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ALTERNATIVE WAYS OF ENERGY SUPPLY IN RURAL AREAS

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Abstract: Optimization of thermal energy and electricity production processes using renewable energy source (RES) is extremely important for agricultural horticultural, and production farms. The article is devoted to the search for the best available techniques to the optimize the process of obtaining heat energy from RES to meet the energy needs in Polish agriculture.

The food industry is particularly energy-intensive and as a result, when introducing various innovative technological processes, strong emphasis is placed on rational energy consumption and minimizing its losses, as well as on the secondary use of waste heat.

The direct result of using RES devices is also a reduction in greenhouse gas emissions into the air.

Keywords: renewable energy source, agriculture, biomass

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Introduction

Energy has always been essential for the production of food and rural development. Prior to the industrial revolution, agriculture's primary energy input was the sun: plants grew naturally from photosynthesis and then served as food for livestock, which in turn provided fertilizer (manure) and muscle power for farming. With the adoption of farm machinery, synthetic fertilizers and other modern technologies, food production has become increasingly reliant on fossil fuels such as synthetic nitrogen fertilizers, petroleum-based agrochemicals and diesel-powered machinery (Hitaj, Suttles 2016; FoodPrint 2019).

From the production of fertilizers to the processing and transport of food products to the market, the industrial food system depends on fuels to produce commodity crops (*Figure 1*, *2*). Food crops are very often devoted to energy production – for example corn, which is used to make ethanol as a fuel, or cereals are burned to produce thermal energy. The present reliance of the agriculture industry on finite energy sources that negatively impact the natural environment is not sustainable.

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There are energy alternatives at every step along the process that can help our food system become more sustainable (FoodPrint 2019).

Since the early 2000s, the energy policy and market conditions have affected the agriculture sector as both a consumer and producer of energy.

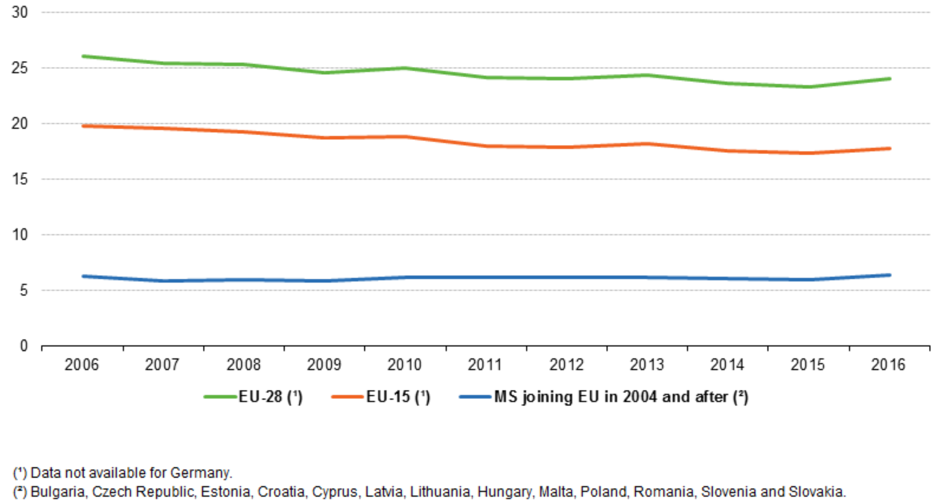

Figure 1. Energy consumption by agriculture, 2006-2016 (million toe[3])

Source: (Eurostat 2019)

