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POSSIBILITIES OF OBTAINING RENEWABLE ENERGY IN DAIRY FARMING[1]

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ABSTRACT

Modern livestock facilities necessary in the production of milk, meat or other animal products should be constructed with environmental protection in mind, while ensuring high quality of production and animal welfare. The high level of mechanization in modern dairy farms, including automated and robotic processes, allows obtaining high quality raw material (e.g. milk), and significantly increasing labor and production efficiency. In addition, the use of photovoltaic (PV) panels, heat recovery from milk and obtaining biogas from the manure fermentation process, contributes to large energy savings on the farm. Excess of natural fertilizers, which are an animal byproduct, can be used as a substrate for methane fermentation. The presented examples of obtaining renewable energy allow improving the economic efficiency of animal production. They also ensure appropriate environmental conditions through the innovative management of natural fertilizers.

Introduction

Modern animal production systems, used in functional livestock buildings equipped with modern devices and machines, ensure high quality of the obtained raw material and animal welfare.

The high level of mechanization of production operations and shaping the quality of production requires high energy consumption, especially electric power (Bisaglia et al., 2012). Currently, great attention is paid in R&D studies to minimizing the use of conventional energy through the use of, e.g. solar energy, or heat recovery from production processes, e.g.

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Milk. The studies focus also on obtaining energy in the form of biogas as a result of methane fermentation of manure (Michalska et al., 2013).

Solar power generates energy from a renewable source: sunlight. PV panels used to produce electric power are environmentally friendly and noise-free. Depending on the available possibilities, the panels can be mounted, e.g. on the roof, or on the ground, and their size can be adapted to the specific energy needs (Cukrowski, 2017; Michalska et al., 2013).

The use of heat from the technological process of cooling milk is one of the elements of reducing fuel consumption. It contributes to the improvement of the natural environment, e.g. by CO_2 reduction. Recovery of heat energy received from chilled milk can be used to prepare domestic hot water. It can then be used in the livestock building, or in the household, either for production purposes, or to maintain hygiene or to prepare meals (Borowski, 2019; Pineda Quijano et al., 2017; Olkowski et al., 2013; Szulc and Myczko, 2010).

Biogas production is a good method of managing organic waste or natural fertilizers. Biogas, produced as a result of methane fermentation in landfills or biogas plants, can be used for the production of electric and heat power. It can also be treated and compressed, to be used as transport fuel (Putmai et al., 2020; Zapałowska and Gacek, 2019; Sikora and Tomal, 2016; Bacenetti et al., 2015; Bond and Templeton, 2011).

The main purpose of the work was to analyze the opportunities of obtaining renewable energy in animal production, especially in dairy farming. The studied renewable energy sources were heat recovered from milk cooling, solar power from roof-mounted PV panels and biogas from methane fermentation of manure, along with its transportation, depending on the needs of different users.

The possibility of using renewable energy in exemplary livestock buildings - the use of renewable energy sources in livestock buildings (Figures 1 and 2) using heat exchangers

A heat exchanger is a device that exchanges heat between a heating medium with a higher temperature and a heated medium with a lower temperature. In the co-current exchanger, the heating medium flows in the same direction as the heated medium. A counter-current exchanger is one in which the heating medium flows through the exchanger in the opposite direction to the heated medium. Co- and counter-current heat exchangers are flow-through heat exchangers.

Counter-current heat exchangers are smaller than co-current heat exchangers at the same heat output. The latest generation of capacitive heat exchangers is stratified storage tanks, which are hot water tanks without a coil. This tank is connected to a plate heat exchanger, which is to heat the water in the stratified tank.

Thanks to the new design and change in the method of heating water, stratified tanks are half the size of traditional storage heaters, and the time of heating water is also shorter.

Plate heat exchangers are characterized by a very intense heat exchange between the heating medium and the heated one. They are water-water, flow-through exchangers, usually working as counter-current exchangers. They are made of copper or stainless steel plates, bolted or soldered. They are characterized by a high heat transfer coefficient, small dimensions at high thermal outputs, high resistance to pressure and temperature changes, simple and easy installation (Zhang et al., 2018; Pineda Quijano et al., 2017; Olkowski et al., 2013; Szulc and Myczko, 2010; Kupczyk et al., 2001).

