INNOVATIVE DAIRIES - ENERGY INDEPENDENCE AND WASTE-FREE TECHNOLOGIES AS A CONSEQUENCE OF BIOGAS AND PHOTOVOLTAIC INVESTMENTS

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Abstract
This article presents the innovative perspectives of Polish and, above all, Lodz dairies. The possibilities of exploiting the potential of the enterprises in the dairy industry and their directions of development are described. It is emphasized that the dairy industry does not always have to be associated with constant demand for energy, but that it can also become its supplier. Biogas and photovoltaic solutions available to individual companies that have already been globally tested are proposed.

Key words
biogas, dairy waste, dairies, agri-food industry, photovoltaics

1. Introduction

The problem of the management of post-production waste is not a new problem for companies of all branches of industry. Each facility is obliged to dispose of its own waste in an environmentally safe manner and in compliance with Polish legislation. In principle, this obligation contributes to the generation of significant costs to the producer of the goods and to the producer of the waste at the same time. The most common way of proceeding is to commission the collection and professional disposal of waste to specialized companies, which is a convenient but expensive solution.

The examples of many European countries, including Sweden, Germany, and Denmark indicate clearly that there is another way [1, 2, 3]. An entrepreneur can, and should, make a profit from his or her own waste, with respect to both industry and finances. This is fully possible with the use of biogas technology, which uses organic waste as a substrate for biogas, and thus for clean energy. Such technologies are applicable in many industries, which should entice entrepreneurs to implement them universally [4].

The process of biogas production is anaerobic degradation of organic matter with the participation of microorganisms. The successive sequence of reactions leads to the creation of a high-energy bio-fuel, which is a mixture of mainly two components: methane (about 60%) and carbon dioxide (about 40%). The performance of the whole process is strongly dependent on maintaining the temperature regime, the appropriate pH of the reaction mixture, and maintaining the proper ratio of the elements of carbon and nitrogen [5]. Hence, it is very important to select suitable substrates for process purposes and for the control of physicochemical parameters throughout the process. The advantages of such technologies are the production of energy for the enterprise's needs, for its sale to the grid, and for the possibility of disposing waste at the source [6].

In Łódź Voivodeship, as shown by the authors' earlier studies, the dairy industry dominates the sector of small and medium-sized enterprises [7]. In many respects, type of substrates used and generated organic waste make this is a uniform industry. Dairy producers from the Łódź region show considerable interest in the possibility of extracting energy from their own waste as an alternative to its costly disposal. The authors decided to meet their expectations and show that the dairy industry can be innovative in many different ways.

One of the possibilities for improving the competitiveness of dairies is to use biogas technologies on the premises. Due to the nature of the activity and its size, the suggested solutions should concern the "micro" scale, which has not yet been recognized in Poland despite all its advantages. Already basic cost calculations for the disposal of waste generated and the possible financial gain from their energy use show significant benefits for entrepreneurs. At present, dairy product manufacturers either donate their waste for animal feed or pay for its collection, sometimes up to several thousand PLN monthly. Assuming that the primary dairy waste is whey in the amount of 1 t/year, it can be estimated that using it in methane fermentation will produce about 30 m^3 of biogas a year, which is the equivalent to 0.16 MWh of energy per year. With average quantities of waste whey for the Łódź voivodeship, these calculations assume even more optimistic values.

This article presents the innovation potential of dairies in Łódź. It speaks to the possibilities of exploiting the potential of each individual enterprise and the recommended directions of development. It highlights the fact that industry does not always have to be associated with constant demand for energy, but that it can also become its supplier. The article also draws attention to solutions available to individual companies that are already tested on a global scale.

2. The business profile and impact of dairies on the environment

The dairy industry is one of the largest branches of the food industry in Poland, both in terms of total weight of raw material and consumption of water, heat, cooling, packaging, and transport [8]. It is also considered to be the largest source of food processing waste, which poses a serious threat to the environment. This industry also generates significant streams of organic waste. The raw material processed in each dairy is the cow's milk. Niche areas of dairy such as goat milk or buffalo milk processing for mozarella cheese are omitted in these considerations . The amount of wastewater and waste produced depends on the size of the plant. It is estimated that 1.44 liters of water is consumed per one liter of milk processed for drinking milk. Cheese production is more water-intensive and reaches 1.6 to 2 liters of water per one liter of processed milk. Approximately 80 to 90% of used water becomes sewage. Their impact on the environment must be constantly controlled because dairy waste water is mainly of organic origin. A particularly dangerous liquid waste that can be found in the wastewater stream is whey. Its biological degradation requires relatively large amounts of oxygen (BOD_5 from 30,000 to 50,000 g O_2/dm^3).

