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CONTRIBUTIONS TO HARNESSING THE WIND ENERGY POTENTIAL OF THE REPUBLIC OF MOLDOVA

Field of study: 221.02. "Energy conversion technologies and renewable resources (wind energy)"

Abstract of the doctoral thesis in engineering sciences

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The thesis defense will take place on **September 5th, 2024**, at **09:00**, in the meeting of the doctoral thesis defense committee at the Technical University of Moldova: 31 August 1989 street, no. 78, study block no. 2, room 2-222.

The doctoral thesis and the abstract can be consulted at the Library of the Technical University of Moldova and on the ANACEC website.

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I. CONCEPTUAL LANDMARKS OF THE RESEARCH

Relevance and importance of the issue addressed.

In today's world, energy consumption intensifies every year in most countries. Energy, water, and food resources are key to satisfying basic human needs. Thus, the global demand for these resources is rapidly increasing, and in the coming decades, a growth in energy consumption is expected due to global urbanization.

The use of energy defines the beginning of human civilization, from the mastery of fire for comfort and cooking to the evolution of human civilization, leading to nuclear power plants, automobiles, airplanes, personal computers, and the internet. Throughout the centuries, human society has evolved using energy more and more, where energy consumption is necessary for the functioning of contemporary society, the prosperity of nations, and the survival of our civilization. Energy is produced and used in various forms: airplanes and automobiles use liquid hydrocarbon fuels; power plants primarily convert energy from coal, natural gas, nuclear sources into electricity; and a contemporary household uses electricity and natural gas for household comfort, entertainment, and food preparation. Since most activities in our society are based on the use of energy, energy supply networks have been developed over the past three centuries: electricity is supplied to consumers through electric transmission and distribution networks; thermal energy, as well as natural gas, are delivered through a complex system of pipelines and ships that cross the oceans daily to supply oil to refineries. The economic impact of energy supply and energy trade is extremely important for all states. Most of them face energy supply security issues, and many international treaties and agreements are concluded on energy resources as a major issue.

The main factors underlying the increase in energy demand are population growth and urbanization, economic growth, and climate change. By 2030, global energy consumption is projected to increase by 50%. This will substantially exacerbate the global energy shortage, especially in regions and countries with energy and/or water deficits. This continued growth cannot be sustained in the long term, necessitating the proper management of these resources in a sustainable manner.

Households consume considerable amounts of resources (water, food, and energy) to meet the daily demand of residents. The household is a unit of demand and can also be the most suitable unit for influencing consumption practices. A significant portion of energy and water consumption can be attributed to household uses.

Thus, energy consumption for household hot water needs, as well as other sectors, constitutes a significant part of the energy balance. In general, household water and electricity consumption are usually linked, and studying this relationship can identify opportunities to streamline consumption, which implies an integrated approach to these two components.

The contribution of energy to water heating in the household sector is significant. The residential sector is a major consumer of both energy and water. Globally, household hot water consumption has increased over the past decades, leading to increased electricity consumption for water heating, accounting for approximately 40% of total consumption. The majority of electricity consumption is used for lighting, water heating, cooking, and air conditioning.

In this regard, harnessing renewable energy sources in general, and harnessing wind potential in particular, becomes a primary concern both globally and nationally. While one of the main reasons globally is the desire to reduce greenhouse gas emissions, at the national level, there is also a stringent need to diversify energy sources and reduce dependency on imports. Harnessing wind potential necessitates studying energy potential and wind characteristics to identify potential wind farm locations and evaluate possible installation capacities.

Currently, energy generated by wind turbines and other renewable energy conversion systems is exclusively oriented towards electricity production. Globally, the small wind turbine market is developing at an accelerated pace. The vast majority of modern small wind turbines are used for electricity production. This is because electrical energy can be converted into other forms of energy, such as mechanical, thermal, chemical, electromagnetic radiation, etc. However, converting electric energy produced from renewable sources into thermal energy is a less efficient method due to losses, both mechanical and electrical, in the transformation chain: mechanical energy - electrical energy - thermal energy.

In this context, it should be mentioned how rational it would be to directly convert wind energy into thermal energy, considering that thermal energy can be easily obtained from electrical energy, which, in turn, is obtained with the help of an electric generator driven by the same wind turbine. It all depends on the installation specifics of small-scale wind turbines for electricity production. For the efficient exploitation of small-scale wind turbines, they can be used in three categories of connection systems: off-grid system (stand-alone mode), on-grid system (grid-connected), or in a hybrid system. For an off-grid system, the wind installation must be equipped with electric batteries and an inverter to maintain the quality of electrical energy. The off-grid system offers total independence from the national power grid, but this entails high costs for electric batteries. An on-grid system involves connecting the wind installation to the grid and operating synchronously with the electrical grid; in this case, the installation is equipped with a corresponding inverter. The on-grid system, in turn, entails lower installation costs but has complete dependence on the electrical grid; if the voltage disappears from the grid, the consumer is no longer supplied with electrical energy, even if the wind turbine is producing electrical energy. A hybrid system is connected to the electrical grid and includes electric batteries for storing electrical energy. This system requires the highest initial investment.

Furthermore, the tariff for a unit of electrical energy is higher than the tariff for a unit of thermal energy. Additionally, the rural population requires thermal energy for space heating, in technological processes, and for heating water. In the near future, these potential consumers of thermal energy will not be connected to centralized or district heating systems.

As a result, natural gas and other fossil fuels are widely used for thermal energy production, which has a negative environmental impact due to greenhouse gas emissions into the atmosphere. Clearly, there is a need to reduce the use of fossil fuels for this purpose by developing and implementing renewable energy conversion systems. Thus, thermoelectric generators with thermoelectric currents can have considerable potential.

In turn, the thermogenerator with permanent magnets is a thermal generator for the direct transformation of mechanical work, which can be generated by a wind working body, into thermal energy through thermoelectric currents. Thus, induction heating is based on the penetration of the electromagnetic field into conductive materials placed in a time-varying magnetic field. Subsequently, the thermoelectric currents, determined by the induced electromotive forces, lead to the heating of the conductive materials through the Joule effect.

The main characteristics of electromagnetic induction heating are:

- transmission of electromagnetic energy from permanent magnets, which create the exciting magnetic field, to the heated object, without direct contact;
- rational use of energy for heat generation, including in some processes where it replaces fuel heating.

The direct conversion of wind energy into thermal energy could be an alternative solution to the options mentioned above. It has the following advantages:

1. The thermal energy generator can be at least 2.5 times cheaper than an electric generator of the same power. This is based on the following arguments: expensive active materials such as copper for windings, electrical steel, electrical insulation, varnish for impregnation are not used; only the permanent magnets needed for the thermal generator are still costly. The production technology is similar to that of generator production, but it eliminates the need for stamping, winding, varnish impregnation, etc.
2. The thermal energy generator does not contain wearing parts (except for bearings). The service life can exceed 20 years.

3. The wind energy potential can be fully utilized: the thermal generator operates across the entire range of wind speeds. The energy accumulator - a water reservoir - is cheaper than electric batteries and does not require maintenance expenses.

The purpose and objectives of the thesis are as follows.

The purpose of the thesis is to assess the wind potential for second-level administrative-territorial entities (districts) for the production of thermal and electrical energy, research and design a wind thermogenerator for the direct conversion of wind energy into thermal energy, which would provide residential sectors with thermal energy and contribute to achieving the Republic of Moldova's objectives regarding the valorization of renewable energies.

The objectives established to achieve the aim of the thesis are as follows:

- analyze the power sector over the past 10 years, including electricity production from renewable sources;
- determine the perspective of using renewable thermal energy in household in rural areas of the Republic of Moldova;
- carrying out a study of energy potential and wind characteristics at heights of 50 and 100 meters above ground level;
- identification locations for potential wind farms and assess possible installation capacities in second-level administrative-territorial entities (districts);
- research and design a small-scale wind thermogenerator.

The scientific novelty and originality of the work consists in the identification of problems and possible solutions regarding the perspective of using renewable thermal energy in household in rural areas and developing a calculation method for a small-scale wind thermogenerator for thermal energy production for the residential sector. The significant scientific problem solved involves the research and design of the wind thermogenerator for the direct conversion of wind energy into thermal energy for the production of hot water in rural areas.

The theoretical importance and applicative value of the thesis.

This thesis contributes scientifically to a relatively new field - the direct conversion of wind energy into thermal energy. It proposes a new scheme of the wind thermogenerator with permanent magnets, for which a patent has been obtained. Additionally, based on the study of energy potential and wind characteristics, wind energy potential maps have been obtained for second-level administrative-territorial entities, based on which the theoretical possible wind installation capacities for each district have been evaluated. The results contribute to achieving national objectives regarding the promotion of renewable energy use and also contribute to improving the situation in the rural sector regarding hot water supply through the direct conversion of wind energy into thermal energy.

The research hypothesis.

The direct conversion of wind energy into thermal energy can contribute to:

- Exploiting the wind potential at heights lower than 50 meters;
- More efficient utilization of wind energy potential for thermal energy production compared to electricity production;
- Improving the situation in the rural sector regarding hot water supply.

Research methodology synthesis and justification of chosen research methods.

The study utilized the Wind Atlas Methodology in conjunction with the specialized Wind Atlas Analysis and Application Program, along with wind speed and direction data measured by UTM (Technical University of Moldova), and the topographic map of the Republic of Moldova. For each district, maps of average annual wind speed and wind power density at heights of 50 and 100 meters above ground level were calculated and presented. The territory of each district was classified based on the power density value, and the theoretically possible wind power that could be installed was calculated.

For the analysis of induction heating in the wind thermal generator with permanent magnets, a study of the characteristics of the magnetic field generated by permanent magnets was conducted. A simplified calculation of the parameters and characteristics of the thermal generator with permanent magnets was performed, based on which simulations were carried out using SOLIDWORKS Electromagnetic Simulation software. These simulations aimed to simulate electromagnetic fields and the induction heating process, involving the calculation of electric/magnetic field parameters, eddy currents, and determination of material temperatures during induction heating.

Approval of obtained results.

The main results of the conducted investigation have been presented and approved at several seminars, symposiums, and conferences at both national and international levels:

- International Conference on Electromechanical and Energy Systems” SIELMEN-2019. 10-11 October 2019;
- International Conference "Days of the Academy of Technical Sciences of Romania 2019", 14th Edition, October 2019, Chisinau;
- "Technical-Scientific Conference of Students, Masters, and PhD Students", UTM, March 26-29, 2019;

- "Technical-Scientific Conference of Students, Masters, and PhD Students", UTM, April 2020;
- "Technical-Scientific Conference of Students, Masters, and PhD Students", UTM, March 23-25, 2021;
- International Conference on Electromechanical and Energy Systems "SIELMEN-2021", October 7-8, 2021;
- "Technical-Scientific Conference of Students, Masters, and PhD Students", UTM, March 29-31, 2022;
- "National Conference on Electrical Drives" (CNAE), 20th edition, Timisoara | May 12-13, 2022;
- International Fair of Innovation and Creative Education for Youth (ICE-USV), July 10-12, 2022, Suceava, Romania;
- International Conference On Electrical Engineering And Systems (ICEES), September 21-23, 2022, Resita, Romania;
- International Conference on Electromechanical and Energy Systems "SIELMEN-2023", October 12-13, 2023.

Summary of thesis sections.

The thesis comprises an introduction, four chapters structured into paragraphs, abstracts in Romanian, English, and Russian, a list of abbreviations used, general conclusions and recommendations, a bibliography consisting of 96 titles, and 7 appendices. The total number of pages of the thesis is 133 (excluding the bibliography), containing 113 figures and 25 tables.