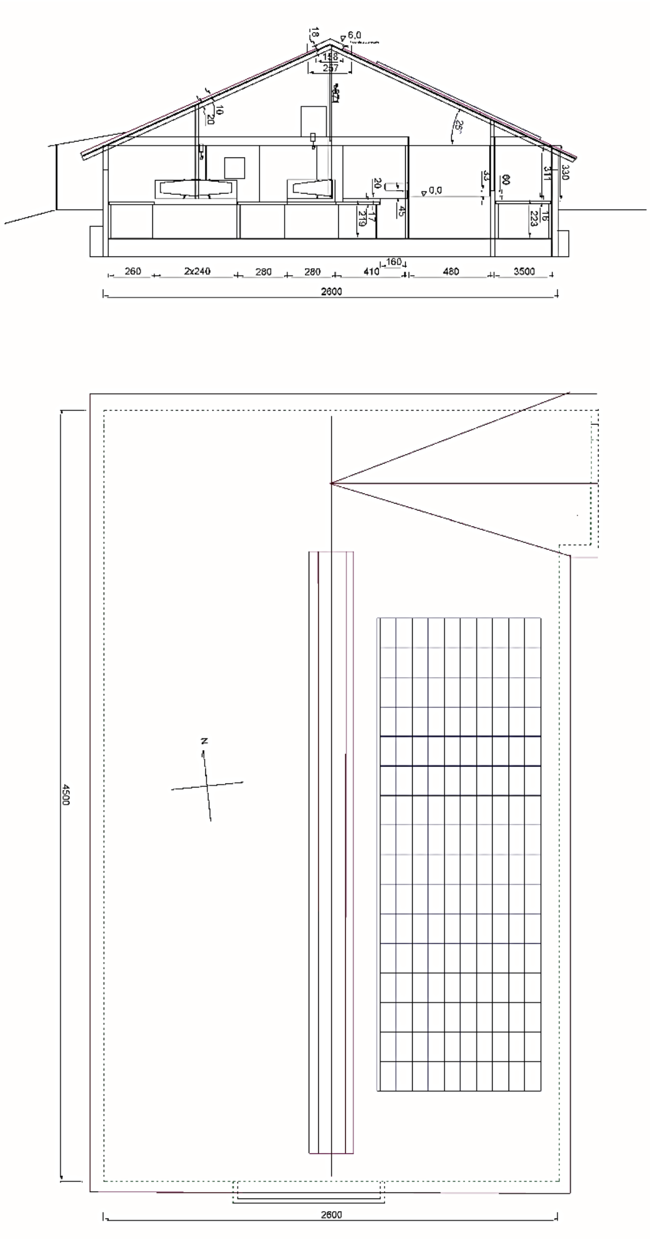

Figure 1. Layout diagram of PV panels on a loose housing, box stall livestock builing: PV area - 2704 m^{2}; – 10 rows x 16 panels = 160 pcs.; – 160 pcs x 255 W = 40.8 kW; – Technology - crystalline silicon; – Installed power - 40 kW; – Roof slope 25 °