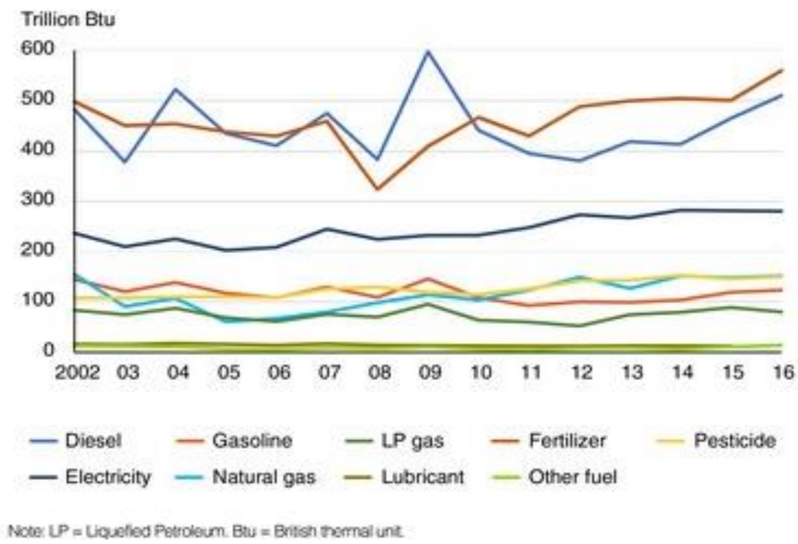

Figure 2. Energy consumption by agriculture sector by type of energy, 2002-2016

Source: (Hitaj, Suttles 2016)

[3] Tonnes of oil equivalent.

Agriculture has long been a consumer of energy, directly in the form of gasoline and diesel fuels, electricity, and natural gas and indirectly in energy-intensive inputs such as fertilizer and pesticides. In recent decades, agriculture has started producing energy, such as biofuels and renewable electricity, and farmers have allowed their land to be used for oil and gas drilling or organized wind farms (*Figure 3*). As the agriculture and energy markets have become increasingly linked, farmers have been impacted by changes in the energy sector through both expenditures and revenue (Hitaj, Suttles 2016; FoodPrint 2019; Mielczarek 2018, pp. 196-207).

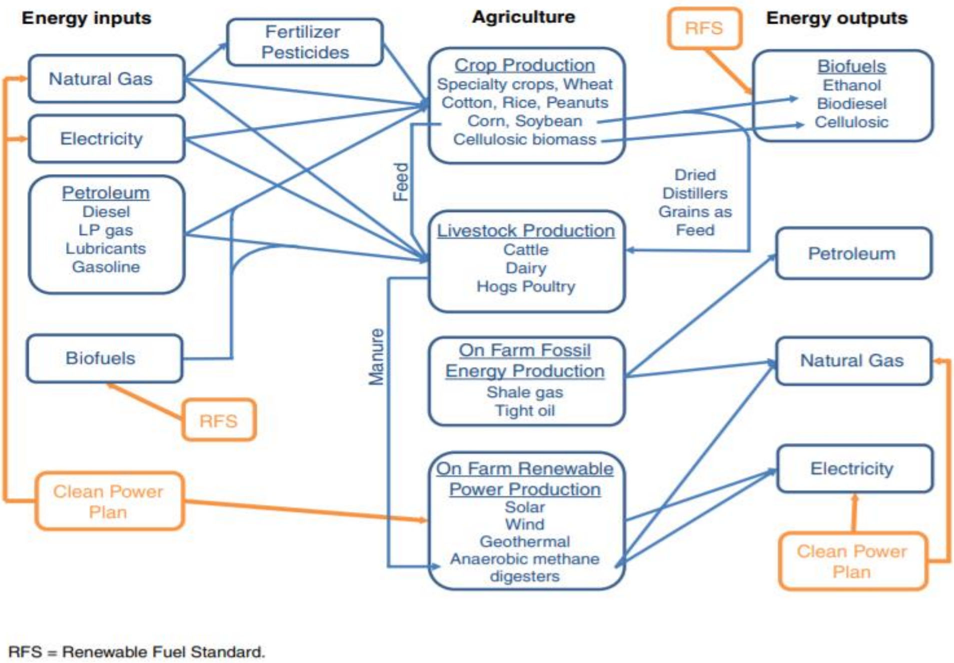

Figure 3. Relationship between agriculture and energy

Source: (Hitaj, Suttles 2016)

The current study is devoted to the search for the best available techniques to the optimize the process of obtaining heat energy from renewable energy sources (RES) to meet the energy needs in agriculture. Progress in the field of technical equipment powered by renewable sources opens new possibilities for the use of energy derived from nature in the countryside. The choice of the energy source and techniques for its use on farms should be supported by both the previous analysis, concerning the possibility of applying design solutions, as well as the results of economic analysis.

