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Photovoltaic Cells as an Alternative to Conventional Energy in Dairy Cattle Farming

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A current and important issue in the field of agriculture which is zootechnics in the world and in our country is to prevent the harmful effects of intensive livestock production on the natural environment. Current research focuses not only on issues defining the current state but also on the search for possible solutions for methods restricting the environmental risk associated with the development and improvement of the above production. The research concerns mainly harmful gas admixtures which are emitted from animal farms, i.e. farm buildings and manure storage areas on these farms as well as the content of biogenic compounds in the waste. Taking into account the problem of environmental protection and its dependence on animal production, it should be stated that an equally important issue is the energy consumption on animal farms, livestock buildings as well as in the applied technological solutions and devices. This issue is directly related to the issues of fighting the climate change (Chel and Kaushik, 2011, Weiske et al., 2006). So far, research has focused on the issues of the microclimate of premises or the impact of the type of heating on the animals. Therefore, so as the research on the impact of animal production on the environment should have a comprehensive dimension - its scope should also take into account the above-mentioned issues of energy saving.

Modern thermal power engineering, despite the promotion and implementation of alternative or renewable resources, is still largely based on fossil fuels, which is particularly important in Poland, where resources such as coal are still relatively large, widely used and will remain irreplaceable for a long time. In the case of smaller power, alternative energy sources are increasingly conquering the market. Specialised heat exchangers and heat pumps, recuperators and other devices recovering lost energy, e.g. in ventilated air, they are becoming more and more popular.

The sun is the main source of energy on Earth. It provides a steady and predictable energy flow of up to 1.35 kW per square meter of the planet's surface. Photovoltaic (PV) technology, capable of exploiting these resources, was developed in the 1950s of the 20th century. However, despite investing in research to increase efficiency and significantly reduce costs, solar panels are still a relatively rare sight on the roofs of houses, let alone livestock buildings in Europe. However, since 2005, the development of the European PV market has been growing at a high rate. The undisputed leader in Europe and in the world is Germany thanks to its installed 600 MW. This increase could be even higher if it were not for the reduction of global production due to the continuous shortage of the basic raw material for most PV technologies - silicon. In order to provide renewable energy, solar energy can be used in two ways: electricity generation and water heating. Photovoltaic technology uses semiconductor materials that carry electric charges to absorb light. Most commercial PV systems are based on silicon technologies. Two of them occur in processes similar to those used in the production of microprocessors, using silicon wafers of high purity. Monocrystalline silicon is very efficient but quite expensive whereas polycrystalline silicon is cheaper but less efficient and produces less power per part area. Thin-film silicon technologies have also been developed to replace amorphous or microcrystalline silicon in large-area flat substrates, such as glass.

Solar thermal energy systems for heating water in central heating or cooling systems are equally important. Water heating using solar energy is a fully mature technology. The annual surface area of solar water heaters in the EU Member States is almost 1.5 million m^2. Some European countries, including Spain ordered the inclusion of solar heating in new and refurbished heating installations. This technology includes the use of flat flow panels or rows of black plastic pipes placed on the southern roofs. Such solar heating systems, designed for hot water and central heating, operate at temperatures up to 60° C (Latała, 2010). In Poland, there are opportunities to use solar energy for heating purposes similar to those found in Germany, Denmark and the Great Britain. Ireland, Belgium and the Netherlands have slightly better conditions. With regard to the possibility of producing electricity using photovoltaic technology, all the above-mentioned countries, including Poland, have similar conditions. The annual total of solar radiation on the horizontal surface in Poland oscillates around 1000 kWh/m^2 and ranges from 950 to 1250 kWh/m^2. In Mikolajki it is about 1068 kWh/m^2, in Zakopane – about 1000 kWh/m^2, and in Warsaw – about 962 kWh/m^2. The sum of total radiation for spring and summer months (April-September) is on average 775 kWh / m^2 for Poland, and 225 kWh / m^2 in winter months. In addition to the magnitude of solar radiation, an important meteorological factor in the analysis of the use of solar energy is insolation, or the number of hours per year with a direct visible solar operation. The average sunshine for Poland is around 1600 hours / year, 75% of which is in the spring and summer period. For example, the average annual sunshine for Warsaw is around 1649 hours / year, for Paris around 1840 hours / year and for Copenhagen around 1860 hours / year.