The volume, concentration of pollutants, and the composition of sewage from the dairy plant depend on the type of product being processed, the type of production, and the purification methods used. Other factors affecting the composition and load of sewage are raw materials, the technological level of the plant, washing and disinfection processes, and the amount of water consumed. Sewage from dairies is largely derived from cleaning technological installations. The load on such wastewater is quite high because the installations that are heavily contaminated with organic substances like milk and its byproducts are washed. At the same time, this waste water is relatively easily biodegradable.

Sewage from dairies contain dissolved sugars (mainly lactose), proteins and fats. They are usually characterized by high COD of 3,500-6,000 mg O_2/dm^3. At the same time, BOD_5 may even reach the level of 3000 mg O_2/dm^3. Slurry content in this wastewater reaches 500 mg/dm^3. Sewage from dairy water is also rich in nitrogen, which is understandable due to the raw material being processed. The concentration of nitrogen forms is Kjeldahl nitrogen (N_{og}) 150 mg/dm^3, nitric nitrogen ($N\text{-}NO_3^-$) 3 mg/dm^3, and $N\text{-}NH_3$ 60 mg/dm^3. The characteristic component of dairy wastewater is calcium up to a concentration of 100 mg/dm^3. In addition, such wastewater is rich in surfactants (anionic and nonionic) and disinfectants that contain chlorine or hydrogen peroxide. This wastewater may also contain pathogens leached from contaminated materials or from production processes.

Dairy industry sewage can be divided into three main categories:

- Process water, which includes water used for cooling and heating. This wastewater is usually free from contamination and can be reused after minimal cleaning, or simply discharged into the storm water system.
- Industrial water, coming mainly from cleaning equipment that has come in contact with milk, milk by-products, or whey. This wastewater stream may contain milk, cheese, whey, or cream.

- Sanitary sewage, which is usually directly discharged to the sewage treatment plant.

The main sources of organic load in sewage that are produced in dairies are cream, butter, and cheese . Examples of parameters characterizing the dairy sewage are presented in Table 1.

Table 1. Composition of dairy sewage

Parameter	Measure	Process/ Type of production							
		Wash ing	Chees e	Casein	Curds	But- ter	Milk powder	Pro- cessed cheese	Drinking milk
pH		9.6	7.0	6.4	6.6	7.5	7.6	7.2	7.2
COD	mg O_2/dm^3	1200	3950	1360	3420	1055	2090	1450	2090
BOD_5	mg O_2/dm^3	515	1760	1300	1900	690	1135	875	1160
Oxidisability	mg O_2/dm^3	290	500	480	1020	200	575	485	550
Dry residue	mg $/dm^3$	nb	2020	1800	1920	1100	1090	3250	1460

Source: [10]

Dairies also produce technological liquid and solid waste. Such waste is buttermilk, which is a byproduct of processing cream for butter. The chemical composition of buttermilk depends on the milk used. On average, buttermilk contains 91-92% water, 3.8-4.2% lactose, 3-3.4% nitrogen compounds, 0.1-1% fat, and about 0.7% other minerals, including calcium compounds. In the case of buttermilk, it is difficult to treat this waste as a nuisance because it is used for secondary processing as an intermediate to produce drinking buttermilk or some types of processed cheese [11, 12].

Another important waste is whey (waste code 020580), which is a byproduct of cheese, curd, casein, and other milk protein preparations. It represents 65-80% of the volume of processed milk. Such a spread is due to the technology of production, which consists of protein precipitation methods and the degree of drying it. Three types of whey are usually distinguished:

- Sweet whey, or rennet whey, which comes from the production of hard, semi-hard, and soft cheeses, as well as rennet casein. Its pH is in the range of 5.9-6.3.
- Acid whey, which is most often a byproduct of curds. Its pH is in the range of 4.3 - 4.6
- Casein whey, which comes from casein production.

The content of organic substances in whey comes within the following ranges: dry weight 4.5-7.3%, fat 0.02-0.4%, protein 0.4-1.1%, lactose 4-5% and mineral ingredients 0.4-0.8% [11, 12]. The overall chemical composition of whey is shown in Table 2. Whey is generally not considered burdensome waste, although its pollution indicators, such as COD of 50,000 mg O_2/dm^3, Kjeldahl nitrogen (N_{og}) 600 mg N/dm^3, nitrate nitrogen ($N\text{-}NO_3^-$) 2,5 mg/dm^3, $N\text{-}NH_4^+$ 60 mg/dm^3, total phosphorus 500 mg/dm^3 and calcium 1000 mg/dm^3 would classify it at the level of extremely concentrated wastewater. Some pollution indicators, especially organic compounds, are comparable even to those found in leachate from mixed landfills.

