures for electricity production from WPP can be calculated on the basis of the following mathematical relat,on:

$$R_{IM} = E_P \cdot P_{IM}, \tag{7}$$

where R_{IM} represents revenues from incentive measures for the production of electricity from WPPs [€], A_{E_P} represents the amount of electricity generated from the WPP [kWh], and P_{IM} represents price (height) of incentive measures for the production of electricity from the WPP [c€/kWh].

Revenues from incentive measures to avoid greenhouse gas emissions can be calculated on the basis of the following mathematical relationship:

$$R_{GHG} = A_{GHG} \cdot P_{GHG}, \tag{8}$$

where R_{GHG} represents incomes from incentive measures to avoid greenhouse gas emissions [€], A_{GHG} represents the amount of avoidance of greenhouse gas [kgCO$_2$], and P_{GHG} price (height) of incentive measures to avoid greenhouse gas emissions [€/kgCO$_2$].

In the world and in Europe, two major ecological and economic mechanisms are used to encourage the avoidance of greenhouse gas emissions, and emission trading systems and carbon tax [21].

After detailed verification and determination of the techno-economic and environmental aspects of the proposed solution of the wind power plant (WPP) at a certain microlocation, it is necessary to determine the factor of the return of the investment in the WPP (ROI factor).

The investment return factor in the WPP is calculated on the basis of the following mathematical formula:

$$ROI = \frac{R_T - C_T}{C_T} \cdot 100\%, \tag{9}$$

where ROI represents the return factor of the investment in the WPP, R_T represents total revenues of the realization of a WPP, and C_T represents total costs of the realization of the WPP.

4. WIND POWER PLANT “FTN”

Within the concept of idea project of microgrid “FTN” in a university campus based on the application of different types of distributed energy sources (two photovoltaic power plants with nominal output power of 9.6 kW and 16.3 kW, the cogeneration plant for combined heat and power production with a nominal output of 5 kWe and 9.9 kWt, two electric vehicles with a power of 2.5 kW and 4 kW, a 200 kWh battery energy storage system), the realization of the installation and integration of the WPP "FTN" is planned.

4.1. *Microlocation of the WPP “FTN”*

The realization of the installation of the WPP “FTN“ and its integration into the microgrid “FTN“ is planned on a flat roof of the FTN building. The height of the FTN is 30 meters, and the geographic coordinates of the microlocation of the building are 45.246187° for latitude and 19.851871° for longitude [22]. The satellite view of the microlocation of the WPP “FTN” is shown in Figure 3.

In Figure 3, letter A marks the main FTN building consisting of amphitheatres, classrooms, computer center, reading room, library, offices, student services and other accompanying premises, letter B marks the building of the Mechanical Institute of the FTN, while the letter C marks the building "Tower" of the FTN represents the microlocation at which the WPP "FTN" will be realized.

Fig. 3. Microlocation of the WPP “FTN” [22] (Source: Google maps)

Prior to the process of implementation of the proposal for the construction and integration of the WPP "FTN", it is necessary to carry out an assessment of the potential of wind energy, detailed checks, analyses, enable and provide processing of data on ambient conditions on the microlocation of the planned WPP.

Regarding the very matter, in order to fulfill these conditions and to enable and provide detailed data on the ambient conditions for the microlocation of the small FTN FTN, the FTN has built a mini meteorological station "FTN".

The mini meteorological station consists of communication devices and measuring equipment (calibrated solar cell, anemometer, wind turbine, etc.) that enable and provide remote access over the Internet, provide, monitor and store key data on the intensity of solar radiation, wind speed, wind direction, wind blow, air temperature and relative air humidity.

The wind velocity measurement at the microlocation of the WPP “FTN” was realized using an anemometer whose technical characteristics allow and provide detection of horizontal wind speed based on the opto-electronic device for converting wind speed into the frequency and further transformation into an analog signal at the electrical output [23].

Determination of the wind direction at the microlocation of the WPP “FTN” was realized using a low inert WT whose technical characteristics enable and provide wind direction detection in a radius of 0 ° to 360 ° that is connected to a 5-bit encoded disk that is opto-electronically scanned and further converted to an analog signal at the electrical output [24].

Anemometer and windproof construction consists of stainless materials (aluminum, plastic and stainless steel) that provide and provide protection of rotating parts from freezing, and protection of sophisticated components of energy electronics and other elements from unfavorable weather conditions (snow, ice, hail, rain).

The illustration of the mini meteorological station "FTN" is shown in Figure 4.

Fig. 4. The mini meteorological station “FTN”.

4.2. *Wind power plant “FTN”*

The WPP “FTN” is planned to be connected to the main distribution grid (grid-tied) and consists of the following main parts and components:

- wind generator,
- invertor (DC/AC power converter),
- AC box with DC and AC switching and protective devices,
- communication control devices and measuring equipment, and
- bidirectional meter for measuring electrical energy.