When weighing the advantages and disadvantages of using RES installations in agriculture, the fact that a reduction in greenhouse gas emissions in the place of their manufacturing is connected with reduced budgetary resources of the municipality or county intended for environmental protection and health, should also be taken into account.

Agricultural industry and energy supply

Agriculture is one of the main consumers of fuels and heat energy (*Figure 4*). At present, for example, in Polish farms about 70% of the cubic volume is heated by coal stoves (Dworakowska 2016, p. 11; Kott 2015, pp. 55-56).

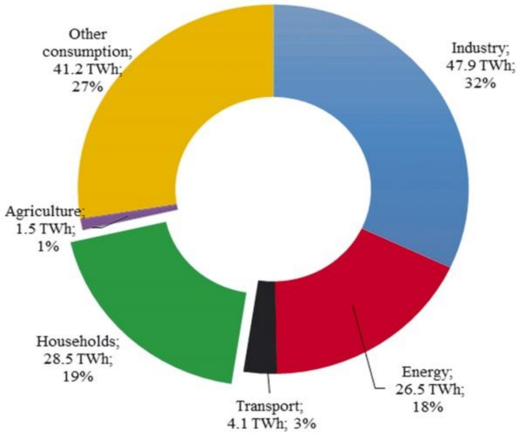

Figure 4. Electricity consumption in TWh by economic sectors in 2013

Source: (Kott 2015, pp. 55-56)

The heating devices currently used in remote and rural constructions, are frequently characterized by low thermal efficiency, and their service is labor intensive, therefore their operating costs are high (*Figure 5*, *6*). They are also a source of significant natural environment pollution by harmful gases and dust (Kalinichenko, Havrysh, Hruban 2018, pp. 199-217; Łakomiak 2018, pp. 172-189).

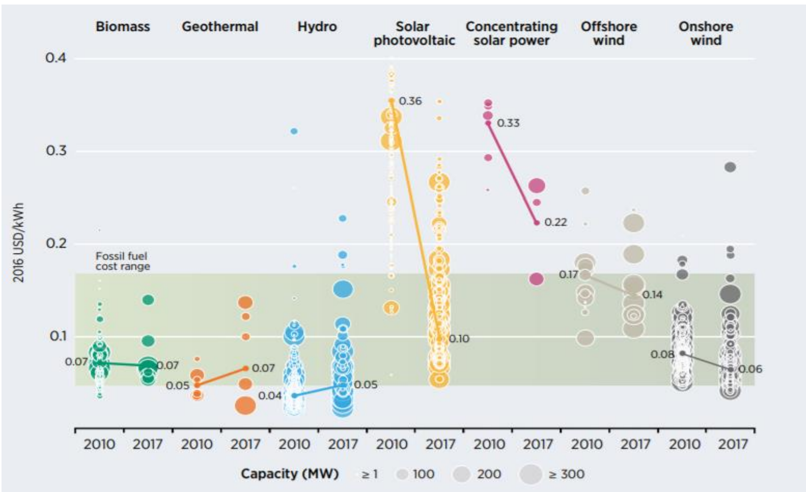

Figure 5. Global levelised cost of electricity from utility-scale renewable power generation technologies, 2010-2017

Source: (IRENA 2017)

Figure 6. Levelised cost of electricity by capacity factors of bioenergy-fired projects, 2000-2016

Source: (IRENA 2017)

The low efficiency of individual heat sources, designed primarily for the combustion of coke, coarse coal or coal dust, is due to their large consumption and poor technical condition (Cornelis, Meinke-Hubeny 2015).

Energy prices continue to increase. In the progressing air pollution, they will be relatively more expensive. Environmental tax will be imposed in them (*Figure 7*), intended for investments related to environmental protection (Vollebergh 2012; Eurostat 2019).