The total installed capacity in solar systems in Poland in 2016 was around 199 MW. The power of PV installations according to ERO data is over 99 MW. The remaining 100 MW have been installed in micro installations connected to the network but not using the green certificate system. The main producers of energy in micro-installations are natural persons but, increasingly, such installations are established by enterprises. Natural persons choose smaller installations - micro-installations up to 10 kW account for over 90% of all installed in individuals' premises. In turn, entrepreneurs usually create larger micro installations - installations above 10 kW account for approximately 63% (IEO Report, 2017). Increasing efficiency while lowering the cost of cell production creates real possibilities of using them for the production of electricity (tab. 3). In Poland, flat plate solar collectors can also be used as a source of low temperature heat for the production of hot utility water and in drying processes, such as agricultural manufacture.

The capacity of renewable energy sources (RES) installed in Poland at the end of 2016 amounted to over 8.5 GW. The share of photovoltaics - despite continuous, significant growth since 2014 - is still negligible and amounts only to 2.3% in RES capacity and 0.5% in installed capacity in the national energy system. In all the EU countries, at the end of 2016, there was 102.5 GW of installed capacity in photovoltaics. The share of Poland is insignificant and amounts to only 0.1% (IEO Report, 2017).

The comparison of the RES technical potential of Poland and selected Scandinavian countries shows that Poland has relatively high potential for the use of renewable energy. At the same time, a low share of renewable energy in the total energy production in the country is observed in relation to the analogous share in Denmark and Sweden. The analysis of data on the percentage share of individual primary energy sources in total electricity production shows that in most of the analysed countries this production is based on fossil fuels. In Poland, its share is over 97% (mainly lignite and hard coal), in Denmark over 87% (mainly hard coal and natural gas), in the Czech Republic about 78% (mainly lignite and hard coal), in Great Britain about 75% (mainly natural gas and hard coal), in Germany about 60% (mainly lignite and hard coal). In Slovakia and Finland, the share of fossil fuels in electricity production is at a comparable level (in the case of Slovakia, it is about 30%, in Finland about 32%). However, the smallest share of fossil fuels in electricity production can be observed in Sweden (over 4% only). From among the analysed European countries, only Poland and Denmark have no nuclear power plants. In other countries, electricity produced using nuclear energy accounts for from around 19% in the Czech Republic to around 53% in Slovakia. In Great Britain, it is around 22%, in Germany about 31%, in Finland over 32% and in Sweden over 38%. Undoubtedly, the largest production of electricity from nuclear energy is noted in France - about 80% of total production (Rogulska et al., 2003).

Renewable energy sources are characterised primarily by high unit investment input and often a high degree of risk related to the availability of energy they produce. Due to purely economic factors, it can be noticed that the reserve capacity of system power plants and, at the same time, actions aimed at reducing energy consumption with a low rate of economic growth in the country cause that the development of RES will generate additional costs associated with the elimination of existing energy sources. On the other hand, an extremely important aspect of the use of renewable energy associated with the reduction of pollutant emissions, including greenhouse gas emissions, is of no importance when deciding on the construction or modernisation of energy sources in Poland.

The mentioned issues, apart from a few exceptions, are not taken into account in animal production. And yet, intensive animal breeding, with a significant scale and concentration of production, as any industrial activity, should develop methods of energy efficiency (Kolano and Stelmach, 2017).

The scientific purpose of the research was to determine the possibilities of using alternative energy sources along with determining their effectiveness in farm dairy cattle breeding. To achieve the assumed goal, it was necessary to perform such tasks as:

1. carrying an audit on the electric power consumption;
2. determining the actual productivity of renewable energy sources (RES) applied on the farm.

The practical goal of the research was to obtain information on the effective possibilities of reducing the consumption of classical electricity and heat in dairy cattle farming.

Materials and methods

Experimental material

The experiment was carried in buildings in which 350 dairy cows, heifers and calves were maintained. The animals were kept in free stands in identical heated and mechanically ventilated rooms. Lighting and equipment elements of individual rooms, i.e. the thermae, the milk feeding station and the milking machine, were auxiliary supplied by power coming from photovoltaic cells. Suitable control groups were equipped with standard equipment. The animals were fed and maintained in accordance with the applicable standards and with constant access to water.