Keywords: wind potential, wind thermal generator, 3D models, SOLIDWORKS Flow Simulation, renewable thermal energy (t-SRE).

II. CONTENTS OF THE THESIS

In the **Introduction**, general aspects regarding the relevance of the topic and the necessity of direct conversion of wind energy into thermal energy for domestic hot water production are presented. The purpose and objectives of the thesis, as well as the scientific novelty and theoretical importance of the work, hypothesis of the research, research methodology, and summary of the thesis sections are outlined.

Chapter 1 – *Global and national wind power and thermal energy production: the current state,* current status involves an analysis of installed wind capacities worldwide and an examination of the national electricity sector over the past 10 years regarding renewable energy (RE) electricity production. Concurrently, the household structure is analyzed, and the need for thermal energy for domestic hot water heating in the perspective of using wind thermal energy is evaluated. To determine the consumption of thermal energy for water heating, consumption standards for water in residential buildings are determined.

Water consumption standards are determined in accordance with the norms for water consumption for residential and public buildings, specified in the Hygiene Regulation, approved by the Expert Council of the Ministry of Health and Social Protection through Minutes no. 5 dated 31.10.1996, the Regulation on the acquisition, design, installation, reception, and operation of water consumption metering devices, approved by Government Decision no.1228 dated 13.11.2007, the Regulation on the use of communal water supply and sewerage systems, approved by Government Decision no. 656 dated 27.05.2002, and the Regulation on the organization and functioning of public water supply and sewerage services in the municipality of Chisinau, approved by the Decision of the Chisinau Municipal Council no.5/4 dated 25.03.2008.

For consumption norms, over 20 categories of consumption per person are approved, depending on the services provided by the household (drinking water, sewage, hot water, shower, bathtub, toilet, gas heater, etc.). For example, currently, for apartments equipped with drinking water supply, hot water, sewage system, equipped with toilets, sinks, with a bathtub length of 1500 mm and above, and with a shower, the value of the cold water consumption norm is 0.195 m^3/day per person, for household water - 0.105 m^3/day per person, according to the approved regulations.

Hygiene rules and norms present the regulatory directive of the Republic of Moldova, which establishes hygienic requirements (norms) for the design, construction, and operation of water supply systems intended to provide the population with safe and favorable drinking water in terms of organoleptic, physico-chemical, and microbiological qualities.

Hygiene rules and norms extend to the design, construction, and operation of external and internal water supply systems of residential buildings and public buildings, already built or reconstructed, of production and auxiliary buildings at industrial enterprises, located in both existing and newly built populated centers, and also contain main hygienic requirements regarding the maintenance and operation of water supply networks that bring water for drinking purposes and for food production.

The norms for the water requirement per inhabitant/liters/per day/for water supply systems of populated centers, residential buildings, public buildings, auxiliary and production buildings of industrial enterprises must be established separately in each case depending on the degree of development, climatic conditions, and other local conditions, thus based on the normative documents in the field, listed above, including for compliance with hygiene standards, consumption norms for residential houses in rural areas have been determined, as shown in Table1.

Table 1. Water consumption norms for residential houses

No.	Consumers	Reporting unit	Water consumption norm, liters	
			Total	Including hot water
	Residential houses			
1	With potable water supply, without sewer system, without toilet, without bathtub or shower	Per 1 person / day	90	36
2	With potable water supply, sewer system, without toilet, without bathtub or shower	Per 1 person / day	95	40
3	With potable water supply, hot water, without sewer system, equipped with toilet, sinks, with small bathtub or shower	Per 1 person / day	100	45
4	With potable water supply, hot water, sewer system, equipped with toilet, sinks, small bathtub or shower	Per 1 person / day	250	105

It should be noted that according to the results of previous studies conducted in various European countries, as reported in reports on domestic hot water consumption and monthly variations, numerous differences in domestic hot water consumption are evident, as well as a tendency to change over time due to the global increase in energy prices, technological changes, the introduction of individual metering, and a wide variety of other factors that may arise at the local or regional level. Thus, the average annual ratio of domestic hot water consumption is 42% of the total water consumption in households.

In another study carried out to model domestic hot water consumption in households and the energy required for water heating, it is assumed that of the total water used in a household, about 50% requires its heating, used for baths, showers, sinks, washing dishes, laundry and cooking.

According to the norms for drinking water and hot water consumption stipulated in national regulatory documents, it should be mentioned that the ratio between cold water consumption and hot water consumption, for all categories of consumers, is approximately equal to 45%.

The quantity of thermal energy required to heat 1 m^3 of water can be determined according to the technical normative documentation. In the absence of devices for measuring the temperature of cold water, the value of the specific quantity of thermal energy required to heat 1 m^3 of water to the necessary temperature for providing domestic hot water services can be assumed to be equal to $0{,}055\ Gcal/m^3$.

In Table 2 shows the results of the calculation of the specific amount of thermal energy $q_{heating}$ for heating water up to a temperature of $50 - 55\ °C$.

Table 2. Specific thermal energy quantity for heating 1 m^3 of water

Water temperature, °C	Specific thermal energy quantity, $q_{heating}$ Gcal/m^3, at heating temperature	
	50 °C	55 °C
4	0,04545	0,05027
5	0,04446	0,04929
6	0,04348	0,04830
7	0,04249	0,04732
8	0,04150	0,04633
9	0,04050	0,04534
10	0,03952	0,04436
11	**0,03853**	**0,04337**
12	0,03755	0,04239
13	0,03656	0,04140
14	0,03557	0,040415
15	0,03458	0,03943
16	0,03359	0,03844
17	0,03261	0,03746
18	0,03162	0,03647
19	0,03063	0,03549

The recommended values are calculated based on the accepted data in accordance with the normative technical documentation and without considering the thermal energy losses from the pipes of the domestic hot water supply system.

The average water supply temperature is considered according to Table 2, which is a flexible model to accommodate any temperature difference between cold and hot water, taking into account different climatic conditions in various regions depending on seasons and climate. The average temperature of hot water is assumed to be 55 °C.

The consumption of hot water per inhabitant is assumed in accordance with the data presented in Table 1. The calculated values of the energy required for domestic hot water according to the type and distribution of households are presented in Table 3.

Table 3. Calculated values of the energy required for domestic hot water according to the amenities

The energy requirement for heating water, kWh/day											
Water temperature, °C	Specific heat energy, Gcal/m³, at heating temperature	With potable water supply, without sewer system, without toilet, without bathtub or shower					With potable water supply, sewer system, without toilet, without bathtub or shower				
		Norm consumption of water, liters per 1 person/day					Norm consumption of water, liters per 1 person/day				
		36					**40**				
		Number of persons					Number of persons				
	55 °C	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
4	0.05027	2.10	4.21	6.31	8.41	10.52	2.34	4.67	7.01	9.35	11.68
5	0.04929	2.06	4.12	6.19	8.25	10.31	2.29	4.58	6.87	9.17	11.46
6	0.0483	2.02	4.04	6.06	8.08	10.10	2.25	4.49	6.74	8.98	11.23
7	0.04732	1.98	3.96	5.94	7.92	9.90	2.20	4.40	6.60	8.80	11.00
8	0.04633	1.94	3.88	5.82	7.75	9.69	2.15	4.31	6.46	8.62	10.77
9	0.04534	1.90	3.79	5.69	7.59	9.49	2.11	4.22	6.32	8.43	10.54
10	0.04436	1.86	3.71	5.57	7.42	9.28	2.06	4.12	6.19	8.25	10.31
11	**0.04337**	**1.81**	**3.63**	**5.44**	**7.26**	**9.07**	**2.02**	**4.03**	**6.05**	**8.06**	**10.08**
12	0.04239	1.77	3.55	5.32	7.09	8.87	1.97	3.94	5.91	7.88	9.85
13	0.0414	1.73	3.46	5.20	6.93	8.66	1.92	3.85	5.77	7.70	9.62
14	0.040415	1.69	3.38	5.07	6.76	8.45	1.88	3.76	5.64	7.52	9.39
15	0.03943	1.65	3.30	4.95	6.60	8.25	1.83	3.67	5.50	7.33	9.17
16	0.03844	1.61	3.22	4.82	6.43	8.04	1.79	3.57	5.36	7.15	8.94
17	0.03746	1.57	3.13	4.70	6.27	7.84	1.74	3.48	5.22	6.97	8.71
18	0.03647	1.53	3.05	4.58	6.10	7.63	1.70	3.39	5.09	6.78	8.48
19	0.03549	1.48	2.97	4.45	5.94	7.42	1.65	3.30	4.95	6.60	8.25
Water temperature, °C	Specific heat energy, Gcal/m³, at heating temperature	With potable water supply, hot water, without sewer system, equipped with toilet, sinks, with small bathtub or shower					With potable water supply, hot water, sewer system, equipped with toilet, sinks, small bathtub or shower				
		Norm consumption of water, liters per 1 person/day					Norm consumption of water, liters per 1 person/day				
		45					**105**				
		Number of persons					Number of persons				
	55 °C	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
4	0.05027	2.63	5.26	7.89	10.52	13.15	6.13	12.27	18.40	24.54	30.67
5	0.04929	2.58	5.16	7.73	10.31	12.89	6.02	12.03	18.05	24.06	30.08
6	0.0483	2.53	5.05	7.58	10.10	12.63	5.89	11.79	17.68	23.58	29.47
7	0.04732	2.47	4.95	7.42	9.90	12.37	5.77	11.55	17.32	23.10	28.87
8	0.04633	2.42	4.85	7.27	9.69	12.12	5.65	11.31	16.96	22.62	28.27
9	0.04534	2.37	4.74	7.11	9.49	11.86	5.53	11.07	16.60	22.13	27.66
10	0.04436	2.32	4.64	6.96	9.28	11.60	5.41	10.83	16.24	21.65	27.07
11	**0.04337**	**2.27**	**4.54**	**6.80**	**9.07**	**11.34**	**5.29**	**10.59**	**15.88**	**21.17**	**26.46**
12	0.04239	2.22	4.43	6.65	8.87	11.08	5.17	10.35	15.52	20.69	25.86
13	0.0414	2.17	4.33	6.50	8.66	10.83	5.05	10.10	15.16	20.21	25.26
14	0.040415	2.11	4.23	6.34	8.45	10.57	4.93	9.86	14.80	19.73	24.66
15	0.03943	2.06	4.12	6.19	8.25	10.31	4.81	9.62	14.44	19.25	24.06
16	0.03844	2.01	4.02	6.03	8.04	10.05	4.69	9.38	14.07	18.76	23.45
17	0.03746	1.96	3.92	5.88	7.84	9.80	4.57	9.14	13.71	18.29	22.86
18	0.03647	1.91	3.81	5.72	7.63	9.54	4.45	8.90	13.35	17.80	22.25
19	0.03549	1.86	3.71	5.57	7.42	9.28	4.33	8.66	12.99	17.32	21.65

Chapter 2 – *Study of the wind energy potential and wind characteristics for second-level administrative-territorial entities,* maps of the determined wind potential were created for each district, indicating all localities. Additionally, in tabular form, the number of cells, the areas of sites with wind power density equal to or greater than 150 W/m^2 and the theoretical wind capacity in MW that could be installed in each district are presented.

The emphasis of the study was on determining the energy potential and wind characteristics for second-level administrative-territorial entities (districts). The study was conducted within the framework of the state program 20.80009.7007.10, titled "Study of the wind and solar energy potential of the Republic of Moldova and the development of conversion systems for dispersed consumers".