All this makes it necessary to look for new ecologically clean energy sources for heating and domestic hot water (DHW) in urban and rural constructions, as well as in the agriculture and food industries. Devices allowing the use of virtually unlimited resources of renewable energy in agriculture include: heat pumps, solar collectors, photovoltaic cells, furnaces for biomass combustion or gasification, biogas, as well as wind and water power plants (Kalinichenko, Havrysh, Perebyynis 2017, pp. 969-985). There are several fields of thermal engineering in the agriculture and food industry, in which the above mentioned devices should be used in Poland (Sala 2017, pp. 148-155; Gajewski 2015, pp. 4-37). They include refrigeration (cold storage:

vegetables, fruits), dairy (refrigeration-heating systems for dairy, cooling milk after milking), brewing, agricultural and industrial drying technology, heating, ventilation and air conditioning of agricultural objects.

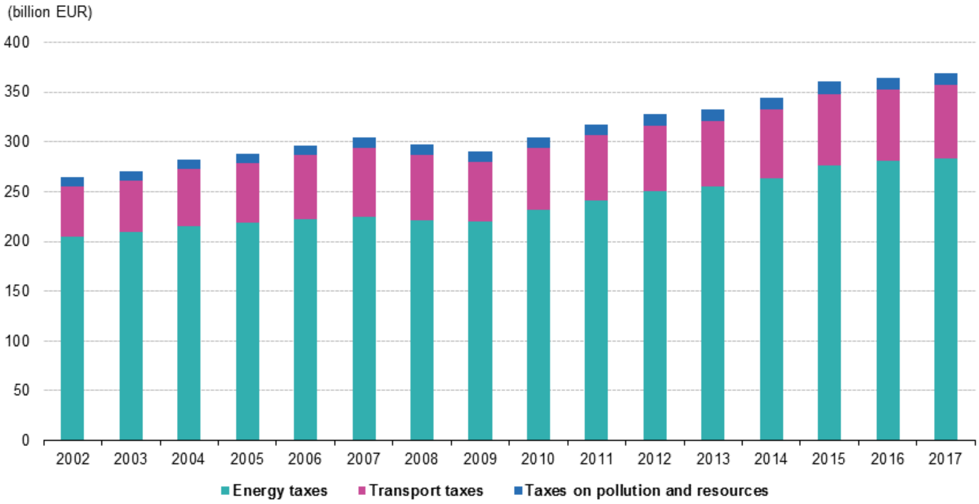

Figure 7. Total environmental tax revenue by type of tax, EU-28, 2002-2017

Source: (Eurostat 2019)

During agricultural production and food processing, there are waste energy streams resulting from, among others: the cooling of milk, heat given off by animals, and the physical enthalpy of animal products. Agricultural waste energy is also suitable for heat recovery in the ventilation systems of premises for animals, using heat pumps.

A direct result of applying RES equipment is also a reduction in the emissions of harmful combustion products into the air.

Nowadays, the rapid development of devices using RES is observed in the field of theoretical work optimizing their design, operating parameters, and practical application.

In the design, research and development phases of equipment using RES as fuel, it is necessary to use such calculation and simulation methods which will guarantee the maximum certainty of the prototype to obtain the planned properties and features of the object for future effective implementation in the agriculture and food industries (Tytko 2011, pp. 345-380; Lewandowski, Ryms 2013, pp. 225-310).

The required conditions for the development of devices that use RES as fuel can be established by an adequate mathematical model of the process of heat and mass transfer, taking into account the maximum number of parameters affecting the real characteristics of the object, supported and verified by experimental and practical results.

Optimization of the manufacturing process of thermal energy and electricity of major equipment using RES is useful for agricultural, and horticultural farms (Grzybek, Gradziuk, Kowalczyk 2001, pp. 21-65).

From the above mentioned solutions, it follows that a detailed description and optimization of thermal processes that occur in equipment using RES in the farm are necessary because of the need for further understanding of thermodynamic phenomena, as well as for the development of design and applications.