Experimental design

The experiment used a photovoltaic power of 2.2 kW and a voltage of 16 V. The installation was equipped with an energy meter, converter and inverter converting direct current into alternating current with a rated voltage of 230 V and a frequency of 50 Hz. The system was equipped with gel batteries balancing the excess and power shortage resulting from insolation. These alternative energy sources have been used to supply the following receivers:

- 3 volumetric hot water heaters (boilers) with a total capacity of 300 litres;
- automatic milk feeding station;
- milking machine;
- illumination of cowshed, calf-heifer house and calving pen, equipped with the total of 35 internal luminescent receivers (fluorescent lamps) with a total capacity of 2.8 kW and 8 external halogen receivers with a total capacity of 2.1 kW.

During the research, three tasks were carried out.

Task no. 1.

An energy audit of a dairy cattle farm was carried out and the course of external insolation conditions and the flow of air masses were measured. This task included work related to the estimation of electricity consumption at particular stages of the farm production. The research was carried out by assembling one- and three-phase energy meters in individual circuits supplying individual elements of technology, e.g. lighting, boilers, milking machine, etc. The second issue was determining the impact of the farm location on the possibility of acquiring solar energy as alternative sources for the production purposes. Measurements were carried out for three years in a continuous cycle. The design of task 1 is illustrated in diagram 1.

Schemat 1. – *Diagram 1.*

Replication/Season of the year	*Calving pen, dry cows, in-calf heifers*	*Calf-heifer house*	*Dairy cows*	*Other facilities*
	No. of animals (head)			
I. *Spring/autumn*	80	110	160	X
II. *Winter*	80	110	160	X
III. *Summer*	80	110	160	X

Task no. 2.

Photovoltaic cells were used to power the dormitory room lighting. The research covered the possibility of supporting the electric power supply generated in photovoltaic cells of room lighting for dairy cows, heifers and calves. For each of the sources, the sectors of maintenance of dairy cows, heifers and calves were connected through the energy meter, equipped with lighting with the total power of 4.92 kW in the form of 35 fluorescent lamps mounted identically under the ceiling and 8 halogen external lamps. The measurements were made for the amount of consumed energy and the efficiency of the receivers. As a control system, lighting was used, with energy supplied from the mains.

Task no. 3.

Photovoltaic cells were used to power the hot-water devices (boilers) and technological devices (milking machine and the water station). Research carried out in this task concerned the possibility of powering electricity generated in photovoltaics - boilers, storing stations and milking rooms in dairy cows, heifers and calves. Measurements were made for the amount of produced energy and the energy consumption by the devices. The design of tasks 2 and 3 is illustrated in diagram 2.

Schemat 2. – *Diagram 2.*

Replication/ season of the year	*Type of power*							
	lighting		*boilers*		*milk feeding station*		*milking machine*	
	power grid	*photovoltaic cell*	*power grid*	*photovoltaic cell*	*power grid*	*photovoltaic cell*	*power grid*	*photovoltaic cell*
	No. of animals (head)							
I. *Spring/autumn*	350	350	160	160	30	30	3	3
II. *Winter*	350	350	160	160	30	30	3	3
III. *Summer*	350	350	160	160	30	30	3	3

Data types and collection methods:

a) measurements of the amount of consumed electricity in powered devices in kWh - electronic electricity meters in a continuous manner,
b) measurements of the amount of consumed electricity in powered devices in kWh - electronic electricity meters in a continuous manner,
c) external climatic conditions on the farm together with insolation - electronic DeltaOhm meters in a continuous manner; the measurements of air velocity and direction at a height of 15 m, insolation at the height of the building roof (7 m).

The method of the obtained data processing.
The collected data was statistically processed with the variance analysis method.

The results of the experiments and their generalisation

Task no. 1. Performing an energy audit of the farm and the course of external conditions of insolation and air mass flow.