Source: a study by ITP

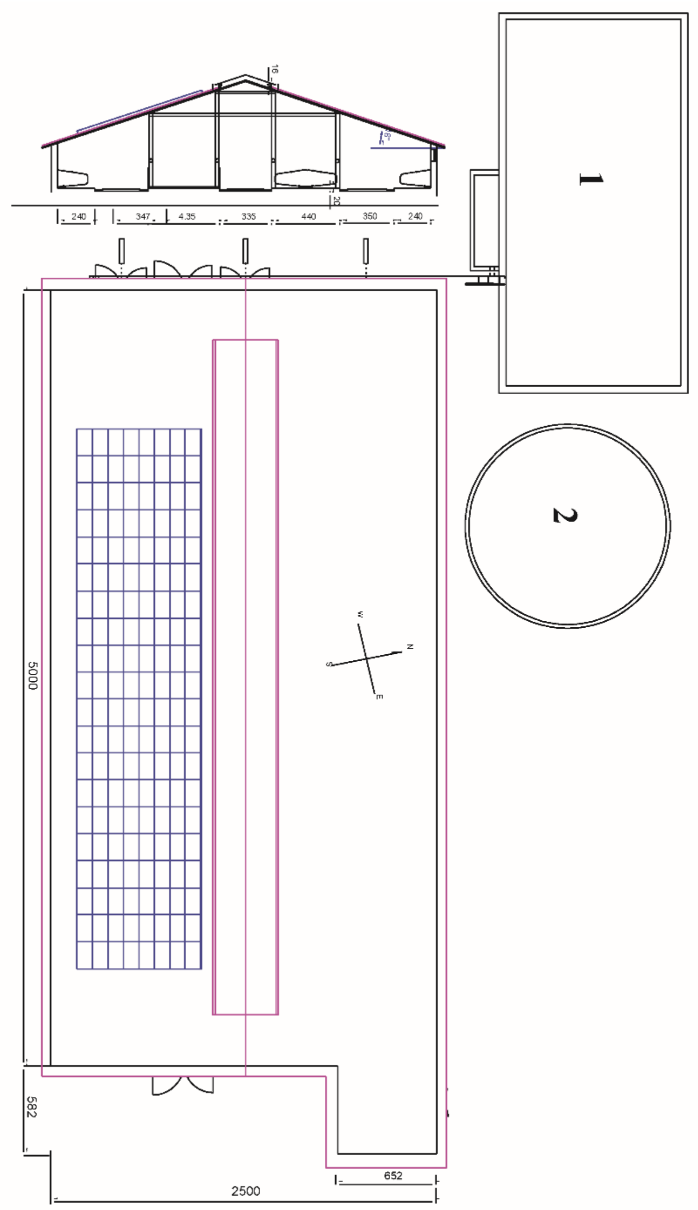

Figure 2. Illustrative layout diagram of the PV panels in a loose housing, box stall livestock building; 1 – solid manure pit, 2 – liquid manure tank: – PV area – 2700 m^2; – 8 rows x 20 panels = 160 pcs. ; – 160 pcs x 255 W = 40.8 kW; – Technology – crystalline silicon; – Installed power – 40 kW; – Roof slope: 18-20 °

Source: a study by ITP

Exemplary solution of heat recovery from milk cooling

Based on the research of the Institut de I'Elevage (The French Livestock Institute), the sample annual power consumption in dairy farming was minimum 160.00 $kWh \cdot LU^{-1}$, 420.00 $kWh \cdot LU^{-1}$ on average, and maximum, 920.00 $kWh \cdot LU^{-1}$. Calculated per liter of milk, it was respectively: minimum 27.00 Wh, 61.00 Wh on average and maximum 120.00 Wh (Paulais et al., 2011). The energy savings are shown in Table 1.

Table 1.
Energy savings in heat recovery from milk cooling

Electric power consumption of the 350,000 l milk capacity cooler tank (27 $Wh \cdot 1l$ of $milk^{-1}$)	9 450 kWh
Savings: 50% energy consumption per tank	4 725 kWh
Return on investment costs	9 years

Source: Paulais et al. (2011)

Heat recovery during the milk cooling

a) Calculation of the amount of heat available for recovery in cooling milk from one cow in one year

– The milk temperature after milking is +38°C.

– According to the standards, milk must be cooled to +4°C in no later than 4 hours.

Determination of specific heat of milk at a temperature of +38°C (311°K):

$$Cml = 444 + 609{,}56 \ln 311 = 3943\ J \cdot kg^{-1} \cdot {}^{\circ}K^{-1} = 3{,}943\ kJ \cdot kg^{-1} \cdot {}^{\circ}K^{-1}$$

Determination of milk density:

$$\xi\ ml = 1166 - 0.45\ T - 1.46\ f\ T + 321.6\ f = 1166 - 0.45\ 311 - 1.46\ 0.04\ 311 + 321.6\ 0.04 = 1021\ kg \cdot m^{-3}$$

where:

Cml – specific heat of milk ($kJ \cdot kg^{-1} \cdot {}^{\circ}K^{-1}$)

ξ ml – milk density ($kg \cdot m^{-3}$)

T – milk temperature (°C)

f – milk fat content.

Determination of the amount of heat recovered in the milk cooling process from one cow per day:

$$Qd = C\ ml \cdot md \cdot t\ (kWh)$$

where:

md – mass of milk obtained from one cow (kg) per day,

t – temperature difference between freshly milked and chilled milk.

Assuming that one cow will produce milk at Vd = 0.016 m^3 per day, the mass of milk per cow per day will be:

$$md = Vd \cdot \xi\ ml = 0.16\ 1021 = 16.3\ kg$$

The recovered amount of heat per day per cow will be:

$$Qd = 3.943 \cdot 16.3 \cdot 34 = 2185 \text{ kJ} = 0.607 \text{ kWh}$$

The annual amount of heat recovered in cooling milk from one cow will be:

$$Qr = Qd\ 365 = 221.5 \text{ kWh}$$

b) Heat recovery from milk cooling

For example, if there are 70 cows in a building, milked with a single-unit milking robot, the amount of heat recovered from milk per day will be 152 950 kJ, which is equivalent to 42.49 kWh of electric power. The annual heat recovery from milk cooling in this building will be 55,826,750 MJ, which is 15 508.85 kWh of electric power.