Table 2. Chemical composition of whey

Water	93-95 %
Protein	0.8-1.0 %
Fat	0.1-0.6 %
Lactose	3.2-5.0 %
Lactic acid	0.1-0.8 %
Ash	0.5-0.8 %

Source: [8]

There are several ways to make and use whey. Already in the dairy, whey protein can be used to produce ricotta cheese, which is poor in casein that is a component of other ordinary cheeses. After processing and drying, whey may be used as a food additive, for example for sweets. First, however, whey is used as feed for farm animals [11, 12]. Each of these methods entails high costs for the plant, so it is imperative to seek out and implement new, efficient technologies that enable the management and disposal of whey on the premises of the company. Alternatives to currently used methods of disposal or management of whey may be technologies based on the anaerobic decomposition of organic substances. Whey is a perfect substrate for fermentation. It seems, therefore, that it can be a cheap raw material to produce high-energy gas fuels [13, 14, 15].

In addition to whey, feed milk is produced in dairies as a liquid by-product, consisting of waste from the production line, as well as milk beakers and other spills (waste code 020599). As its name indicates, the only way of managing this waste is for feed [11, 12]. In dairies, there is also secondary waste from the company's wastewater treatment plant effluents, which is contaminated butter (waste code 020502) from milk fat. There is potential for this waste to be processed along with whey for biogas in co-digestion systems. Past or dubious quality dairy products also constitute waste from companies in this industry. Their succinct characteristics are shown in Table 3. Most solid waste can be processed into other products and byproducts [16].

Table 3. BOD_5 and COD values for selected dairy products

Product	BOD_5 [mg/dm^3]	COD [mg/dm^3]
Milk	114,000	183,000
Skim milk	90,000	147,000
Buttermilk	61,000	134,000
Sour cream	400,000	750,000
Condensed milk	271,000	378,000
Whey	42,000	65,000

Source: [17]

The above characteristics of the activity of Polish dairy companies indicate the essential necessity of solving the problem managing post-production waste in dairies. In the age of the global economic and energy crisis, it seems appropriate to use innovative solutions to effectively use organic waste streams to meet the company's energy needs. In addition, innovative and competitive dairies should also use other renewable energy sources. Further chapters of this paper show how to effectively use the potential of a dairy enterprise and how to derive additional profits from such activities. Proposed solutions can be applied in every dairy in Łódź, especially in those which want to be competitive in the local and national market.

3. Innovations for the dairy industry: in-house biogas plants

Dairies and waste from the dairy industry are the ideal raw material for bioenergy production because they contain significant amounts of readily biodegradable organic pollutants. In addition, they have a high content of water and microelements necessary for microorganisms to live [18]. Hence, the ideal solution for regional dairies seems to be the use of waste streams in the methane fermentation process, where organic waste is converted into clean, renewable energy that is profitable for the company itself. In this process, substrates like whey, fat from fat separators, and wastewater streams can be successfully used as a substrate.

It is estimated that the volume of whey produced in Poland is nearly 2 million m^3 /year [19]. Knowing that the concentration of organic impurities in the whey is 60,000-80,000 mg COD/dm^3, the annual charge of biodegradable matter is estimated to be 120-160 Mt COD. The amount of energy that can be obtained from whey produced using the methane fermentation process is in the range 198-560 GWh/year, which amounts to 542-1534 MWh/d [18]. The potential for producing biogas from whey is shown in Table 4.

Table 4. Characterization of selected substrates along with biogas production potential

	Percentage of dry matter [% of charge]	Percentage of dry organic matter in dry matter content [% of dry organic matter]	Production of methane [m^3/tonnes of dry organic matter]
Whey	5.4	86.0	383.3
Other cheese production wastes	79.3	94.0	610.2

Source: [38]

Wheat alone used as the sole substrate in the methane fermentation process can be quite troublesome and inefficient due to the large content of nitrogen. The desired ratio of C/N elements in the process may be too low, which will adversely affect the production of biogas. Hence, the most common variant for biogas plants in dairies is the co-fermentation of production wastewater with whey, the main organic waste. However, this solution only makes sense if the company does not have a sewage treatment plant. An alternative to the presented variant is co-fermentation of whey with waste fat, which is a byproduct of dairy production. The fat is rich in organic carbon and does not have nitrogen compounds, so the C/N ratio should be more favorable from the point of view of biogas production capacity.