The data obtained for the monitoring of weather conditions for the location of the farm (tab. 1) do not differ significantly from those prevailing in the Krakow-Czestochowa Upland (Woś, 1996). The average annual rainfall amounts here to c. 600-700 mm. The air is relatively dry, and the most days of sunshine occur in late summer and early autumn. The average annual temperature is about 7°C, except in the southern part of the highlands, where it is about 1°C higher. The climate of this area is characterised by the features of continentalism which are manifested, inter alia, by the rare occurrence of high temperature amplitudes. Snow covers are here for the average of about 80 days but this is diversified across the region. As within the entire area of Poland, western winds dominate (about 60%). In winter, weather conditions are most often shaped by Icelandic and Arctic anticyclones. In the summer months, they are a result of the influence of the Azores anticyclone with subtropical air and anticyclone from over Africa. The measured average air velocities at a height of 15 m above the ground surface were higher than 4 m/s, which is the limit for the profitability of generating wind energy. Clouds are a meteorological element that significantly influences the conditions of the solar radiation inflow to the earth surface. The annual sum of insolation - understood as the time in which direct radiation reaches the surface of the earth - is 1583 hours. The intensity of solar radiation here is the lowest (144.5 W / m^2) in January, and the highest (337.4 W / m^2) in May. The highest level of precipitation in this area is characteristic for July, and the lowest for February (tab. 1).

Table 1. Mean weather parameters in the area of the ZD IZ PIB Rudawa cattle farm

Parameter/month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Temperature (°C)	-0,7	0,8	4,9	12,9	15,6	18,9	21,5	17,5	12,9	9,1	3,5	0,2
Humidity (%)	73,56	68,68	62,65	60,15	62,67	63,99	60,69	65,46	71,1	73,7	74,2	74,8
Wind speed (m/s) (h=15 m)	5,5	5,0	5,2	5,0	4,9	4,9	4,8	4,5	4,7	5,1	5,2	5,5
Precipitation (mm)	37,5	29,7	40,2	46,4	53,6	79,2	82,1	72,3	62,4	43,2	42,1	39,2
Intensity of radiation (W/m^2)	144,5	182,5	214,0	287,6	337,4	324,8	310,8	309,4	263,4	206,8	164,2	161,4

On the basis of the obtained results, it should be stated that the weather conditions for the farm location indicate the desirability of installing here facilities for acquiring renewable energy sources, both wind and sun ones.

Table 2. Distribution of energy consumption in dairy cattle farming

Distribution	*Mean energy consumption (kWh/stall/year)*
Lighting for dairy cows	38,7
Lighting in calving pen	59,8
Lighting in calf-heifer house	30,2
Boilers in barn	50,1
Milk feeding station	25,7
Milking machine	12,6

Table 3. Effective energy efficiency per unit from photovoltaic cells

Parameter/Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Photovoltaic cell (kWh/day)	2,19	3,40	6,53	8,38	8,19	8,01	8,28	8,09	6,66	4,90	2,68	1,93

The results of the energy audit on the farm were presented per stand / year in table 2. Such a method is generally accepted in the subject literature and project guidelines for farms (Hörndahl, 2008). It allows for comparison in terms of inputs of different objects using different technologies. The highest energy consumption was determined in the case of room lighting and boiler power supply. Among the objects dominating here was the calving sector with the consumption of 59.8 kWh / stand / year, and among the used technological devices - boilers (50.1 kWh / stand / year). The lowest energy consumption per stand and year was shown for the lighting of rooms for calves and heifers (30.2 kWh / stand / year), and among the devices - for the milking machine (12.6 kWh / stand / year) (tab. 2). High energy consumption for illumination in the delivery room results from the need to look after the animals by the staff and direct dependence between the quality of surveillance and the obtained production results.

The obtained results indicate high energy consumption in farm dairy cattle production. However, it is a less energy-intensive one than the breeding of pigs and laying hens (Bazen and Brown, 2009). Both of these activities, in accordance with the BAT assumptions, are required to use special techniques to protect the natural environment. At the same time, it can be clearly seen that intensive breeding should be interested in reducing the costs of energy purchase and the use of alternative sources.

Tasks 2 and 3. The use of photovoltaic cells to supply indoor lighting and to power equipment for the preparation of hot and cold water (boilers) and technological devices (milking machine and water station).

The energy demand for room lighting is one of the highest in terms of the size of the energy farm audits carried out, which is also confirmed by experiments held within farms in Italy (Ghisellini, 2014; Hold et al., 2016; Murgia et al., 2008) but it is not much higher than for technological devices. The balance of energy necessary to supply both of these systems shows that the energy obtained from photovoltaics could supply, on average, up to 10 such installations (Tab. 4). For photovoltaics, the average coverage is 1048.4% and ranges from 321.8 to 280.9% between January and December. It is in these months that sun exposure is the lowest, with a prolonged time of lighting required in the buildings.