In a barn with 144 cows milked in a double-unit, eight-stand milking parlor, the daily heat recovery from milk cooling will be 314 640 kJ, i.e. is 87.408 kWh of elecric power. Annual heat recovery during the milk cooling in this building will be 114,843.60 MJ, which is equivalent to 31,903.92 kWh of electric power.

Installation of phtovoltaic panels on the roofs of livestock buildings

Photovoltaic (PV) panels will be installed on the more favorable sides of the roofs, where the sun operates the longest during the day. A view of the panels installed on the roofs of livestock buildings is shown in Figures 1 and 2, respectively. On the part of the roof with PV panels an appropriately painted anti-corrosive trapezoidal sheet must be used for roofing.

– Dimensions of a single panel: 100 cm in width x 169 cm in height
– Power obtained from a single PV panel: 255 W
– Cost of installing a 1 kW PV installation: approx. PLN 4,500

Technical and economic data on the PV installation on livestock building roofs are presented in Table 2.

Table 2.
Technical and economic data on the PV installation on livestock building roofs (Fig. 1 and 2)

Livestock building	Roof panel area (m^2)	Panel power (kW)	Roof slope (degrees)	Sunlight side of the roof	Total cost of the PV installation (PLN)
1 (in Fig. 1)	2704	40.8	25	eastern	180,000
2 (in Fig. 2)	2704	40.8	18-20	southern	180,000

Source: own study

The total cost of the PV installation together with the control panel and accessories for the distribution of power for use in the livestock building and for sale to the external grid in both barns is PLN 180,000.

The user will be able to use the produced PV power at any time. When it is used up, the system will automatically switch to the external grid.

Efficiency of PV panels and the use of PV power in a livestock building

The efficiency of monocrystalline silicon PV cells currently ranges between 14% and 17%, and of multicrystalline cells, between 13% and 16% (Pławecki et al., 2019). There are also specially designed monocrystalline cells with a 20% efficiency. Unfortunately, due to the small scale of production and high manufacturing costs, they are much more expensive than classic monocrystalline cells, at 14-17% efficiency (Zapałowicz, 2019).

The efficiency of the cell decreases with an increase in temperature - this can be minimized with good ventilation. Without ventilation, losses are 5% lower than with ventilation. At high temperatures, a 0.5% reduction in efficiency per 1°C can be assumed. According to research, if the cell temperature increases from 25°C to 55°C, the efficiency will decrease by approx. 15%.

The rated electric power of PV cells is given for a temperature of 25°C. Typical PV panels usually operate at a temperature of 55-75°C, which results in a decrease in power generation by 12-25% of the rated power value.

At just 50% of sunny days a year, if average annual single demand for electric power is approx. 3.5 kW, then with the total power of the PV system at 40.8 kW, the power supply for the livestock building will reach approx. 50% (Pławecki et al., 2019; Zapałowicz, 2019).

Innovative solutions for obtaining biogas from substrates above 20% dry matter

The characteristics of the technology for obtaining biogas from the leached organic manure fraction is subject to Patent Application No. P.421062 of 30.03.2017.

The method of biogas production and the necessary assembly are presented in detail in Figure 3. Following a necessary adaptation, this technology can also be used in other animal production farms.

The purpose of the presented innovative solution, pending patent, is the production of biogas from manure and determining a necessary assembly, taking into account the process of manure processing, to obtain a solid fraction, suitable for reuse as litter or as a raw material for compost and a liquid fraction for use as a natural fertilizer for feeding plant crops, in addition to gas. The project allows achieving two main goals. The first is management of natural manure in the solid form while maintaining good agricultural practices, i.e. preventing contamination of groundwater. The second goal is gas production to meet the energy demand of the farm.

The invention’s design is presented in Figure 3 (vertical section). The livestock building 1 was designed to be technologically connected to the solid manure pit 2, in which manure 3 is collected, loaded with a loader 4 (coupled with a tractor) into containers 5. During collection in the manure pit, as well as during loading into the container 5, the liquid manure 3 is gravity drained into the preliminary tank 6, located below the loading surface.