For the study, the Wind Atlas Method accompanied by the specialized program Wind Atlas Analysis and Application Program was used, along with wind speed and direction data measured by the Technical University of Moldova and the topographic map of the Republic of Moldova. For each district, maps of the annual average wind speed and wind power density at heights of 50 and 100 meters above ground level were calculated and presented. The territory of each district was classified based on the power density value, and the theoretically possible wind power to be installed was calculated.

In the maps presented in the paper, the wind potential is determined for each district, with the surface of each cell being 100 x 100 meters. All localities are indicated, and additionally, in tabular form, the number of cells, the areas of sites with wind power density equal to or greater than 150 W/m^2 and the theoretical wind capacity in MW that could be installed in each district are presented. The classification of each district's territory is based on digital maps of wind power density for a specific height. These maps represent the sum of a certain number of rectangles or cells, referred to in the WAsP program as "Resource grid." The number of cells with power density ranging from 150 W/m^2 to 400 W/m^2 at a height of 100 meters was identified. Knowing that the area of each cell is 0,01 km^2 and the number of cells for each interval, the areas of surfaces where wind power density falls within one of the mentioned intervals were calculated. Assuming the use of wind turbines with a unit power of 3.0 MW per km^2 in areas with energy potential between 150 and 400 W/m^2, the total theoretical power possible to be installed for each district was calculated.

The determined wind energy potential is theoretical, which is quite large, but the actual utilization possibility can be tens or even hundreds of times smaller due to technical restrictions limiting the real potential. To correctly assess the data presented in the maps, it should be noted that the color scale differs from one map to another.

The results of the study conducted for the **Northern Development Region** (NDR) revealed the following:

1. Assuming the use of wind turbines with a unit power of 3.0 MW in areas with energy potential ranging from 300 to 400 W/m^2, the total theoretical power possible to be installed in the analyzed districts of NDR could reach approximately 365 MW. The highest theoretical power could be installed in the Sangerei district - 144 MW, followed by the Floresti district with 90 MW and the Falesti district with 51 MW.
2. For all analyzed districts in the Northern Development Region, the potential wind power density that could be installed is 5 MW/km^2.
3. The highest average annual wind speeds are observed in the Falesti district. At a height of 100 meters above ground level, the average annual wind speed is 7.44 m/s, with wind power density reaching up to - 404 W/m^2.
4. The lowest average annual wind speeds are observed in the Edinet district. At a height of 100 meters above ground level, the average annual wind speed is 6.57 m/s, with wind power density at - 289 W/m^2.

Figure 1 illustrates graphically the theoretical wind power that could be installed for all analyzed districts in the NDR, assuming the use of wind turbines with a unit power of 3.0 MW in areas with energy potential ranging from **300 to 400 W/m^2**.

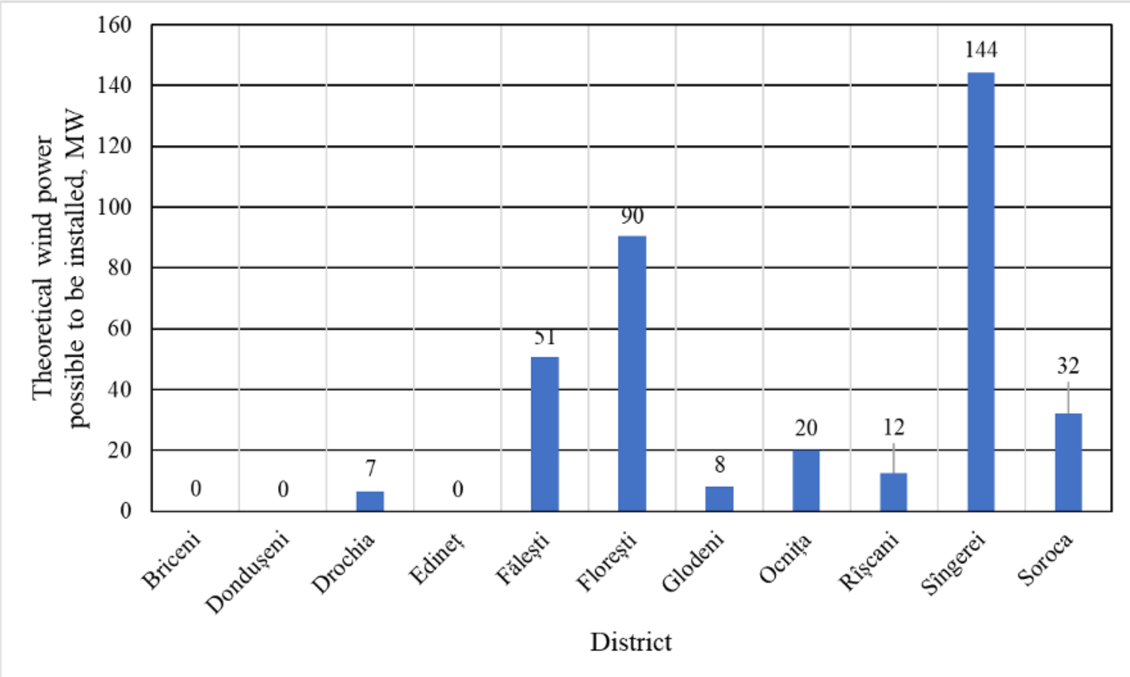


Figure 1. Theoretical wind power possible to be installed in districts of NDR, in areas with energy potential ranging from 300 to 400 W/m^2

The results of the study conducted for the **Central Development Region** (CDR) are as follows:

1. Assuming the use of wind turbines with a unit power of 3.0 MW in areas with energy potential ranging from 300 to 400 W/m^2, the total theoretical power possible to be installed in the analyzed districts of CDR could reach approximately 196 MW. The highest theoretical power could be installed in the Nisporeni district - 76 MW, followed by the Telenesti district with 41 MW and the Hancesti district with 36 MW.
2. For the analyzed districts in the Central Development Region, the potential wind power density that could be installed varies slightly and ranges from 3.2 MW/km^2 (Straseni) to 4.9 MW/km^2 (Anenii Noi).
3. The highest average annual wind speeds are observed in the Nisporeni district. At a height of 100 meters above ground level, the average annual wind speed is 7.46 m/s, with wind power density at 398 W/m^2.
4. The lowest average annual wind speeds are observed in the Ialoveni, Rezina, Soldanesti, and Dubasari districts. At a height of 100 meters above ground level, the average annual wind speed is 6.7 m/s, with wind power density at 286 W/m^2.

Figure 2 illustrates graphically the theoretical wind power that could be installed for all analyzed districts in the CDR, assuming the use of wind turbines with a unit power of 3.0 MW in areas with energy potential ranging from **300 to 400 W/m^2**.

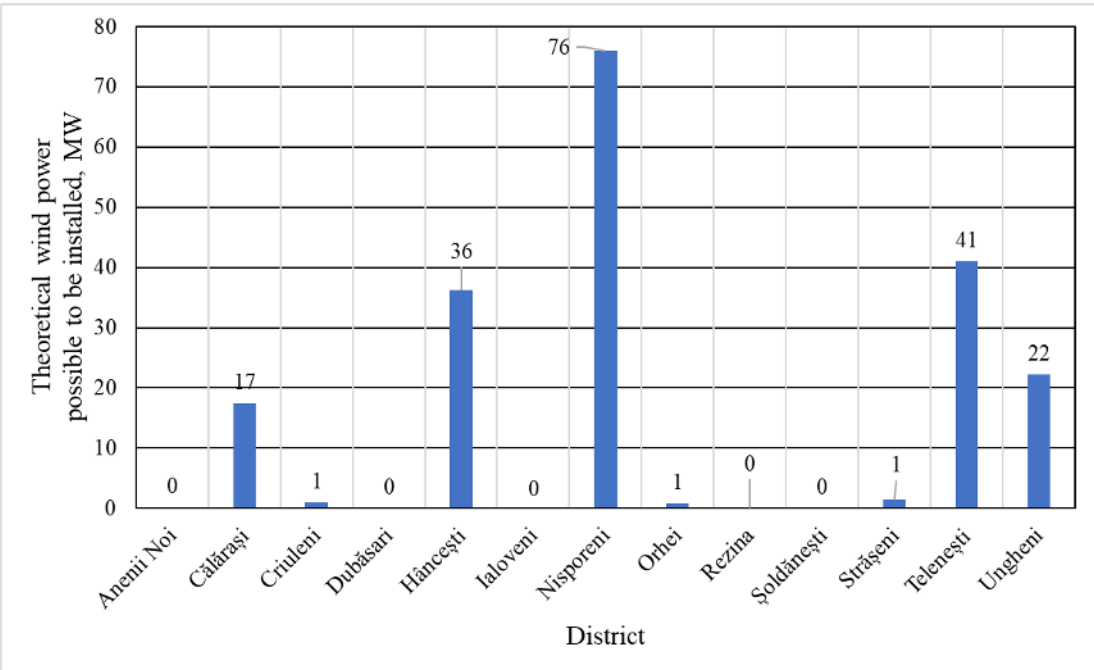


Figure 2. Theoretical wind power possible to be installed in districts of CDR, in areas with energy potential ranging from 300 to 400 W/m^2

The results of the study conducted for the **Southern Development Region and the Autonomous Territorial Unit of Gagauzia** (ATU Gagauzia) are as follows:

1. Assuming the use of wind turbines with a unit power of 3.0 MW in areas with energy potential ranging from 300 to 400 W/m^2, the total theoretical power possible to be installed in the analyzed districts above could reach approximately 617 MW. The highest power could be installed in the Cimislia district - 172 MW, followed by the Causeni district with 107 MW and the Leova district with 104 MW.
2. For all analyzed districts in the Southern Development Region, the potential wind power density that could be installed is 5 MW/km^2.
3. The highest average annual wind speeds are observed in the Cimislia district. At a height of 100 meters above ground level, the average annual wind speed is 7.11 m/s, with wind power density at 380 W/m^2.
4. The lowest average annual wind speeds are observed in the Taraclia district. At a height of 100 meters above ground level, the average annual wind speed is 6.72 m/s, with wind power density at 315 W/m^2.

Figure 3 illustrates graphically the theoretical wind power that could be installed for all analyzed districts in the SDR, assuming the use of wind turbines with a unit power of 3.0 MW in areas with energy potential ranging from **300 to 400 W/m^2**.