The thermal process taking place in devices using RES in a trial form can be described by information sets, which can be divided into three main groups:

- the first group consists of information about the thermodynamic and physical parameters of a process, such as temperature, enthalpy, differences in temperature, density, pressure, flow rate, and others;
- the second group consists of information about the structure of the heating system in which the thermodynamic process occurs, such as the type of collectors used (flat, vacuum), biomass stoves (with an open or closed combustion chamber), heat pump (water – water, air – water), biogas plant (feedstock, fermentation process), small wind farms with a vertical or horizontal axis of rotation;
- the third group is composed of information about the structural sizes of heating system cells, such as the surface of heat exchangers, pipe diameters, type of insulation and others (based on the selected example of a farm).

The thermal processes taking place in RES devices, described with the help of such defined variables, can be subjected to a process of optimization in relation to the above mentioned criteria (usually temperatures). The effectiveness of applying RES equipment is determined by the ratio of the amount of heat gained from RES to the motive energy consumption, their price, installation cost, and operating time. The value of this coefficient depends on various factors, including the following: the type of equipment design, the temperature of the heat source system and the heat utilization system, the power of solar radiation, application, as well as the type of buildings. The scientific problem still includes an understanding and description of the thermodynamic processes taking place in the above mentioned devices in the case of their specific use in agriculture. A thorough examination of these processes is necessary in order to develop the design and applications, reduce their prices and ultimately automatically control their work.

In the literature there is a lack of existing research that accurately presents the topic of optimizing the use of renewable energy devices in farms. There are no comprehensive research results based on which it would be possible to determine the quantitative relationship between the factors influencing the thermodynamic processes and energetic efficiency indicators for devices installed in rural farms. Studies that have been published up to date only allow conclusions to be drawn about quality, not quantity.

RES potential in agriculture

The technical potential of renewable energy sources in the country is estimated to be 450 PJ, i.e. 15.3 million toe, which represents approximately 13% of the current primary fuel consumption in the country (Johansson et al. 2004, pp. 5-7).

In agriculture, this could amount to as much as 25% of all the fuel and electricity consumption. The use of renewable energy beyond the energy aspect also has an impact on reducing the emissions of harmful gases into the atmosphere (*Figure 8*).

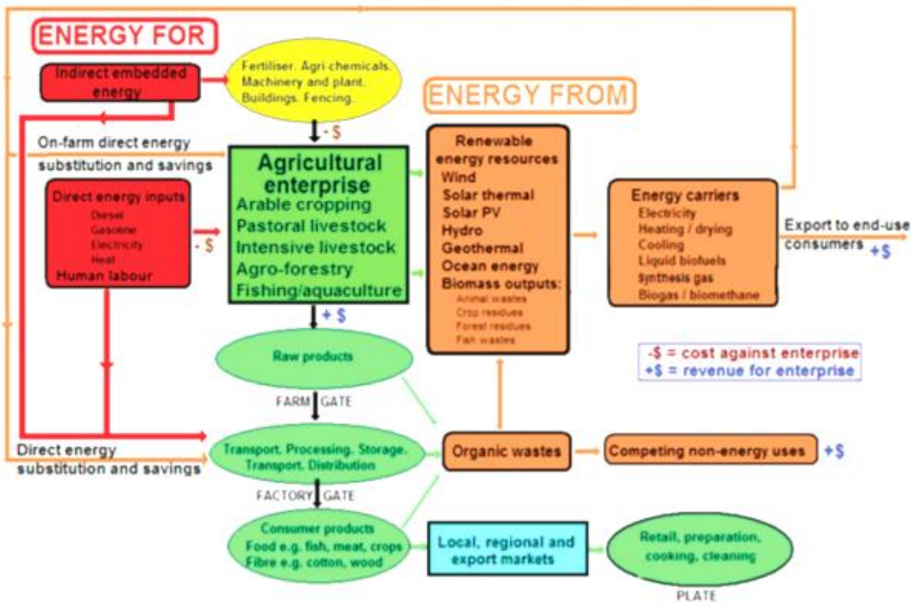

Figure 8. Energy flows through 'large-scale', high-input, corporate business enterprise with raw food products mainly supplying local and regional processing plants, supermarket chains and exporters

Source: (FAO 2011)

It is expected that in rural areas and in agriculture, there will be a significant change in the structure of used fuels and energy (*Figure 9*). By 2020, a great decrease in coal consumption will take place.