According to the idea and main project, the realization of the construction and installation of the WPP “FTN” is planned on a flat roof of the FTN building, in the concept connected to the main distribution grid (grid-tied WPP). After converting the kinetic energy of the wind into the mechanical energy of rotation of the WT, the mechanical energy of rotating the WT into electric energy with the generator of electricity occurs. DC energy at the output of the WT is converted to AC energy by using an inverter (DC/AC converter) located in the distribution box together with DC and AC switching devices and protective elements. Communication control devices and measuring equipment enable and provide remote control and monitoring of the operation of the WPP, as well as monitoring the data on ambient conditions on the microlocation of the WPP. The block diagram of the WPP "FTN" is shown in Figure 5.

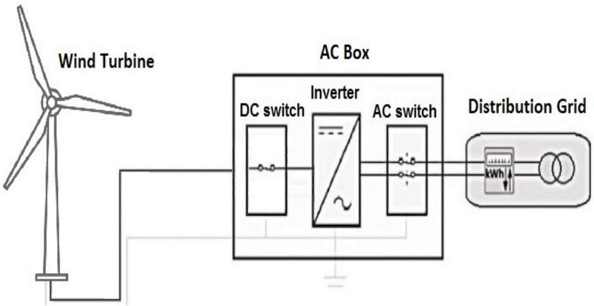

Fig. 5. The wind power plant (WPP) “FTN” – block diagram

For the successful realization of the construction and installation of the WPP “FTN”, it is primarily necessary to fulfill the appropriate criteria that require microlocation in relation to the selection of WTs with appropriate technical characteristics. The main criteria for choosing the appropriate WT within the WPP “FTN” and detailed technical characteristics with the power curve of the WT "FTN" are given below.

4.3. *Wind turbine in the wind power plant "FTN"*

In the framework of the design, planning and projecting of the WPP "FTN", special criteria and details that need to be considered are requirements for the microlocation of the planned WPP "FTN".

Considering the characteristics of the microlocation of the flat roof of the FTN building in the university campus where the realization of the installation of the WPP "FTN" is planned, the application of a WPP with a simple method of installation and production of electricity at the lowest wind speeds is required. In the concrete case of the WPP "FTN", the main criteria used to select the appropriate WTs within the WPP "FTN" are the weight criterion and the cut-in speed criterion.

The detailed technical characteristics of WT in the planned WPP "FTN" project are shown in Table 2.

Table 2

WT in the WPP "FTN" – technical characteristics [25]

Parameter	Characteristic
Rotor diameter	3.5 m
Blades quantity	3pcs
Rated output power	2000 W
Maximum output power	2950 V
Working voltage	DC 24/36/48/960/120/240 V, AC 220 V
Annual average energy production	4672 kWh (in rate 5 m/s wind speed)
Working wind speed	3 m/s – 25 m/s
Initial wind speed	2.5 m/s
Nominal wind speed	8 m/s
Maximum rotate speed	400 r/min
Blade pitch control	Fixed pitch
Speed regulation methods	Yawing and electrical magnet switch
Stop methods	Manual brake + Hydraulic brake
Weight	220 kg
Battery full charge	about 8 hours

Power curve of the WT in the WPP "FTN" is shown in Figure 6.

Illustrative view of the structure of the WT of a wind power turbine with a nominal output of 2 kW after installation at a particular microlocation is shown in Figure 7.

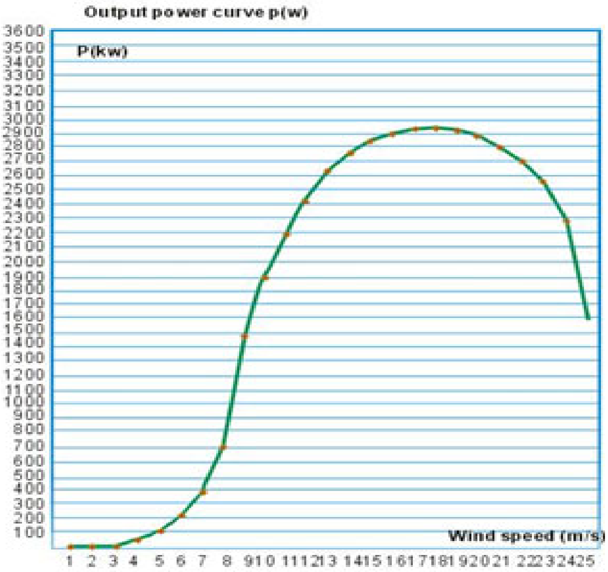

Fig. 6. The WT in the WPP "FTN" – power curve [25]. (Source: https://www.windpowercn.com/products/21.html)

Fig. 7. The WT with a nominal output of 2 kW - an example of the appearance after installation [25]. (Source: https://www.windpowercn.com/products/21.html)

4.4. *Techno-economic and ecological analysis of justification of the realization of installation of the WPP "FTN"*

In order to verify the justification of the implementation of the construction of the WPP "FTN" on the roof of the FTN building and its integration into the microgrid "FTN" based on the application of several different types of distributed energy sources, the techno-economic and environmental analysis of the aspects of the proposed WPP "FTN" was carried out.