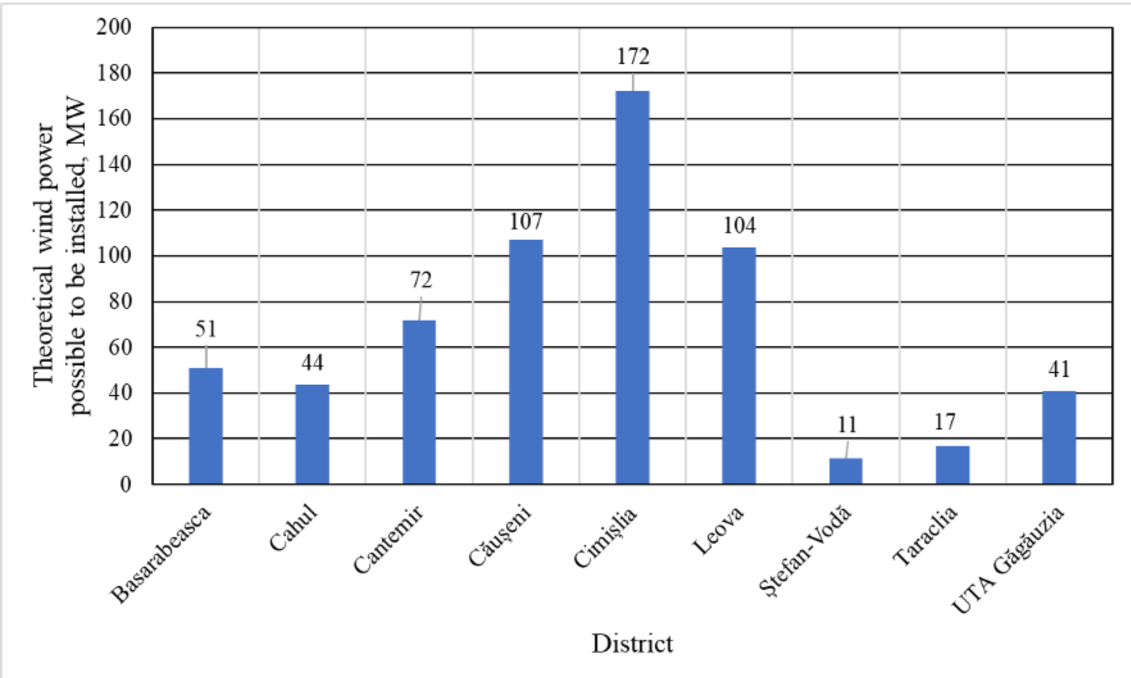


Figure 3. Theoretical wind power possible to be installed in districts of CDR, including ATU Gagauzia, in areas with energy potential ranging from 300 to 400 W/m^2

Chapter 3 – *Direct conversion of wind energy into thermal energy* presents the calculation of parameters and characteristics of the permanent magnet thermogenerator. The results of simulations performed in SOLIDWORKS Electromagnetic Simulation are presented to study the magnetic field of the generator and determine the temperatures of the jackets (armature) depending on the rotor rotation speed. Additionally, simulations were conducted in SOLIDWORKS Flow Simulation to determine the temperature variation in the thermogenerator discharge pipe according to flow rate and to determine the liquid pressure variation in the intake pipe according to flow rate.

The thermal generator refers to machines that convert mechanical energy into useful work in general, and specifically to thermal generators for the direct transformation of mechanical work, generated by a wind working element, into thermal energy through eddy currents. In the field of thermal generators, two essentially different development directions are identified. Thus, the conversion of mechanical energy developed, for example, by the rotor of a wind turbine, can be transformed into heat based on:

- Joule's principle, used to demonstrate the mechanical equivalent of heat;
- Foucault's principle, based on electromagnetic induction with eddy currents.

As a prototype, the technical solution chosen involves a thermal generator consisting of two main components - the inductor with permanent magnets, and the armature made of massive magnetic material, in which eddy currents are induced.

The technical problem solved by constructive modifications of the thermal generator (Figure 4), consists of increasing the conversion efficiency of the mechanical energy of a wind turbine into thermal energy. The solution to the formulated problem is achieved by the fact that the wind thermal generator, which contains an inductor with permanent magnets, is driven by the rotor of a wind turbine, which rotates concentrically relative to the jacket of the armature through which a heat transfer fluid circulates. The armature, in turn, consists of two concentrically oriented jackets - one inner and one outer - delimited by a free space in which the inductor made of non-ferromagnetic material is placed, on the cylindrical surface of which longitudinal grooves are milled in which the permanent magnets are mounted.

According to the second variant, the inductor of the generator is made of non-ferromagnetic material, and on its cylindrical surface, grooves with concave side walls are milled, in which permanent magnets with convex side surfaces are mounted and fixed.

According to the third variant, the inner and outer jackets of the armature can be connected either sequentially, to ensure the circulation of the heat transfer fluid in a single flow, or in parallel, to ensure circulation through separate flows of the heat transfer fluid.

The technical result consists of a significant increase in the interaction surface between the permanent magnets and the armature, thereby increasing the efficiency of converting wind energy into heat.

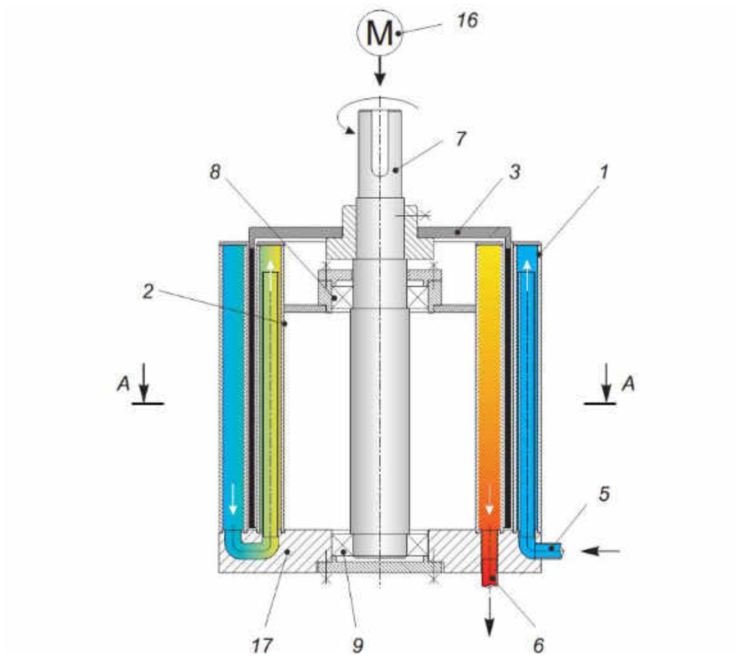
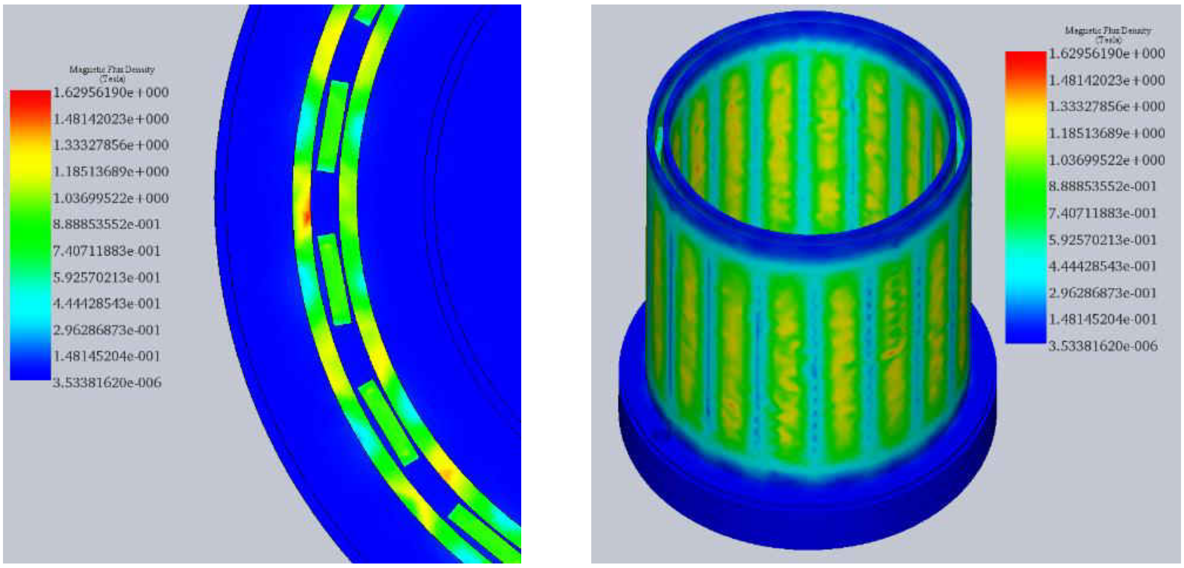


Figure 4. The longitudinal sectional view of the thermal generator assembly

Simulation of the magnetic field of the thermogenerator with permanent magnets. To conduct the study of the magnetic field of the thermogenerator with permanent magnets, simulations were performed using SOLIDWORKS Electromagnetic Simulation software, which allows for the simulation of electromagnetic fields; calculation of electric/magnetic field parameters, eddy currents, mechanical force, and torque parameters, etc. SOLIDWORKS Simulation provides a virtual environment for testing and analyzing a model, allowing for the evaluation of its performance for model improvement. For this purpose, the software employs a numerical method called the Finite Element Method (FEM) Analysis.

Below are images showing the distribution of the magnetic field generated by the permanent magnets through the cylinders of the thermogenerator armature. The purpose of the simulations is both to analyze the distribution of the magnetic field and determine its characteristics, and to adjust and optimize the geometry parameters of the thermogenerator to achieve better characteristics. The simulations were conducted in dynamic mode, applying different rotational speeds to the thermogenerator rotor. Figure 5 shows images of the magnetic field distribution through the cylinders of the thermogenerator armature at a rotation speed of $100\ rpm$. According to the simulation results, areas can be observed in the armature cylinders where the values of magnetic induction are higher. The maximum values of magnetic induction, observed in dynamic mode, are in the range of $1{,}62 - 1{,}72\ T$.



a **b**

Figure 5. Distribution of the magnetic field in the armature cylinders.
a) sectional view; b) general view

Subsequently, simulations were conducted to determine the temperatures of the armature jackets based on the rotor rotation speed. Table 4 presents the results of the simulation of the induction heating of the armature material, with temperatures of the inner and outer cylinders separately presented under the simulation conditions where the ambient temperature $T_a = 20\ °C$ and the initial material temperature $T_i = 20\ °C$, for rotor rotation speeds ranging from 34 to 600.

Table 4. The values of the armature material temperature
depending on the rotor rotation speed of the thermogenerator

Rotation speed, $\boldsymbol{n, rpm}$	Frequency, $\boldsymbol{f, Hz}$	Inner cylinder temperature, $\boldsymbol{T_{c\,i.}}$, °C	Outer cylinder temperature, $\boldsymbol{T_{c.e.}}$, °C
34	5	20,58	20,66
67	10	22,17	22,47
134	20	29,96	31,30
200	30	36,86	39,08
267	40	50,40	54,35
334	50	55,87	60,50
400	60	71,98	78,68
467	70	75,69	82,88
534	80	85,94	94,47
600	90	88,25	97,10

In Figure 6 the variation of the armature material temperature values as a function of the rotor rotation speed of the thermogenerator is presented graphically, separately for each armature cylinder. The characteristic is directly proportional and can be described as follows: as the rotor rotation speed of the thermogenerator increases, the temperature of the armature material, steel in this case, will also increase. This occurs because the magnetic losses in the armature, which are beneficial in this case, or in other words, the amount of energy induced in the armature material, increases with the frequency of the induced eddy currents.