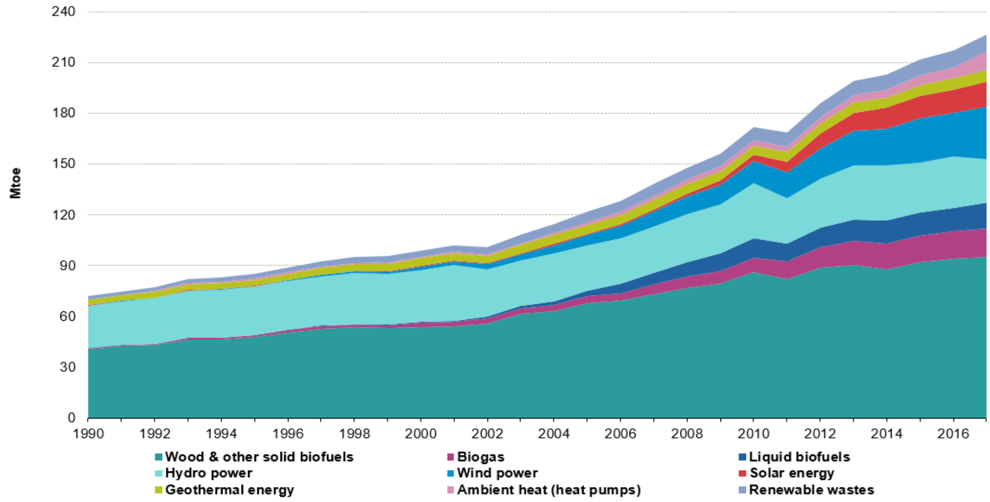

Figure 9. Primary production of energy from renewable sources EU-28 1990-2017

Source: (FAO 2011)

The largest increase will occur in the renewable energy group (*Figure 10*).

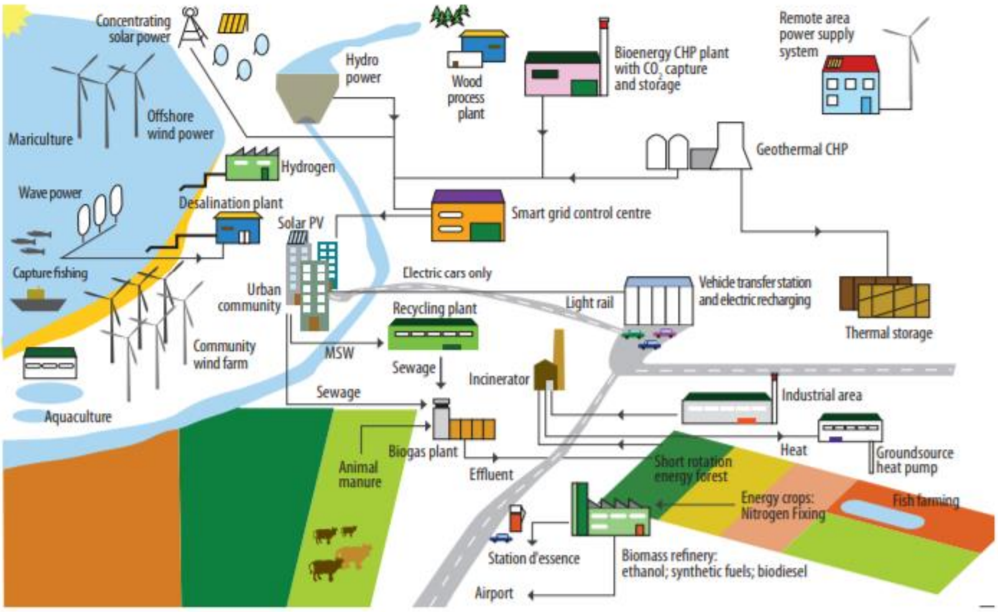

Figure 10. Integrated food-energy systems

Source: (FAO 2011)

Use of RES energy equipment in the agricultural and food industries

Heat pumps

One of the devices using the low-temperature renewable energy source of the Earth and waste is the heat pump. Implementing compressor heat pumps in the energy system allows both the consumption of primary fuels to produce heat, and environmental pollution to be reduced, which is of particular importance in rural areas. It should be emphasized that the compressor heat pump is a "pure" (from the ecological point of view) "transformer" of energy (Tytko 2011, pp. 345-380).