The biogas production unit is a silo flushing chamber 7, divided into hermetically sealed sectors 8, in which containers 5 filled with manure 3 are placed and kept hermetically sealed for approx. 30 days. The containers 5 have openwork floors. In the floor of each of the sectors 8 of the silo chamber 7, there is a drain 9, connected to a drain pipe 10 directed to the organic fraction tank 11, in which the organic fraction accumulates after rinsing the solid manure 3 placed in containers 5 in the silo flushing chamber 7.

Above, in each sector 8 of the silo rinsing chamber 7, sprinkler nozzles 12 are installed, through which the liquid manure is supplied for washing out the solid manure 3. The organic fraction drained off from the solid manure 3 along with solid elements s is directed through a discharge line 10 to the organic fraction tank 11.

The organic fraction tank 11 is connected to the biogas plant fermentation chamber 13 with a pipe 14, at the end of which, in the organic fraction tank 11, a pump 15 is mounted. It pumps the organic fraction into the fermentation chamber 13, where this fraction is fermented.

Biogas, which is a product of methane fermentation, is discharged into the biogas tank via a pipe. The biogas is also produced as a result of manure fermentation 3 taking place in the silo washing chamber 7. It is discharged from each sector 8 through a pipe. After dehydration and desulphurisation, it is pressure-pumped into the tank.

In the side wall of the fermentation chamber 13 tubular containers 17 are mounted, filled with expanded clay, which is a source of methane bacteria, stimulating the fermentation. An important element of the fermentation chamber 13 is the PV collector 18, powering the heaters 19, mounted inside the fermentation chamber 13. A drain pipe 20 is directed from the side wall of the fermentation chamber 13 to the expansion tank 21, enabling gravity drainage of the fermented substrate from the fermentation chamber 13 and maintaining a constant level of the substrate in the fermentation chamber 13. The fermented substrate collected in the expansion tank 21 is fed through a separator drain 22 to the separator 23 via a pump 15 installed in the tank. In the separator 23, solid fractions are separated from the liquid fractions. As a separated mass, the solid fraction is discharged to the heap in the form of a compost plate 24, and then used for animal bedding or compost. On the other hand, the liquid fraction is gravitationally discharged as liquid manure into the final tank 25 connected to the separator 23. This tank has an installed pump 26, which pumps the separated liquid manure through pipe 27 to the sprinkler nozzles 12 installed in the upper walls of the silo flushing chamber 7, for flushing manure 3 accumulated in containers 5. A control valve 28 is mounted on the liquid manure pipe 27 to direct the liquid manure stream to the relevant sector 8. Excess liquid manure is directed to the storage tank via a pipe 29.

An agitator 31, axially mounted in the fermentation chamber 13, is to ensure homogenization of the mass and its uniform fermentation. Another element of the assembly is a screw conveyor 32, which adds the energy plant substrate to the fermentation chamber 13, usually raw crushed corn or corn silage, or grass. Biogas produced as a result of fermentation should be dehydrated and desulphurized. The biogas thus cleaned is then pumped into the storage tank 16. The next stage is the transmission of biogas (biomethane) via pipeline 32 to a cogeneration unit, where biogas will be converted into heat and electric power (Romaniuk et al., 2017a).

An example installation for compressing, transporting and distributing biogas for animal production

Figure 4 shows the biogas compression, transport and distribution system used in the farm located in Jaworze, a part of the Experimental Station of National Research Institute of Animal Production in Grodziec Śląski (Romaniuk et al., 2017b).

The installation's design and prototyping was carried out by the team of the Institute of Technology and Life Sciences, in cooperation with NGV Autogas Sp. z o.o. The concept of the above-mentioned system (Fig. 4) consists of the following technological units: a biogas purification module fed from a biogas tank, a compressor, containers (high pressure cylinders) for storing compressed biogas, placed on a transport trailer, a biogas expansion and extraction station to supply the animal production energy demand, and a reducing valve allowing biogas transportation to power energy receivers.

The view of the biogas refueling and compression station is shown in Figure 5, along with a brief technical description of the compressor.