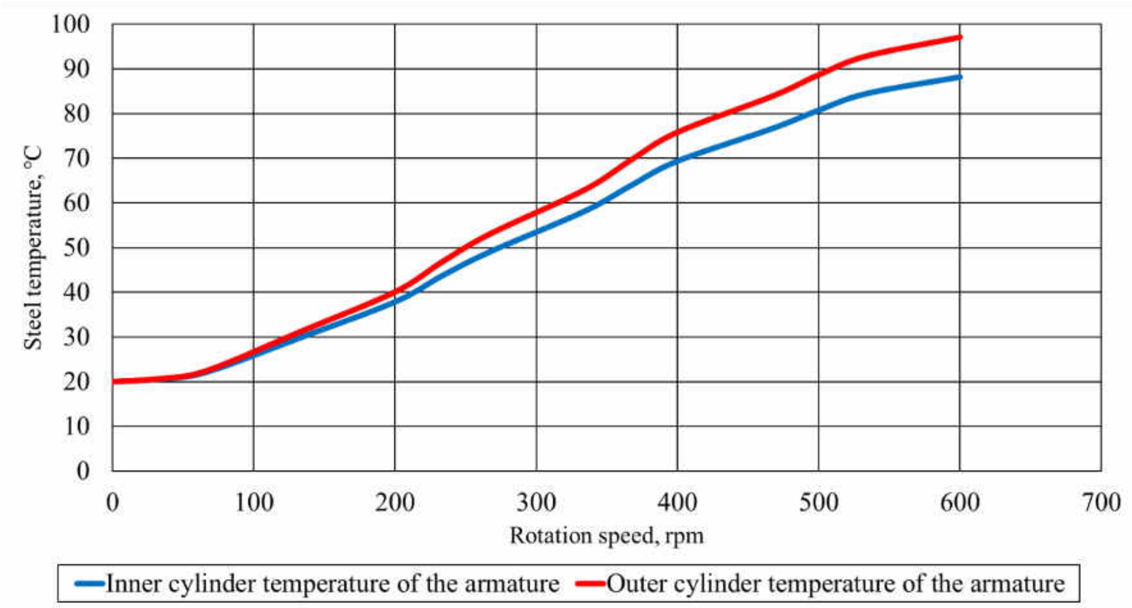


Figure 6. Variation of the armature material temperature depending on the rotor rotation speed of the thermogenerator

Subsequently, three constructive models of the thermogenerator were developed using SOLIDWORKS software to analyze the thermodynamic characteristics of the thermal generator concerning the study of the circulation of the heat transfer fluid through the thermogenerator jackets.

The developed models follow the same constructive principles and operating principles described in the work. The difference lies in the method of admission and circulation of the heat transfer fluid through the thermogenerator jackets. Each developed model was studied both with the jackets connected in series and in parallel. The elaborated models are:

- Direct intake thermogenerator, with the jackets connected in series/parallel, where the liquid intake is directly from the base of the generator, and the heat transfer fluid circulates freely through the circular channels of the jackets;
- Direct intake thermogenerator through a pipe mounted in the outer channel of the thermogenerator and connected in series/parallel with a pipe from the inner channel;
- Directed intake thermogenerator, with the jackets connected in series/parallel, where a metal sheet spiral is mounted inside the thermogenerator jackets, thus directing the flow of the heat transfer fluid through the entire surface of the jackets.

The simulation of the heat transfer fluid flow through the thermogenerator jackets was conducted using SOLIDWORKS Flow Simulation software. The purpose of the simulations is to analyze the fluid flow through the thermogenerator and determine the variation of the heat transfer fluid temperature in the discharge pipe depending on the flow rate $T_2(Q)$, for each constructive model at different imposed jacket temperatures T_0=40 °C, T_0=60 °C and T_0=80 °C.

The analysis of the fluid flow circulation was performed for the following inlet conditions: the liquid temperature in the intake pipe T_1=11 °C, imposed jacket temperatures: T_0=40 °C; T_0=60 °C and T_0=80 °C, ambient temperature T_a=20 °C, negligible external thermal energy losses P_{th}=0 and variation of the liquid flow rate through the thermogenerator jackets from 10 l/h to 3500 l/h.

According to the simulation results, in all cases, for the constructive model of the thermogenerator with direct intake and the model with direct intake through an internal pipe, when connecting the jackets both in series and in parallel, it is observed that there are zones with reduced circulation of the heat transfer fluid in the thermogenerator jackets, as shown in Figure **7** (see highlighted area). Consequently, the circulation of the fluid is uneven, leading to uneven heating of the fluid in the jackets. These zones are inactive in the heat transfer process in the thermogenerator or have low heat transfer, reducing the active working surface in the thermogenerator.

In the constructive model with directed intake, when connecting the jackets both in series and in parallel, the circulation of the heat transfer fluid is more uniform, and therefore the heating of the fluid is more uniform. The active working surface in the thermogenerator is maximized, as shown in Figure 8.

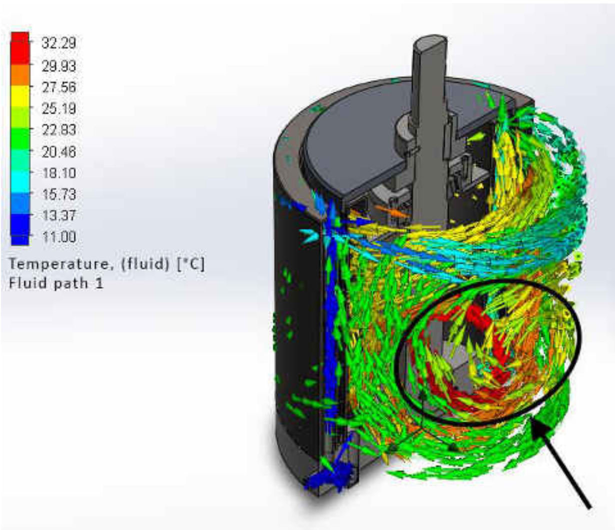


Figure 7. The flow of the liquid through the thermogenerator with direct intake through an internal pipe with the jackets connected in series, T_0=60 °C

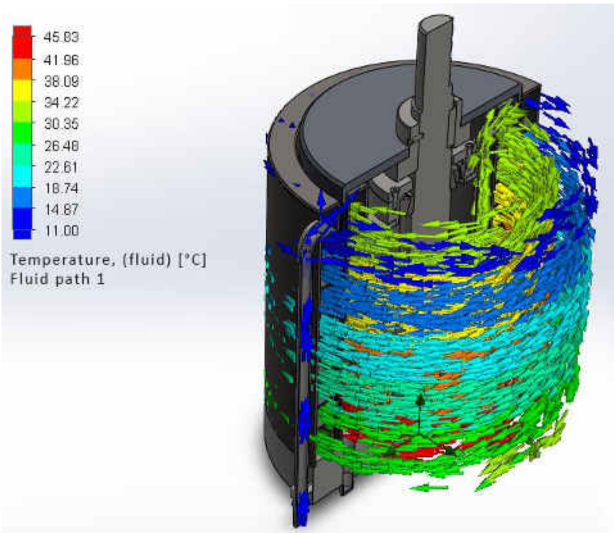


Figure 8. The flow of the liquid through the thermogenerator with directed intake and the jackets connected in series, T_0=60 °C

In Table 5, the results of the simulations regarding the circulation of the heat transfer fluid through the thermogenerator jackets are presented. The imposed temperature of the internal and external jackets is equal to T_0=60 °C, the temperature of the fluid in the intake pipe is – T_1=11 °C, the ambient temperature is T_a=20 °C, external thermal energy losses are negligible P_{th}=0 and the variation of the liquid flow rate through the jackets ranges from 10 l/h to 3500 l/h.

Table 5. Variation of the heat transfer fluid temperature in the discharge pipe depending on the flow rate $T_2(Q)$, T_0=60 °C

Liquid temperature in the discharge pipe depending on the flow rate, at T_0=60 °C; T_1=11 °C; T_a=20 °C; P_{th}=0						
Flow rate, l/h	Temperature T_2, °C					
	Model with jackets connected in series			Model with jackets connected in parallel		
	with direct intake	with direct intake through internal pipe	with directed intake	with direct intake	with direct intake through internal pipe	with directed intake
10	58,50	58,47	59,98	58,29	58,60	59,69
50	51,19	50,20	59,57	46,35	45,21	59,19
100	45,47	44,09	58,01	39,89	38,50	56,82
500	31,63	30,24	47,91	25,24	24,75	36,41
1000	27,50	27,50	44,86	23,04	21,65	33,46
1500	25,68	26,77	43,35	21,82	20,54	31,55
2000	25,10	26,43	42,34	21,71	20,17	30,39
2500	24,34	26,19	41,60	21,75	19,90	29,58
3000	24,00	25,96	41,02	21,40	19,64	28,97
3500	23,93	25,84	40,59	21,26	19,59	28,47

The thermal characteristic for all constructive models, in all cases of jacket temperatures, when connecting the jackets both in series and in parallel, has the same curve shape, which can be characterized as follows: as the liquid flow rate through the thermogenerator increases, the temperature of the liquid in the discharge pipe decreases, as shown in Figure 9. This occurs because at a higher flow rate, the heat transfer fluid fails to heat up sufficiently, resulting in a lower liquid temperature.

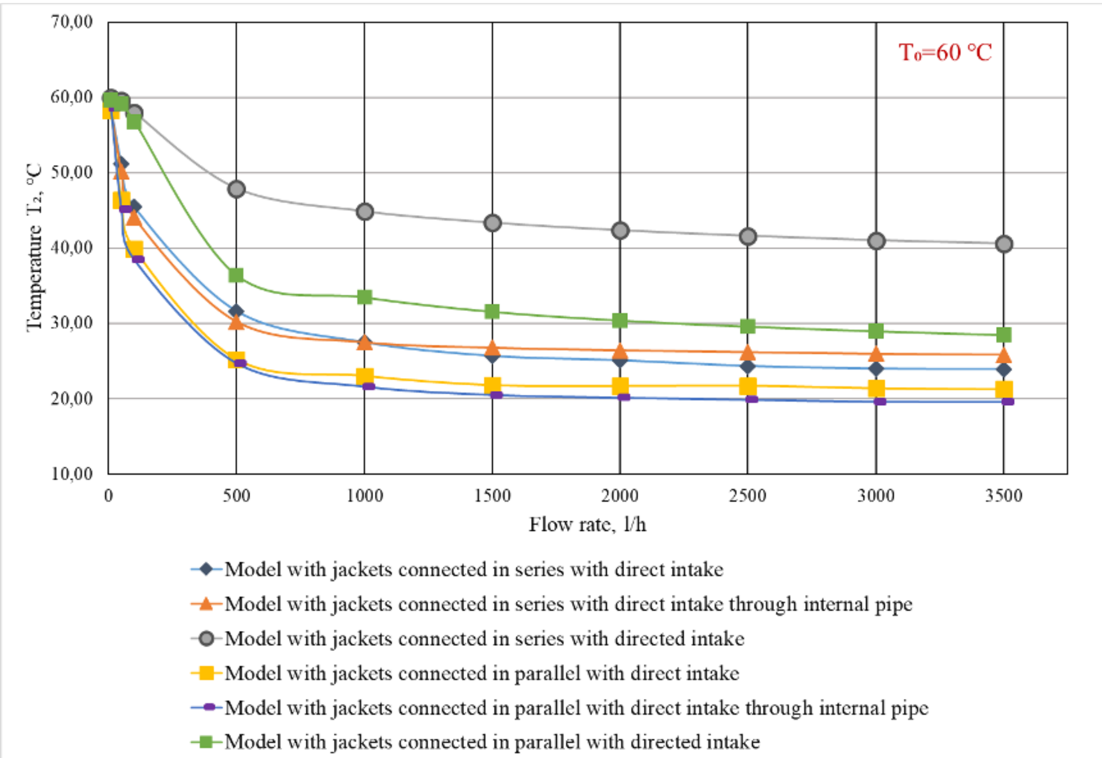


Figure 9. Variation of the heat transfer fluid temperature in the thermogenerator's discharge pipe depending on the flow rate $T_2(Q)$, T_0=60 °C

Chapter 4 – *Studies on the prospects of utilizing wind thermal energy,* a calculation was performed to estimate the thermal energy production of a wind turbine equipped with a permanent magnet thermal generator. A calculation method is presented to determine the wind characteristics for various heights based on developed wind energy potential maps. At the same time, calculations were made to determine the characteristics of a modern wind turbine.