The location of the plant on the premises will not only reduce investment costs such as land acquisition for construction and exploitation costs such as substrate transport, but should partially minimize local community protests related to this type of environmental investment. The proposed solution offers many benefits, such as the in-house waste disposal, financial gain from the sale of the energy produced, and the fulfillment of energy needs. The starting point for understanding the proposed solutions and all their advantages is an attempt to select the right methods for the purification of wastewater generated in the dairy plant as the main stream of waste. The variable nature of dairy industry waste, due to the amount of flow and its pH and solids content, makes it difficult to choose an effective wastewater treatment system. The three main options for the treatment of the dairy industry waste include draining sewage to a nearby treatment plant, removing waste by an outside company, or treating the wastewater within the plant.

The first two options are less favorable due to increasing costs and the fact that the requirements for acceptable levels of BOD_5 and COD in wastewater are becoming increasingly stringent. For this reason, dairies increasingly use the third option and seek solutions to clean sewage on the premises. Oxygen technologies are often used in such cases, but technologies based on the anaerobic decomposition of organic substances are becoming increasingly popular because they allow for the generation of additional energy.

To understand the superiority of anaerobic processes over aerobic ones, compare the COD balance shown in Figure 1. Coal from sewage during anaerobic treatment is largely converted into methane, a valuable gaseous fuel. In addition, a very small amount of carbon remains in the sediment. The great advantage is also the lack of the need to provide significant amounts of energy from the outside. However, the correct course of the process depends on ensuring stable conditions, such as temperature or pH. In the case of aerobic processes, there is a large increase in biomass, which becomes burdensome sewage sludge that can be expensive to transport. In addition, oxygen must be supplied continuously for aeration of wastewater. The economic effect, low energy consumption, and the fivefold reduction of sludge biomass favor the popularization of anaerobic methods in wastewater treatment technology.

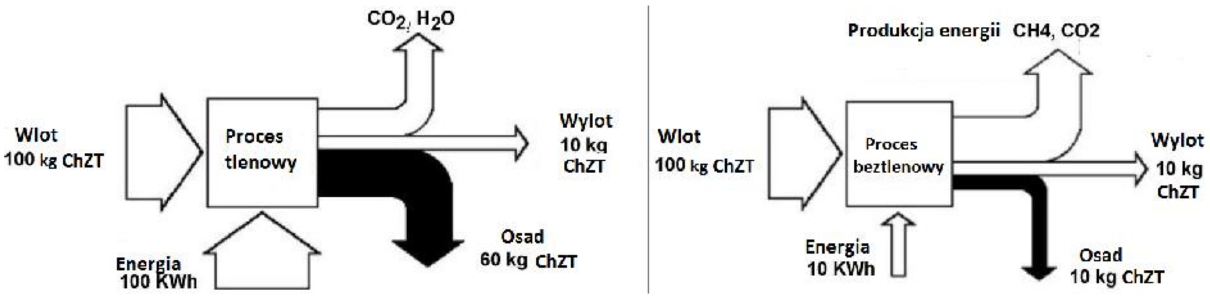


Fig. 1. Comparison of aerobic and anaerobic processes
Source: [20]

Currently, rising electricity prices and rising CO_2 emissions requirements have increased interest in alternative energy sources. Biogas plants with anaerobic processes are an ideal solution for dairy industry waste management, while generating energy that can be used in a wide variety of applications, such as the production of electricity, heat, or as motor fuel or gas. This is a very economically advantageous solution, because in addition to savings and income from energy production, it generates considerable savings by reducing the cost of disposal.

There are also disadvantages to anaerobic processes. An important part of the microbial population, methanogenic bacteria, are very sensitive to any change in conditions, therefore the process requires close monitoring and control. The growth rate of these organisms is relatively low. Anaerobic systems in which the acid and methane phases occur in one reactor may be susceptible to various negative factors and, consequently, the optimum purification process is not carried out. The anaerobic decomposition process can therefore be divided into two phases. Nowadays, two-stage anaerobic systems are increasingly being developed, where the acid and methane phases are implemented in separate reactors. It is now considered that separate acid fermentation is a prerequisite for effective methane fermentation. Acid fermentation leads to the formation of intermediate products in which volatile organic acids dominate, and methane fermentation is the conversion of these metabolites into stable carbon dioxide and methane end products. In such a biphasic system, it is necessary that the first reactor contains the maximum number of hydrolytic, acidogenic, and acetogenic bacteria, and that the second reactor has the maximum number of methanogenic bacteria [21].