In order to carry out the techno-economic and ecological analysis of the feasibility of using the FTN wind farm and obtaining the results of maximum quality, appropriate measurements of the wind characteristics on the microlocation of the WPP ”FTN” are enabled and ensured. Wind speed measurements were performed at height of 40 meters every 10 minutes for a period of 1 year, with the data stored in the appropriate table.

The actual distribution of the average wind speed at the microlocation of the WPP “FTN” is shown in Figure 8.

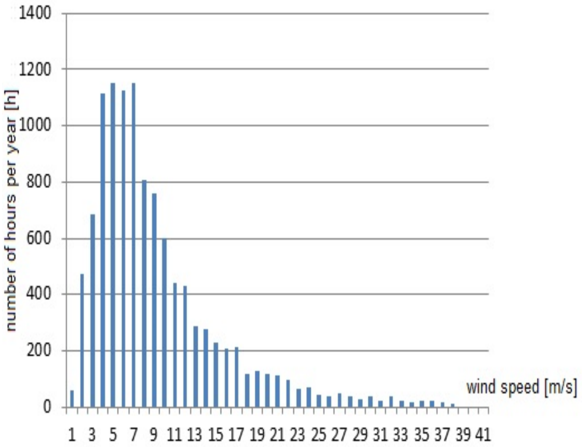

Fig. 8. The actual distribution of average wind speed at the microlocation of the WPP “FTN“

The average wind speed and wind rose at the microlocation of the WPP ”FTN” are shown in Figure 9.

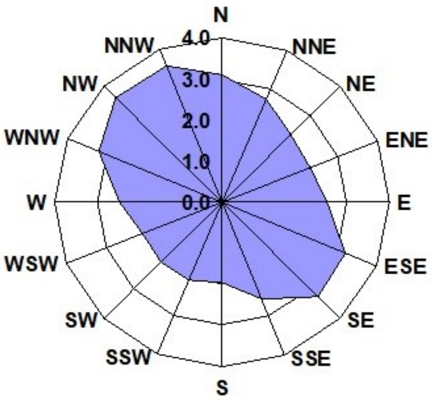

Fig. 9. The average wind speed and wind rose at the microlocation of the WPP “FTN”

Based on the analysis and processing of data on the wind potential and wind characteristics (average wind speed on the microlocation of the WPP “FTN”, electricity generation estimation was carried out.

The estimation of the production of the WPP “FTN” on an annual basis for each month of the year is shown in Figure 10.

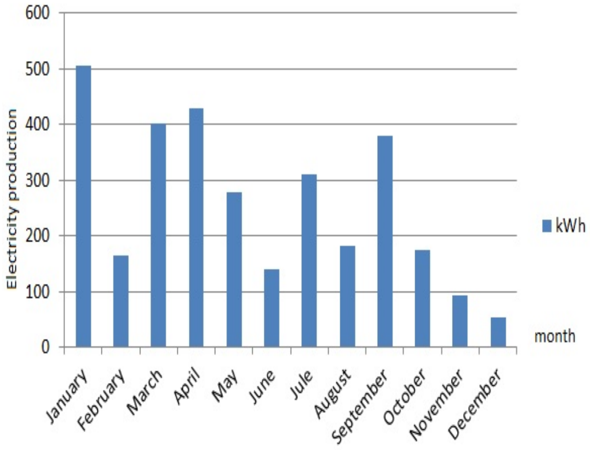

Fig. 10. The estimation of the electricity production of the WPP “FTN”

Power curve of the WT in the WPP “FTN” at the microlocation of the WPP “FTN” is shown in Figure 11.

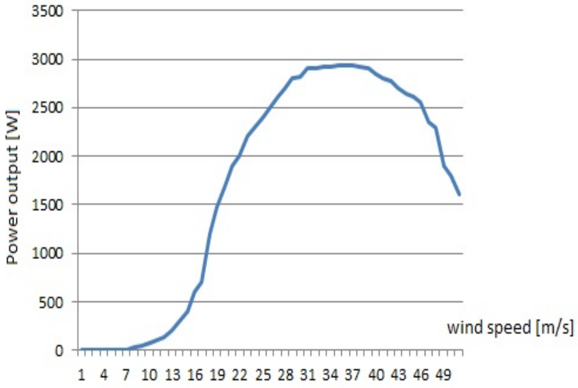

Fig. 11. The power curve of the WT at the microlocation of the WPP “FTN”

The technical and economic analysis of the feasibility of the construction of the WPP “FTN” includes calculations and estimates of the total costs and total revenues for the realization of the construction of the WPP “FTN” and its integration into the main distribution grid.