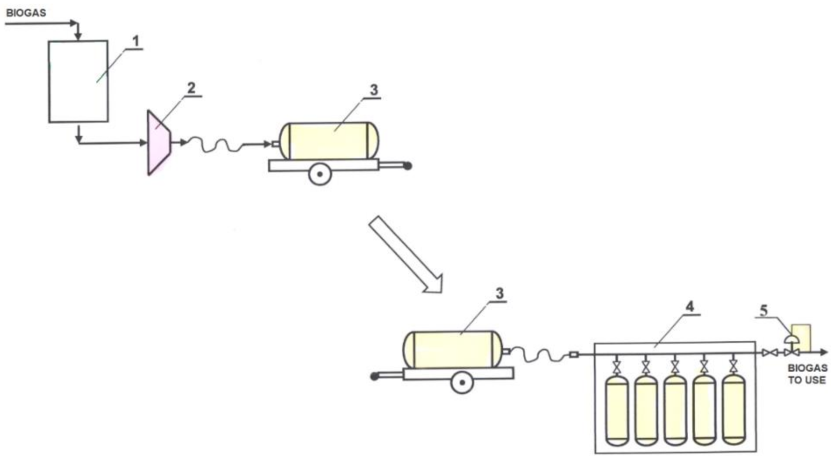

Figure 4. A transport and distribution unit for small amounts of biogas, Patent No. 232201 of 13.06.2017.: 1 – purification unit for biogas fed from the biogas tank; 2 – compressor; 3 – containers (high pressure cylinders) for storing compressed biogas, placed on a transport trailer; 4 – biogas expansion and extraction station to supply animal production energy demand; 5 – reducing valve to enable biogas transport to power energy receivers

Source: own study

Figure 5. View of the gas installation in the gas compression station. Gas compressor with maximum power consumption of 2.5 kW and a rated capacity of 5 m^3/h (at 15°C and 200 bar, with an inlet gas pressure of 0.1 bar)

Source: own materials and obtained from the company NGV Autogas Sp. zo.o

The view of the connected cylinders with the reducing valve, supplying biogas receivers is shown in Figure 6.

Figure 6. View of the cylinder connection to the biogas supply

Source: own materials

The transport trailer with loaded biogas cylinders is shown in Figure 7.

Figure 7. View of the transport trailer with biomethane cylinders, secured on the trailer.

Source: own materials

Summary

Modern livestock facilities necessary in the production of milk, meat or other animal products should be constructed with environmental protection in mind, while ensuring high quality of production and animal welfare. The development of specialized animal production farms is mainly restricted by:

– Environmental emissions, incl. CO_2, NH_3, CH_4, NO_x, H_2S, groundwater and soil contamination, dust and noise levels
– Production safety-related reasons, including animal welfare, human safety and user-friendliness, quality of the produced raw material
– The economics, including price stability for agricultural products, energy raw material and power prices.

The presented examples of obtaining renewable energy allow improving the economic efficiency of animal production. They also ensure appropriate environmental conditions through the innovative management of natural fertilizers. Currently, much attention is paid to the use of renewable energy to improve environmental conditions in livestock buildings, as well as to minimize production costs. Obtaining energy from milk cooling, PV panels and biogas aims to improve them in the micro- and macro-scale. The technological possibilities of obtaining biogas from manure, as well as micro scale biogas transport techniques and technologies, using simple sets of devices, allow for local energy storage in the form of biogas.

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MOŻLIWOŚCI POZYSKANIA ENERGII ODNAWIALNEJ W CHOWIE BYDŁA MLECZNEGO

Streszczenie. Nowoczesne obiekty inwentarskie niezbędne w procesie produkcji mleka, mięsa lub innych produktów, powinny uwzględniać uwarunkowania związane z ochroną środowiska przy zapewnieniu wysokiej jakości produkcji oraz uwzględnieniu dobrostanu zwierząt. Wysoki poziom mechanizacji w nowoczesnych oborach krów mlecznych, w tym automatyzacja i robotyzacja, umożliwiają pozyskanie surowca (np. mleka) o wysokiej jakości, a także pozwalają na znaczący wzrost wydajności pracy i produkcji. Dodatkowo zastosowanie paneli fotowoltaicznych, odzysku ciepła z mleka oraz pozyskiwania biogazu z procesu fermentacji, przyczynia się do dużych oszczędności na energii w gospodarstwie. Nadmiar nawozów naturalnych, powstających w wyniku produkcji zwierzęcej, może być wykorzystywane jako substrat do fermentacji metanowej. Przedstawione w pracy przykłady pozyskania energii odnawialnej umożliwiają poprawienie efektywności ekonomicznej produkcji zwierzęcej, a także zapewnienie odpowiednich warunków środowiskowych przez innowacyjną gospodarkę nawozami naturalnymi.

Słowa kluczowe: odzysk ciepła, mleko, panele fotowoltaiczne, fermentacja metanowa, nawóz naturalny, biogaz