The first phase is different from the second in terms of population of microorganisms, degradation rate, degradation process, and products. Isolation of the acid phase allows optimization of the conditions required for many complex organic chemicals present in wastewater to be broken down into short chain volatile fatty acids (VFA) and other simple compounds.

At present, there are many plants at dairies that successfully produce biogas from whey with the addition of other substrates. Below are examples of existing installations.

Biogas plant in Siedliszczki

The 0.99 MW biogas power plant was implemented by Wikana Bioenergia company in Siedliszczki (Piaski municipality). The installation was launched on October 7, 2011. The main raw material for biogas is a specially prepared corn feed with the addition of whey and slurry liquid substrates. The raw material comes from the crops grown in the surrounding farms and from the District Dairy Cooperative in Piaski. Electricity generation is combined with heat generation in the cogeneration process. The main components of the power plant complex are two fermentation tanks, one post-fermentation tank, and a cogeneration unit. An open silo is an indispensable element of the infrastructure, as well as an open lagoon where the fermentation liquid is collected. The installation produces 23.9 MWh of electricity per day. The estimated annual amount of electricity produced is 7,876 GWh of electricity and 8,199 GWh of heat [23].

Fig. 2. Biogas plant in Siedliszczki
Source: [22]

Biogas plant Ehrmann AG, Moscow, Russia

In the Ehrman dairy, about 600 m^3 of wastewater is produced per day in the production of yoghurt. Due to high costs, a solution was sought to drastically reduce the amount of sludge while obtaining biogas. After separating the solid impurities in the averaging tank, the fluctuations in the amount of wastewater, fat content, and pH values are compensated. Once the pH value is set, the organic matter is hydrolyzed. Fatty substances are separated in the process of flotation. A heat exchanger system that includes inflows and outflows optimizes the heat balance. In the Biomar® AFB reactor, augmented anaerobic biogenic treatment is achieved through appropriate biodegradation by producing biogas that is used energetically in the boiler room. In the next phase of the oxygen treatment, COD, BOD$_5$, N and P are removed. The wastewater then flows gravitationally to the final treatment where small amounts of sediment are formed. The gases that are generated during the purification are mineralized in a clarifier by programmed control with process visualization. The installation works fully automatically, meeting all environmental requirements, with the lowest possible operating costs.

Fig. 3. Biogas plant at the diary in Ehrmann in Russia
Source: [24]

Biogas plant in Umeä, Sweden

Norrmejerier in Umeå is the first dairy in Sweden that has combined their production cycle with their own biogas plant (Figure 4). In this biogas plant, dairy wastewater is cleaned together with the whey. Processing such large amounts of whey is problematic. It is usually waste that is fed to the animals. However, after studying new technologies in dairies in Germany, Switzerland, and Belgium, the Norrmejerier management decided to use ultrafiltration of whey. Most whey proteins are removed by using this method, which are a valuable raw material used to produce new food products. Biogas is produced from the rest of the whey, sewage, and other waste in the anaerobic process. Raw dairy products pass through the hydrolysis chamber (800 m^3) before they are pumped into the bioreactor. Then, in the process of flotation separation, the fats are removed, which are later decomposed in two separate mesophile reactors (35°C), each of 100 m^3 volume. The remaining substrates go to two reactors with a total volume of 5,000 m^3, where their decomposition at 37°C takes place. The leachate from the post-fermentation sludge is recycled to the bioreactor to maintain adequate compaction of bacteria in the reactor and shorten retention time (3.6 days) without risk losing bacterial cultures. In total, 35,000 kWh of energy per day and 10,000 MWh of biogas per year are generated by the fermentation process, with an additional 7,000 MWh generated by heat pumps. Sludge is obtained after the fermentation process, cooled to 15°C, and then stored. It is later used to produce mulch pallets and filling material for road construction [25].