Investment costs of the main construction and technical parts of the WPP (main electrical and mechanical parts of WTs, energy and communication devices and measuring equipment), operating and maintenance costs (regular service, planned/unplanned interventions and team exits on the ground, switch of switches and fuses, etc.). The cost of decomissioning is shown in Table 3.

Table 3

The WPP "FTN" – total costs

Type of costs	Amount of costs
Investment costs (€)	3,300.00
Operation & management costs (€)	1,000.00
Decomissioning costs (€)	150.00

Table 4 shows the average annual production of wind power generation FTN, average annual incomes from incentive measures for the production of electricity from WPP, lifetime production of WPP "FTN" (25-year period), as well as lifetime income from incentive measures for the production of electricity from WPP.

Table 4

The WPP "FTN" – techno-economic revenues

Type of revenue	Amount of revenue
Annual average electricity production (kWh)	3,110.00
Annual revenues from incentive measures for the production of electricity from WPPs (c €/kWh)	286.12
Lifespan electricity production of electricity (kWh)	77,750.00
Lifespan revenues from incentive measures for the electricity production from WPPs [€]	7,153.00

Average annual avoided greenhouse gas emissions achieved through the operation of the WPP "FTN", average annual incomes from incentive measures for avoiding greenhouse gas emissions, lifetime of greenhouse gas emissions with the effect of greenhouse gases achieved through the operation of the WPP "FTN", as and lifetime incomes from incentive measures for avoiding greenhouse gas emissions from WT in the WPP "FTN" operation are shown in Table 5.

For the specific case of the WPP "FTN", for the most unfavourable case without carbon tax, the return of investment factor (ROI) is as follows:

$$ROI = \frac{7{,}153.00-4{,}450.00}{4{,}450.00} \cdot 100\% = 60.74\% \quad (10)$$

For the specific case of the WPP "FTN", for the most favourable case with carbon tax, the return of investment factor (ROI) is as follows:

$$ROI = \frac{8{,}086.00-4{,}450.00}{4{,}450.00} \cdot 100\% = 81.71\% \quad (11)$$

Table 5

The WPP "FTN" – ecological revenues

Type of revenue	Amount of revenue
Annual average avoided emissions of greenhouse gases ($kgCO_2$)	1,866.00
Annual revenue from incentive measures for avoiding greenhouse gas emissions (€/tCO_2)	37,32.00
Lifespan avoidance of greenhouse gas emissions ($kgCO_2$)	46,650.00
Lifespan revenue from incentive measures to avoid greenhouse gas emissions [€/tCO2]	933.00

5. DISCUSSION

The results of the carried out techno-economic and environmental analysis of the feasibility of the construction of the wind power plant (WPP) "FTN" and its integration into the main distribution grid show that the total cost of the FTN wind turbine (WT) generation is 4,450 €, while the total techno-economic revenue from incentive measures for the production of electricity from WPP and environmental revenues from incentive measures to avoid greenhouse gas emissions amounts to € 7,153 (the most unfavourable case, without a carbon tax) and € 8,086 (the most favourable case, with a carbon tax).

The results of the calculated return of investment factor (ROI) show that at the end of the life of the WPP "FTN" a profit of 81.708% (most unfavourable case, no carbon tax) and 77.464% (the most favourable case with a carbon tax) can be realized.

Based on the obtained results of the techno-economic and ecological analysis of the feasibility of the construction of the WPP "FTN" and its integration into the main distribution grid, it can be observed that the value of total revenues is significantly higher than the value of the total cost of the realization, which the proposal for the WPP "FTN" makes techno-economic and an environmentally justified solution.

6. CONCLUSION

This paper presents the proposal of a wind power system as one of the distributed energy sources, whose integration will be realized in the university campus within the planned microgrid based on the application of different types of distributed energy sources. In order to verify the feasibility of implementation of the proposed solution of the roof wind power system with a nominal output of 2 kW, a techno-economic and ecological analysis of the aspects of the application was carried out. The results of the work conclude that at the end of the life of the wind power plant (WPP) the total revenues are higher than the total costs and that the realization of the proposed solution of the WPP "FTN" in the idea project of microgrid ”FTN” is technically economic and environmentally justified. Further research will focus on the integration of other types of distributed energy sources (cogeneration plants, electric cars and electrical energy storage systems) and the techno-economic and environmental analysis of the aspects of their application.

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