There are several reasons why wind energy conversion systems should be more widely used for producing thermal energy for hot water or residential space heating. The main arguments are as follows:

1. Energy consumption structure of the Republic of Moldova: Out of the total energy resources consumed in 2021, equivalent to 2853 thousand tons of oil equivalent (t.o.e.), only 12% was consumed in the form of electricity. The remaining 88% was consumed in other forms of energy, including heating residential spaces, industrial processes, food preparation, and water heating.
2. Simplicity and cost-effectiveness of wind equipment for thermal energy production: Wind equipment for thermal energy production is simpler and cheaper compared to electricity production.
3. Addressing the issue of energy storage and utilization during calm periods: The problem of accumulating and using thermal energy during calm periods is easily solved. The cost ratio between an electric accumulator and a thermal accumulator of the same capacity is greater than 10, and the lifespan of the thermal accumulator is longer.
4. Efficient utilization of wind energy potential: The power of an air flow is proportional to the cube of the wind speed. Wind energy conversion systems must operate efficiently across the entire range of wind speeds, for example, from 3 to 20 m/s. The nominal power of small wind systems corresponds to a wind speed of 11-12 m/s. Therefore, at a wind speed of 20 m/s, a wind energy conversion system into electricity should have an overload factor of 5-6. However, in reality, this factor is around 1.2-1.3, primarily limited by the permanent magnet generator (PMG). The overload factor of the PMG is in turn limited by the properties of insulating and conducting materials.

As a result, for wind speeds higher than the nominal speed, the converted wind power into electricity needs to be limited, consequently leading to a sharp decrease in the efficiency of mechanical energy conversion into electricity. Therefore, it is rational to use a different type of generator – one that directly converts mechanical energy into thermal energy with a higher overload factor. Such a generator can be a thermal generator with eddy currents.

For calculating the annual amount of thermal energy production, the following input data are required: the power characteristic of the wind turbine $P(V)$ and the probability distribution function of wind speed, $f(V)$. The latter can be calculated using the Weibull function for which the coefficients A and k have been determined for heights of 10 and 20 m at the point of interest. Figure 10 presents the power characteristics $P(n,V)$ of the wind turbine and the power characteristic $P(n)$ of the thermal generator with eddy currents, while Figure 11 presents the power characteristic $P(V)$ of the small wind turbine AeroCraft 1002H: rotor diameter $D = 2{,}4\ m$, nominal power $P = 1\ kW$, wind speed $V = 9\ m/s$ for the case when the turbine is equipped with a thermal generator.

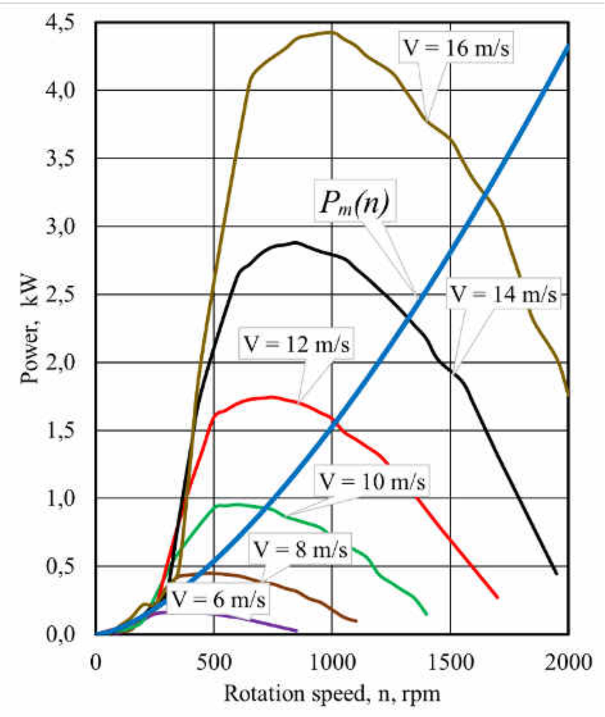


Figure 10. The characteristics of the turbine $P(n,V)$ and the thermal generator $P_m(n)$

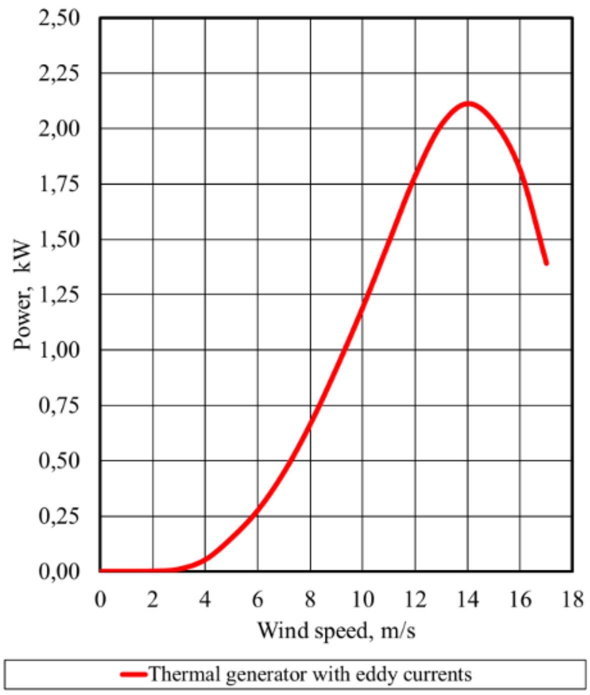


Figure 11. The power characteristic $P(V)$ of the wind turbine

Table 6 presents the power characteristic of the wind turbine when equipped with a thermal generator.

Table 6. The power characteristic $P(V)$ of the wind turbine

V	m/s	1	2	3	4	5	6	7	8	9
$P(V)$	W	0,04	0,81	10,11	52,67	149,97	275,43	447,26	663,66	917,07
V	m/s	10	11	12	13	14	15	16	17	18
$P(V)$	W	1191,48	1488,50	1785,96	2017,44	2112,20	2029,33	1811,39	1391,29	723,96

Using the Weibull distribution (1), knowing the values of coefficients A and k determined for the point of interest at the respective heights, the probability distribution of wind speed $f(V_i)$ has been calculated at the point of interest for heights of 10 and 20 m.

$$f(V) = \frac{k}{A} \cdot \left(\frac{V}{A}\right)^{k-1} \cdot \exp\left(-\left(\frac{V}{A}\right)^{k}\right) \tag{1}$$

Tables 7 – 8 present the numerical values of the probability density function of wind speed. For values greater than 14 m/s, $f(V_i)$ is very small and can be neglected. From the perspective of wind climatology, this means that at the point of interest, at the respective heights, winds with speeds greater than 14 m/s are extremely rare. Figures 12 – 13 depict the Weibull distributions.

Table 7. Results of the function calculation $f(V_i)$, $H = 10\ m$

V_i	m/s	1	2	3	4	5	6	7	8	9
$f(V_i)$	%	11,74	20,78	23,08	19,28	12,79	6,89	3,05	1,11	0,34
V_i	m/s	10	11	12	13	14	15	16	17	18
$f(V_i)$	%	0,08	0,02	0,00	0,00	0,00				

Table 8. Results of the function calculation $f(V_i)$, $H = 20\ m$

V_i	m/s	1	2	3	4	5	6	7	8	9
$f(V_i)$	%	7,25	15,15	19,83	19,86	16,11	10,83	6,08	2,87	1,14
V_i	m/s	10	11	12	13	14	15	16	17	18
$f(V_i)$	%	0,38	0,11	0,02	0,00	0,00				

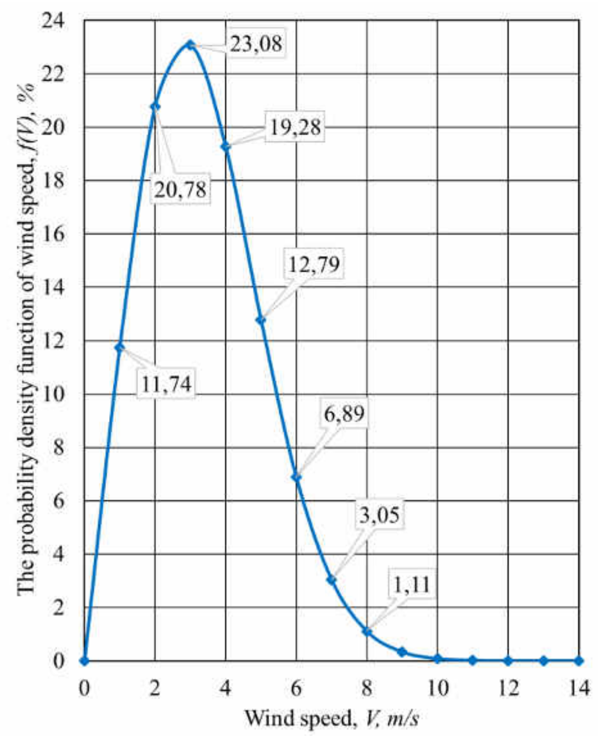


Figure 12. Weibull distribution of the wind speed probability function, $H = 10\ m$

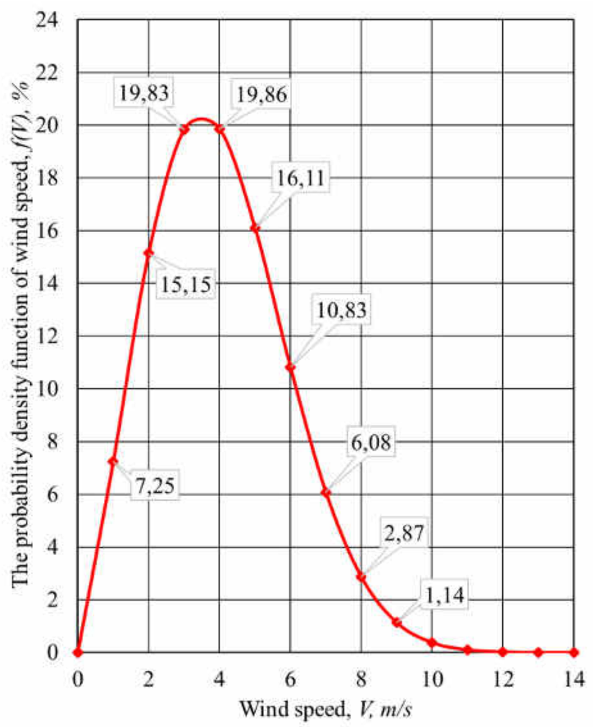


Figure 13. Weibull distribution of the wind speed probability function, $H = 20\ m$

The annual thermal energy production is calculated using the formula:

$$ET = T_{an} \cdot \eta \cdot \sum_{i=1}^{V_{max}} f(V_i) \cdot P(V_i) \quad (2)$$

where: $T_{an} = 8760\ h$ – the number of hours in a year;

$\eta = 95\ \%$ – the efficiency of the thermal generator;

$f(V_i)$ – the probability of wind speed V_i;

$P(V_i)$ – the mechanical power of the turbine at wind speed V_i.

At height $H = 10\ m$, using the $f(V)$ distribution from Table **7** and the power characteristic $P(V)$ for the wind turbine from Table 6, substituting the values into equation (2), we obtain the annual production of thermal energy:

$$ET_{an} = 8760 \cdot 0{,}95 \cdot 76{,}23 = 634354{,}24\ Wh = 634{,}35\ kWh \quad (3)$$

At height $H = 20\ m$, using the $f(V)$ distribution from Table 8 and the power characteristic $P(V)$ for the wind turbine from Table 6, substituting the values into equation (2), we obtain:

$$ET_{an} = 8760 \cdot 0{,}95 \cdot 129{,}85 = 1080630{,}69\ Wh = 1080{,}63\ kWh \quad (4)$$

Clearly, at a greater height above ground level, the wind characteristics are better, resulting in a higher amount of energy produced by the turbine. For the chosen point of interest, the thermal energy production increased by 70% at a height of 20 m compared to the production at a height of 10 m.