Fig. 4. Biogas plant Umeä, Sweden
Source: [26]

As illustrated by the examples, dairy innovation is possible. Using the methane fermentation process to dispose of organic waste and wastewater leads to significant minimization of company costs and assurance of full energy independence of the enterprise. Going one step further, such technologies can generate additional profits from the sales of surplus electricity and heat. The solid product resulting from the fermentation, after thickening and drying, can be sold to local farmers as a full-fledged organic fertilizer. The added value of using such technology in your own dairy plant may be close collaboration with the local community, giving both parties some benefits, including intangibles. The society trusts the producer, and in return prefers to get the company's goods and to promote them. It is also more serious about the possibility of greater cooperation as a supplier of further co-substrates for the fermentation process, and the possible recipient of the energy produced. Such cooperation is beneficial for everyone and is a guarantee of joint, local success.

4. Photovoltaics as an alternative energy source for dairy production

The dynamically growing demand for energy in most countries of the world is forcing new technological solutions [27, 28]. At the same time, striving for the protection of the natural environment along with striving for the diversification of power sources and the need to ensure energy security cause increased interest in opportunities for the use of renewable energy [29]. One such option is electricity obtained by photovoltaic conversion, during which no waste or pollution is generated. Photovoltaic energy is a renewable resource that is friendly to the natural environment [30]. Solar panels do not cause any noise and they can be built in the immediate vicinity of human settlements. Long-term fault-free operation of the solar cells allows them to be operated for up to thirty years [31], while they are easy to assemble and install, enabling the power supply of mobile receivers or in difficult terrain conditions away from the grid [32, 33]. The modular design of the battery cells also makes it easy to adjust the size of the system to the energy needs of the receiver.

Over the last few years, photovoltaics have shifted from the area of interest of researchers and preliminary implementation work to real use in the energy sector of most developed countries (Figure 5). It is worth noting that the recent increase in the production of photovoltaic modules, as well as the installed electrical power from these modules, is unprecedented and incomparable to any other type of generator. Despite the economic crisis between 2008 and 2011, a global increase in installed capacity from photovoltaic sources was recorded at above 1300% and an increase in module production at 6000% [34]. According to the report of the European Photovoltaic Industry Association in 2011, the installed capacity of photovoltaic equipment in the world amounted to over 64 GW, which was almost twice the value from the previous year. Similarly, the number of companies operating in the photovoltaic industry is increasing, which is accompanied by an increase in employment. It is projected that by 2030, photovoltaics should meet 14% of global electricity demand [35].

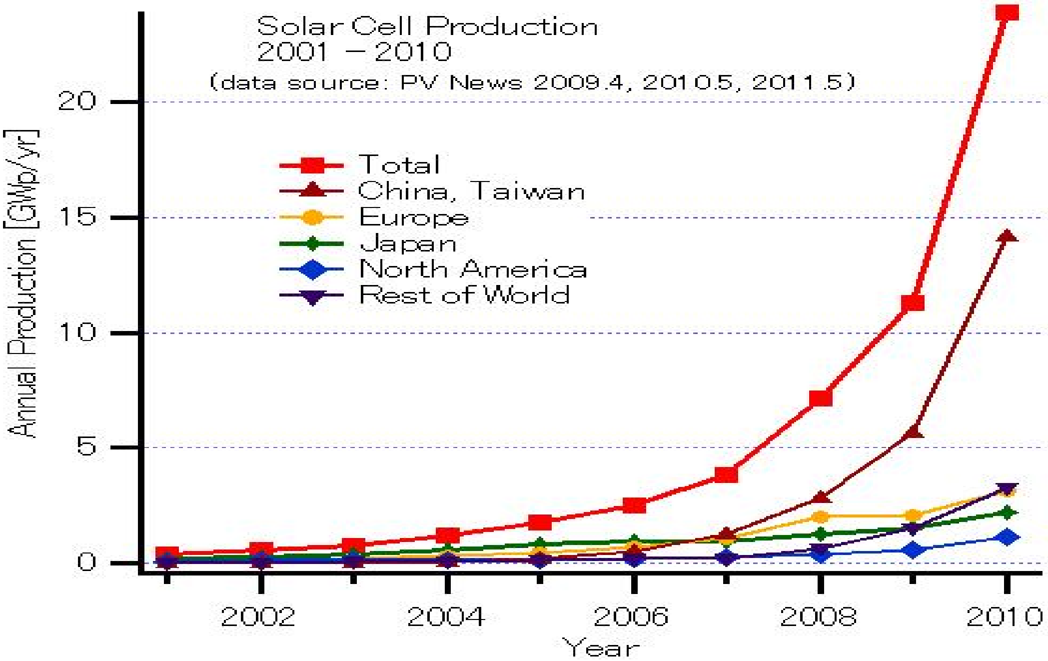
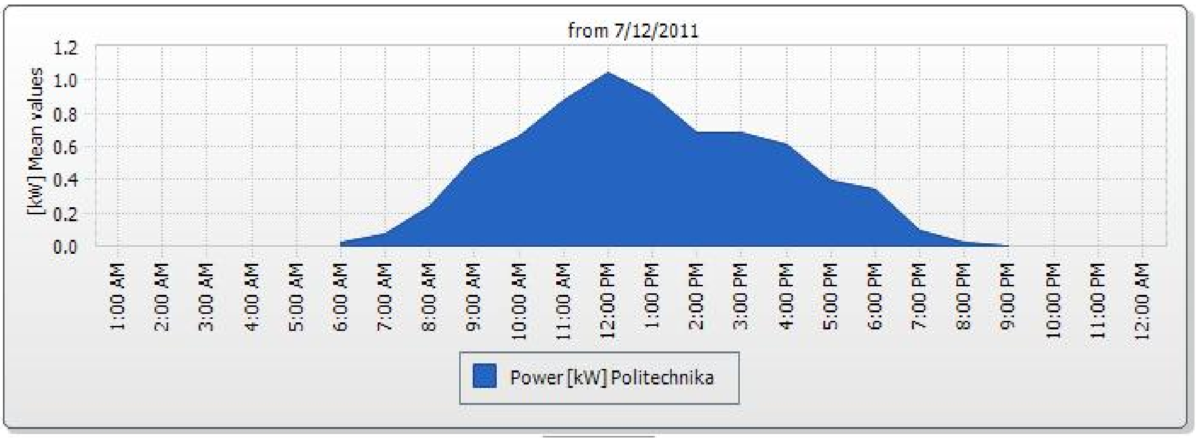