Table 4. Balance of energy needed to power the lighting system, water heaters, milking machine and milk feeding station in the barn

Month	Requirement (kWh)/stall	Effective energy efficiency	Energy Covered	Max. number of powered stalls
		Photovoltaic cell (kWh)	Photovoltaic cell (%)	Photovoltaic cell
I	21,1	67,89	321,8	3
II	20,8	95,20	457,7	5
III	19,2	202,43	1054,3	11
IV	17,7	251,14	1418,9	14
V	16,6	253,89	1529,5	15
VI	14,5	240,3	1657,2	17
VII	15,1	256,68	1699,9	17
VIII	15,5	250,79	1618,0	16
IX	16,8	199,80	1189,3	12
X	18,1	151,90	839,2	8
XI	20,4	80,40	394,1	4
XII	21,3	59,83	280,9	3
Mean	18,09	175,9	1038,4	10

Summary

Based on the results, it should be stated that the possibility of using renewable energy sources in dairy cattle farming is a viable alternative to the current practice. Having considered the total costs of the installed power unit, it is necessary to emphasise the economic profitability of such investments. The prices of solar systems range from 4.4 thousand PLN / kW net for a 1000 kW solar farm to 7.5 thousand PLN / kW for a domestic installation with the capacity of 1 kW. According to the surveyed producers and distributors, photovoltaics will develop the fastest in the business prosumer sector (capacity up to 200 kW), i.e. in the enterprise sector (IEO Report, 2017). IEO data indicate that this is the second sector, after physical persons, where photovoltaics develops in the most dynamic way. The total costs of RES installations are unfortunately higher than those declared by the sellers. A relatively high cost of, for example, a wind generator, with its highest efficiency of use is associated with the purchase of an attested mast and the implementation of expensive foundations. This cost quickly decreases with the increase of the generator power but it is dependent on the potential windiness in the area (Clarke, 2003). As for the solar collectors, the further development of technology will not bring a decisive breakthrough (Abu-Zour, 2006), in the case of photovoltaics one should count for a gradual improvement in the efficiency of these devices in the near future (Esen, 2004). It is related to the replacement of expensive silicon - semiconductor paints. The implementation of these solutions will reduce installation costs by several dozen percent. Such changes should also bring a revision of the national program in the field of solar energy. All the more so that in the short term agriculture will also take over the functions of fighting the climate change (Bos et al., 2003, Janzen et al., 2005). This approach is consistent with the assumptions of the national energy policy, including the diversification of energy sources. Finally, for the breeders themselves, it seems important to reduce the costs of beef production by lowering the energy expenditure (Hörndahl, 2008).

On the basis of the obtained research results, the following generalisations can be formulated.

1. The greatest hopes should be related in the future to the use of photovoltaic cells. However, already at this stage, they can effectively support conventional energy sources, even in the range of several dozen percent of the active power demand for devices.
2. The use of alternative energy sources in dairy cattle farming may affect the estimated greenhouse gas emissions from the entire country, calculated under the IPCC. In addition, the costs

of dairy cattle farming may be reduced. The popularisation of the issue may affect the growth of the importance of renewable energy in the national diversification of energy sources.

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PHOTOVOLTAIC CELLS AS AN ALTERNATIVE TO CONVENTIONAL ENERGY IN DAIRY CATTLE FARMING

Summary

The scientific objective of this study was to determine possible sites of energy recovery and alternative energy sources as well as their efficiency in dairy cattle farming. To achieve the set goal, an energy audit of a dairy farm was performed and the use of photovoltaic cells to power the lighting of facilities, boilers, milk feeding stations and a milking machine was determined. During the study, measurements were made of electricity consumption and production, power output of the devices, their quality parameters, and outdoor microclimate. The work was conducted on a farm of 350 dairy cows, heifers and calves kept in a loose-housing system. The experiment used 2.2 kW photovoltaic cells. The above energy sources were used to power the following receivers: lighting of facilities for dairy cows, heifers and calves, as well as boilers, milk feeding stations and a milking machine.

It was concluded from the results that the use of photovoltaic cells at the present stage may effectively contribute to conventional energy sources on a dairy farm.

Key words: photovoltaic cells, dairy cattle, GHG emission