Analyzing the data regarding the energy requirement for preparing hot water based on facilities (Table 3), under the conditions of the selected point of interest, according to the calculations of thermal energy production for the small wind turbine, the following observations were made:

- The amount of thermal energy produced at a turbine height of 10 m would cover the annual energy needs of a household equipped with a water supply system, without sewerage system, without a toilet, without a bathtub or shower for one person ($660{,}65\ kWh$) practically in full or partially for two persons;
- At the same time, if the turbine were installed at a height of 20 m, in this case, the amount of thermal energy produced would cover the energy needs of a household already equipped with a water supply system, without a sewerage system, equipped with a toilet, washbasins, with a small bathtub or shower for one person ($828{,}55\ kWh$) in full or partially for two persons.

III. GENERAL CONCLUSIONS AND RECOMMENDATIONS

1. The total installed capacities of RES at the national level have shown a positive trend over the past years, yet still remain insufficient, considering that the production of e-RES for the year 2022 amounted to 196.237 GWh or 4.8% of the total electricity consumption. Furthermore, based on the study, it was found that in the rural sector, approximately 77.6% of households lack hot water heating systems, necessitating rural households to rely on other, often fossil, sources for thermal energy, including for hot water preparation. In this context, the development of a new field – the direct conversion of wind energy into thermal energy and the use of thermal generators with permanent magnets driven by wind turbines – is currently relevant. This would contribute to addressing an important social issue - providing hot water to the rural population - and would enhance the exploitation of wind potential.
2. Thus, it becomes necessary to conduct a study to determine the available wind energy potential at the local level, to assess the theoretically possible capacities for both thermal and electrical energy production. The study is conducted for administrative units at the second level (districts), for which wind energy potential maps of average wind speed and wind power density at heights of 50 and 100 meters have been developed. Accordingly, the territory of each district was classified based on the value of power density ranging from $150\ W/m^2$ to $400\ W/m^2$ at a height of 100 meters, and the theoretically possible wind power capacity was calculated. Therefore, according to the obtained results, the following observations were made:
    - assuming the use of wind turbines in areas with energy potential ranging from $300\ W/m^2$ to $400\ W/m^2$ with each turbine having a unit power of 3.0 MW, the highest power capacities in the respective regions could be installed as follows: 144 MW in the Sangerei district of NDR, 76 MW in the Nisporeni district of CDR, and 172 MW in the Cimislia district of SDR. It should be noted that the total theoretical power capacity depends on the area of the respective district – the larger the area, the greater the installed power capacity;
    - for the northern and southern districts of the country, the potential wind power density is 5 MW/km^2, while for the central districts, it varies, ranging between3,2 (Straseni) and 4,9 MW/km^2 (Anenii Noi);
    - the highest average annual wind speeds at a height of 100 m above ground level range from 7.4 in the north and center to 7.1 m/s in the south.

3. In order to harness the wind potential and improve the situation in the rural sector regarding hot water supply, a new technical solution has been proposed - the direct conversion of wind energy into thermal energy. For this purpose, a patented technical solution has been proposed - *Wind heat generator with eddy currents*. The distinctive features of the proposed technical solution include a higher efficiency of over 95%, a simple and reliable construction, no need for expensive materials except for the permanent magnets required for the thermal generator, which are still costly.
4. Various constructive models of the permanent magnet thermogenerator have been developed, and a series of calculations and simulations have been conducted using specialized software SOLIDWORKS Electromagnetic Simulation to determine the characteristics of a small-scale thermogenerator. Studies have been carried out to determine the characteristics of the magnetic field generated by the permanent magnets, with the ultimate goal of determining the temperatures of the armature cylinders as a function of the rotor speed. It was found that the temperature increases with the increase in revolutions, reaching an armature temperature of $97{,}1\ °C$ at a rotor speed of $600\ rpm$.
5. Simulations were also conducted in SOLIDWORKS Flow Simulation to study the flow circulation of the heat transfer fluid through the thermogenerator's jackets for various constructive variants. The aim was to determine the optimal construction where the liquid circulation is more uniform and the active working surface on the jackets is maximized. An optimal variant was identified - the constructive model with directional intake, both in series and in parallel connection of the jackets. In this case, the circulation of the heat transfer fluid is more uniform, resulting in a more even heating of the liquid and maximizing the active working surface in the thermogenerator. Based on these results, the temperatures of the heat transfer fluid in the discharge pipe were determined as a function of the liquid flow rate. The conclusion remained the same: the temperatures are highest when the active working surface is approximately twice as large.
6. During the simulations, the variation in the pressure required in the intake pipe to maintain the necessary liquid flow for each constructive model was analyzed. These data will be used to calculate the necessary characteristics of the circulation pump, which will ensure a constant pre-set flow rate of the liquid through the thermogenerator's jackets.
7. It was found that the constructive model of the thermogenerator with directional intake generates a useful heat flow two to three times higher compared to other models.
8. It is worth mentioning that there is a positive effect on the thermal characteristics of the thermogenerator as a result of installing metal sheet spirals in the thermogenerator's jackets

to direct the flow of the heat transfer fluid - the temperature values of the heat transfer fluid in the discharge pipe are over 70% higher compared to other cases.

9. The scientific results obtained in the thesis, which refer to the study of wind energy potential and the characteristics of the thermogenerator with permanent magnets, as well as the estimation of thermal energy production, are valid for any point and height above ground level. They will serve as a support for local public authorities in making decisions regarding energy policy at the local level. As an example, we present the results obtained for the point of interest near the locality of Magdacesti, Criuleni district. The following results were obtained:
   - based on the data from the wind energy potential maps, the wind characteristics were calculated at heights of 10 and 20 meters. Thus, at a height of $10\ m$, the average wind speed is $3{,}39\ m/s$, and at a height of $20\ m$, it is $4{,}03\ m/s$;
   - according to the proposed method for calculating wind characteristics, the Weibull distribution coefficients necessary for performing the calculations and estimating the energy production of a wind turbine were determined. For a height of 10 m, the Weibull coefficient A is 3,83 m/s, and k is 2,1054; for a height of 20 m, the Weibull coefficient A is 4,55 m/s, and k is 2,2431;
   - based on the wind characteristics determined at the respective heights, the thermal energy production of a wind turbine with a thermogenerator with permanent magnets was calculated. Accordingly, at a height of 10 m, the annual amount of thermal energy produced would be 634,35 kWh, and at a height of 20 m, it would be 1080,63 kWh. It was found that the production of thermal energy increased by 70% at a height of 20 m compared to the production at a height of 10 m;
   - According to the calculations, the studied thermogenerator has a nominal conventional power of approximately $300\ W$ (the induced current frequency is $50\ Hz$), and at a speed of $600\ rpm$ (the induced current frequency is $90\ Hz$), it is approximately $700\ W$.

Recommendations for future research.

1. Based on the wind energy potential maps presented in the study for second-level administrative-territorial units (districts) and the proposed calculation method for determining wind characteristics at heights ranging from 10 to 150 meters, an interactive online platform about the wind energy potential of the Republic of Moldova could be developed.

2. Development and construction of a system consisting of a small-scale wind turbine with horizontal or vertical axis and a thermogenerator with permanent magnets, followed by laboratory experiments and real-world field trials.

List of publications on the thesis topic

Collective specialty books:

1. RACHIER, Vasile, **MANGOS, Octavian**, SOBOR, Ion, CHICIUC, Andrei. „Wind Energy Potential of the Republic of Moldova", Technical University of Moldova, Faculty of Energetics and Electrical Engineering, Department of Electrical Engineering. – Chisinau: S.n., 2023 (Bons Offices). – 275 p. ISBN 978-5-36241-124-4. (Monograph).

Articles in scientific journals from the National Registry of Profile Journals:

1. **MANGOS, Octavian**, RACHIER, Vasile, SOBOR, Ion, CAZAC, Vadim. Regarding the characteristics of the wind in northern region districts of the Republic of Moldova. In: Journal of Engineering Sciences. 2022, vol. 29, nr. 1, pp. 121-129. ISSN 2587-3474. DOI: https://doi.org/10.52326/jes.utm.2022.29(1).11
2. **MANGOS, Octavian**, RACHIER, Vasile, SOBOR, Ion, CAZAC, Vadim. Wind energy potential and wind characteristics for the districts of the central development region of the Republic of Moldova. In: Journal of Social Sciences. 2022, vol. 5, nr. 4, pp. 100-118. ISSN 2587-3490. DOI: https://doi.org/10.52326/jss.utm.2022.5(4).08

Articles in scientific conference proceedings included in WoS and SCOPUS Databases:

1. SOBOR, Ion, **MANGOS, Octavian**, TĂRÂŢĂ, Stela. The Present State of the e-RES Sector in Moldova Republic. In: *Sielmen Proceedings of the 13th international conference on electromechanical and power systems*. 13th edition, October 9-11, 2019, Craiova. New Jersey, SUA: Institute of Electrical and Electronics Engineers Inc., 2019, p. 0. ISBN 978-172814011-7. DOI: https://doi.org/10.1109/SIELMEN.2019.8905902
2. **MANGOS, Octavian**. Study of the Circulation of Heat Transfer Fluid in the Permanent Magnets Thermo-Generator. In: *Sielmen Proceedings of the 11th International Conference on Electromechanical and Energy Systems*. 11th edition, October 7-8, 2021, Iasi. Chisinau: Pro Libra, 2021, pp. 538-542. ISBN 978-166540078-7.
DOI: https://doi.org/10.1109/SIELMEN53755.2021.9600357
3. RACHIER, Vasile, **MANGOS, Octavian**, SOBOR, Ion. The Southern Development Region of the Republic of Moldova in Context of the Wind Energy Potential. In: *Sielmen 14 International Conference on Electromechanical and Energy Systems*. 14th edition, October 11-13, 2023, Craiova. Institute of Electrical and Electronics Engineers Inc.: Editura ALMA, 2023, pp. 1-6. ISBN 979-835031524-0.

DOI: https://doi.org/10.1109/SIELMEN59038.2023.10290790.

4. **MANGOS, Octavian,** RACHIER, Vasile, SOBOR, Ion. Determination of Wind Characteristics for Different Heights Based on Digital Maps of the Wind Potential of the Republic of Moldova. In: *Sielmen 14 International Conference on Electromechanical and Energy Systems*. 14th edition, October 11-13, 2023, Craiova. Institute of Electrical and Electronics Engineers Inc.: Editura ALMA, 2023, pp. 1-4. ISBN 979-835031524-0. DOI: https://doi.org/10.1109/SIELMEN59038.2023.10290830.