Fig. 5. Growth of world production of photovoltaic modules in 2000-2010
Source: [36]

The facts clearly indicate the importance of photovoltaic installations for modern energy systems. This is also reflected in many programs supporting the development of such energy sources, especially in European countries. Due to the EU's renewable energy development plan and the reduction of pollution, commonly called 3×20%, Poland is also committed to the intensive development of environmentally friendly energy [37]. Also, the new Energy Law, as expected, should facilitate the widespread introduction of photovoltaic installations to the National Energy Network.

Considering the above, it is necessary to emphasize the unique profile of the production of a typical photovoltaic installation, which is especially predisposed for industrial applications, including in the processing and dairy industries. Due to the typical daily lighting in moderate climates, photovoltaic systems are particularly advantageous in compensating the shortages of electricity in the daily cycle, with the highest production in the so-called "energy peak". Studies conducted at the Department of Semiconductor and Optoelectronics Devices of the Łódź University of Technology for different types of solar cells (Fig. 6) confirm the incidence of the highest production of PV energy from photovoltaic sources in the Polish climate between the hours of 8:00 and 18:00 in the summer, during the work of most food processing plants, including dairies.



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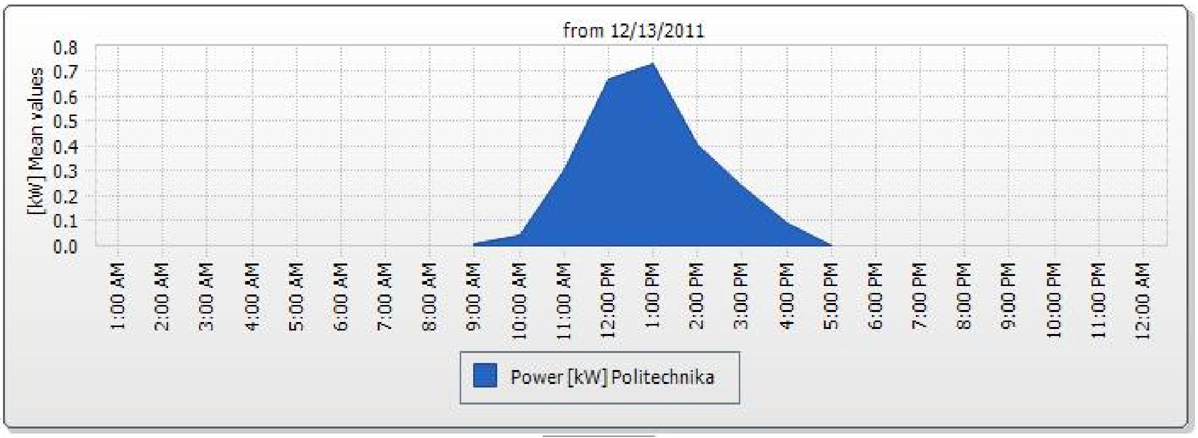
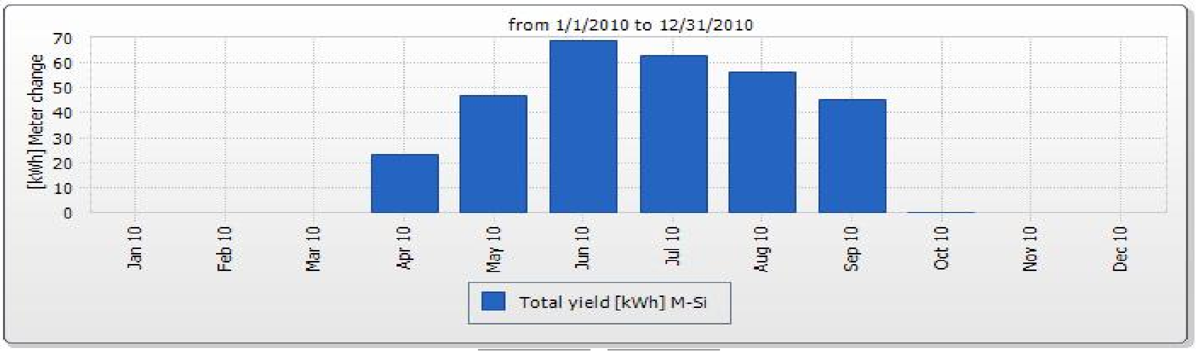