Articles in conference proceedings and other scientific events included in other databases accepted by ANACEC:

1. **MANGOS, Octavian**. Study of the experimental characteristics of thermal solar collectors. In: *Technical-scientific conference of students, master's and doctoral students*. Vol.1, March 26-29, 2019. Chisinau, Republic of Moldova: 2019, pp. 138-142. ISBN 978-9975-45-588-6. https://ibn.idsi.md/vizualizare_articol/84329
2. **MANGOS, Octavian**. Prospects for the use of wind electrical and thermal energy nationwide. In: *Technical-scientific conference of students, master's and doctoral students*. Vol.1, April 1-3, 2020. Chisinau, Republic of Moldova: 2020, pp. 53-56. ISBN 978-9975-45-632-6. https://ibn.idsi.md/vizualizare_articol/106133
3. **MANGOS, Octavian**. Study of the pressure and distribution of heat transfer fluid in the thermogenerator with permanent magnets. In: *Technical-scientific conference of students, master's and doctoral students*. Vol.1, March 29-31, 2022, Chisinau, Republic of Moldova: Tehnica-UTM, 2022, pp. 84-88. ISBN 978-9975-45-828-3. https://ibn.idsi.md/vizualizare_articol/161522
4. **MANGOS, Octavian**. Evaluation of energy consumption in households for heating domestic hot water. In: *Technical-scientific conference of students, master's and doctoral students*. Vol.1, March 23-25, 2021, Chisinau, Republic of Moldova: Tehnica-UTM, 2021, pp. 146-149. ISBN 978-9975-45-699-9. https://ibn.idsi.md/vizualizare_articol/133811
5. **MANGOS, Octavian**. Analysis of heat flows in the eddy current wind generator. The 3th International Conference On Electrical Engineering And Systems (ICEES). 21 – 23 September 2022, Resita, Romania. ISSN-v online: 2734-7680, ISSN-L: 2734-7680 VOL.67, No.1, 2022. pp. 85-92. DOI: https://doi.org/10.24193/subbeng.2022.1.8
6. **MANGOS, Octavian**, SOBOR, Ion, CAZAC, Vadim, BURDUNIUC, Marcel. Study of the pressure and distribution of heat transfer fluid in the thermogenerator with permanent magnets and eddy currents. National Conference on Electric Drives CNAE-2022. 12-13

mai 2022, Timişoara. ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering. ISSN: 1584-2665 [print]; ISSN: 1584-2673 [online]. Tome XX [2022] Fascicule 3 [2022], pp. 37 – 40; https://annals.fih.upt.ro/pdf-full/2022/ANNALS-2022-3-04.pdf

7. **MANGOS, Octavian**, CIUPERCĂ, Rodion, SOBOR, Ion. Wind heat generator with eddy currents. Book of abstracts of the VIth International Fair of Innovation and Creative Education for Youth (ICE-USV), July, 10 – 12, 2022, Suceava, Romania. ISSN 2821 – 7543, ISSN-L 2821 – 7543. No. 6/2022, pp. 27 – 29. https://ice-usv44.webnode.ro/copie-a-current-edition/

Patent granted by the State Agency for Intellectual Property:

1. **MANGOS, Octavian**, CIUPERCĂ, Rodion, SOBOR, Ion. Wind heat generator with eddy currents. Patent 4815 (13) B1, F03D 9/00; H05B 6/02; F24H 1/10. Technical University of Moldova. Deposit number A2020 0068. Deposit date 26.08.2020. Published 31.07.2022. http://www.db.agepi.md/Inventions/details/a%202020%200068

ADNOTARE

Autor – MANGOS Octavian. **Titlul** – *Contribuții la valorificarea potențialului energetic eolian al Republicii Moldova. Teză* de doctor în vederea conferirii titlului de doctor în științe inginerești la specialitatea *221.02. „Tehnologii de conversie a energiei și resurse regenerabile (energie eoliană)”.* Chișinău 2024.

Structura lucrării: Lucrarea include introducerea, patru capitole, concluzii generale și recomandări, bibliografie din 96 titluri și include 7 anexe, 133 pagini, 113 figuri și 25 tabele. Rezultatele obținute sunt publicate în 14 lucrări.

Cuvinte cheie: potențial eolian, termogenerator eolian, modele 3D, SOLIDWORKS Flow Simulation, energie termică regenerabilă (t-SRE).

Domeniul de studiu – științe inginerești și tehnologii.

Scopul lucrării constă în evaluarea potențialului eolian pentru entitățile administrativ-teritoriale de nivelul doi (raioane) pentru producerea energiei termice și electrice, cercetarea și proiectarea unui termogenerator eolian pentru conversia directă a energiei eoliene în energie termică, care ar asigura sectorul rezidențial cu energie termică și care ar conduce la atingerea obiectivelor Republicii Moldova privind valorificarea energiilor regenerabile.

Obiectivele lucrării: analiza sectorului electroenergetic în ultimii 10 ani, inclusiv a producției de energie electrice (EE) din surse regenerabile (e-SRE), determinarea perspectivei utilizării energiei termice regenerabile (t-SRE) în gospodăriile casnice din sectorul rural al Republicii Moldova, realizarea studiului potențialului energetic eolian și ale caracteristicilor vântului la înălțimi de 50 și 100 m deasupra nivelului solului, identificarea amplasamentelor pentru eventualele centrale eoliene și evaluarea capacităților posibile de instalat în entitățile administrativ-teritoriale de nivelul doi (raioane), cercetarea și proiectarea unui termogenerator eolian de mică putere pentru sectorul rezidențial.

Noutatea și originalitatea științifică a lucrării: constă în identificarea problemelor și căilor posibile de rezolvare privind perspectiva utilizării energiei termice regenerabile (t-SRE) în gospodăriile casnice din sectorul rural și elaborarea metodei de calcul a termogeneratorului eolian de mică putere și producerii de energie termică pentru sectorul rezidențial.

Problema științifică importantă soluționată: constă în cercetarea și proiectarea termogeneratorului eolian pentru conversia directă a energiei eoliene în energie termică pentru producerea de apă caldă menajeră în localitățile rurale.

Importanta teoretică: aduce contribuții științifice într-un domeniu de interes relativ nou – conversia directă a energiei eoliene în energie termică, se propune o nouă schemă a termogeneratorului eolian cu magneți permanenți, pentru care s-a obținut brevet de invenție.

Valoarea aplicativă a lucrării: rezultatele lucrării vor contribui la îmbunătățirea situației în sectorul rural în ceea ce privește alimentarea cu apă caldă și în consecință asigurarea Obiectivului de Dezvoltare Durabilă 6 al ONU, dar și ar contribui la atingerea obiectivelor trasate în HG nr. 102 din 05.02.2013 „Cu privire la Strategia energetică a Republicii Moldova până în anul 2030”, privind promovarea utilizării energiei din surse regenerabile și în consecință sporirea securității energetice a țării.

ANNOTATION

Author – MANGOS Octavian. **Title** - *Contributions to harnessing the wind energy potential of the Republic of Moldova*. Doctoral thesis for PhD qualification in engineering science *221.02. „Energy conversion technologies and renewable resources (wind energy)"*. Chisinau 2024.

Thesis structure: The paper comprises an introduction, four chapters, general conclusions and recommendations, 96 references, 7 annexes, 133 pages, 113 figures and 25 tables.

The results are published in 14 scientific papers.

Keywords: wind potential, wind thermal generator, 3D models, SOLIDWORKS Flow Simulation, renewable thermal energy (t-SRE)

Field of study – engineering sciences and technologies.

The purpose of the thesis consists in evaluation of the wind potential for administrative-territorial entities of the second level (districts) for production of thermal and electrical energy, the research and design of a wind thermal generator for the direct conversion of wind energy into thermal energy, which would provide the residential sector with thermal energy and which would lead to the achievement of the objectives of the Republic of Moldova regarding the exploitation of renewable energies.

Objectives of the paper: analysis of the electric energy sector in the last 10 years, including the production of electric energy (EE) from renewable sources (e-SRE), determining the perspective to use of renewable thermal energy (t-SRE) in households in the rural sector of the Republic of Moldova, carrying out the study of energy potential and the characteristics of wind at heights of 50 and 100 m above ground level, the identification of locations for possible wind power plants and the evaluation of possible capacities to be installed in the administrative-territorial entities of the second level (districts), the research and design of a low power wind thermal generator for the residential sector.

Scientific novelty and originality of the work: it consists in identifying the problems and possible solutions regarding the perspective of using renewable thermal energy (t-SRE) in households in the rural sector and calculation method development of low-power wind thermal generator and the production of thermal energy for the residential sector.

The important scientific problem solved: consists in the research and design of the wind thermal generator for the direct conversion of wind energy into thermal energy for the production of domestic hot water in rural localities.

Theoretical importance: it makes scientific contributions in a relatively new field of interest – the direct conversion of wind energy into thermal energy, a new scheme of the wind thermogenerator with permanent magnets is proposed, for which an invention patent was obtained.

The practical value of the work: the results of work will contribute to improving the situation in the rural sector in terms of hot water supply and, consequently, ensuring Sustainable Development Goal 6 of the UN, but would also contribute to achieving the goals outlined in GD no. 102 of 05.02.2013 "Regarding the Energy Strategy of the Republic of Moldova until 2030", regarding the promotion of the use of energy from renewable sources and consequently increasing the energy security of the country.

АННОТАЦИЯ

Автор – МАНГОС Октавиан. **Название** - *Вклад в использование потенциала ветроэнергетики в Республике Молдова*. Диссертация о присвоение докторской степени в области инженерных наук, специальность 221.02 - *Технологий преобразования энергии и возобновляемые ресурсы (ветровая энергия).* Кишинев, 2024.

Структура работы: Работа включает введение, четыре главы, общие выводы и рекомендации, библиографию из 96 наименований, 7 приложений, 133 страниц, 113 рисунков и 25 таблиц. Результаты исследования опубликованы в 14 научных работах.

Ключевые слова: ветровой потенциал, тепловой генератор, 3D модели, SOLIDWORKS Flow Simulation, возобновляемая тепловая энергия (т- ВИЭ).

Область исследования – инженерные науки и технологии.

Цель диссертации состоит в оценке ветрового потенциала административно-территориальных образований второго уровня (районов) по производству тепловой и электрической энергии, исследовании и проектировании ветротеплогенератора прямого преобразования энергии ветра в тепловую энергию, что обеспечило бы жилой сектор тепловой энергией и привело бы к достижению целей Республики Молдова в отношении использования возобновляемых источников энергии.

Задачи диссертации: анализ отрасли электроэнергетики за последние 10 лет, в том числе производства электроэнергий из возобновляемых источников (э-ВИЭ), определение перспективы использования возобновляемой тепловой энергии (т- ВИЭ) в домохозяйствах в сельской местности Республики Молдова, изучения энергетического потенциала и характеристик ветра на высотах 50 и 100 м над уровнем земли, определение мест для возможных ветряных электростанций и оценка возможных мощностей для установки в административно-территориальных единицах второго уровня (районах), исследование и проектирование ветротеплогенератора малой мощности для жилого сектора.

Научная новизна диссертации: заключается в выявлении проблем и возможных путей их решения по использованиюя возобновляемой тепловой энергии (т- ВИЭ) в домохозяйствах сельского хозяйства и определении методики расчета маломощного ветротеплогенератора с постоянными магнитами и производство тепловой энергии для жилищного сектора.

Решаемая научная проблема: заключается в исследовании и разработке ветротеплогенератора для прямого преобразования энергии ветра в тепловую энергию для производства горячей воды для бытовых нужд в сельской местности.

Теоретическая значимость: вносит научный вклад в относительно новую область исследований – прямое преобразование энергии ветра в тепловую, предлагается новая схема ветрового термогенератора с постоянными магнитами, на которую получен патент на изобретение.

Прикладное значение работы: результаты работы будут способствовать улучшению ситуации в сельском хозяйстве в части горячего водоснабжения и, как следствие, обеспечению Цели устойчивого развития 6 ООН, а также будут способствовать достижению намеченных целей в постановление правительства № 102 от 05.02.2013 г. «Об Энергетической стратегии Республики Молдова до 2030 года», касающейся продвижения использования энергии из возобновляемых источников и, следовательно, повышения энергетической безопасности страны.

MANGOS OCTAVIAN

CONTRIBUTIONS TO HARNESSING THE WIND ENERGY POTENTIAL OF THE REPUBLIC OF MOLDOVA

FIELD OF STUDY: 221.02. "ENERGY CONVERSION TECHNOLOGIES AND RENEWABLE RESOURCES (WIND ENERGY)"

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