b

Fig. 6. Typical daily photovoltaic energy generation cycles in the summer (July) a) and in the winter (December) b) (source - own research). The results are averaged over four types of photovoltaic cells: a-Si, c-Si, ribbon Si, CIS.

The annual production of photovoltaic energy is tailored to the needs of food processing companies due to the increased consumption of electricity in the summer when chillers are in use. Examples of the averaged distributions of photovoltaic power generation for selected types of installations are shown in Figure 7.



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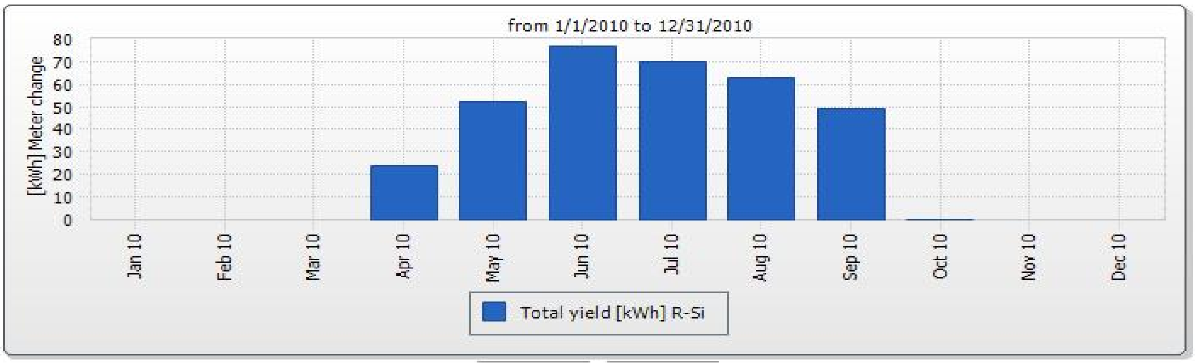

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Fig. 7. Exemplary results of generation of energy from photovoltaic sources based on polycrystalline silicon (a) and ribbon silicon (b) (source - own research).

Observing these dependencies, the use of photovoltaics to power the dairy processing plants should be considered, especially for out-of-town locations that are far from the power lines. During further work, the average energy demand of the dairy plant model will be verified on the basis of actual size measurements in selected plants. An optimized, scalable photovoltaic installation that meets the conditions of work in this facility will be developed, and research will be conducted into the use of alternative renewable energy sources such as solar collector hybrids. Particular attention will also be paid to the adaptation of renewable energy sources to the requirements of the dairy waste disposal process.

5. Conclusion

The rapid development of the dairy industry in Poland has prompted the innovation of this sector of the agro-food industry in many areas of economic activity. The field of application of modern and ecological solutions is above all an attempt to solve the problem of neutralizing several streams of post-production waste, as well as energy consumption of the dairy production process. There are many indications that in the coming years, especially in the Łódź Voivodeship, the dairy industry will become the leader of innovative green technologies and a leading producer of renewable energy.

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