Heat pumps implementing the latest technology allow heat supply systems to be raised to a qualitatively new level, for example for farms.

The great potential for reducing energy consumption is provided by economical rational energy management, especially waste energy, resulting in different technological processes in agriculture (*Figure 11*).

One of the methods of rational and cost effective energy use is the application of heat pump installations. This enables the recovery of energy wasted in the farm, as well as the use of heat sources, not yet applied (Szwajkajzer 2017).

The reuse of heat such as from the piggery can be only provided by the heat pump. The use of this device is also supported by the substantial problem of environmental protection.

Heat pumps are also installed when there is no possibility to directly utilize waste heat (e.g. sewage, slurry).

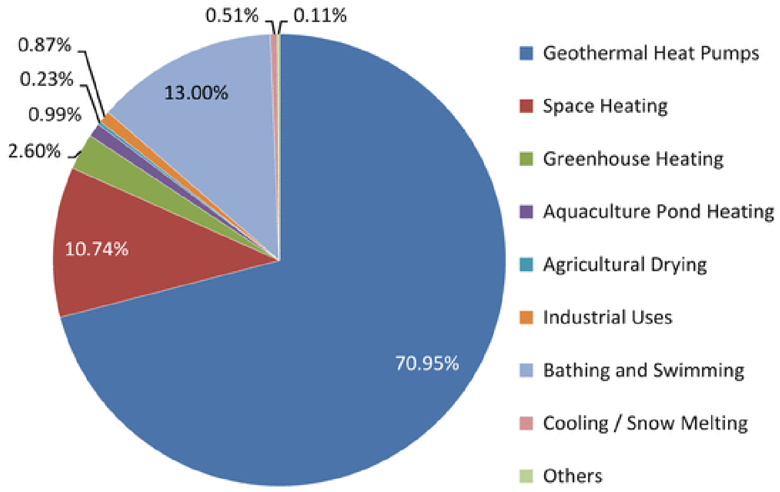

Figure 11. World-wide capacity (with heat pump), MWt

Source: (Lund 2015, p. 3)

Due to energy management in the agricultural and food industry, the use of heat pumps is becoming particularly attractive in heating and cooling systems (combined energy management).

These systems, on one hand, are used for cooling and freezing agricultural products, and on the other hand, for the simultaneous heating for technological purposes on farms. Combined thermal-cooling management is one of the most cost-effective systems of heat pump use. These systems allow simultaneous coverage of the demand for heating and cooling, with a single energy input.

Depending on temperature of the waste heat source and the temperature of the place from which we want to obtain the heat, we can use a water – water, or air – water heat pump.

As described in the literature, the food industry is particularly energy-intensive and as a result when introducing various new technological processes, strong emphasis is placed on the rational use of energy that is already produced by minimizing the losses, as well as on the recovery of wasted energy.

Meat processing industry

Before proceeding to the search for energy reserves, such as in meat industry plants, it is necessary to consider where and which form of energy is implemented. In meat industry enterprises, directly in production, the following forms of energy are used:

– thermal energy in the process of heating: cooking, smoking, and during the processes of conservation, sterilization or pasteurization;
– thermal energy in the processes of cooling or freezing;
– mechanical energy in the process of grinding, homogenization, packaging, in mechanical, hydraulic, and pneumatic transport.

The greatest demand in the meat industry is for thermal energy. Taking into account the processes of cooking, sterilization, maintaining hygienic conditions, and conserving products and intermediates at low temperatures, it must be said that we are still dealing with thermal energy. When considering the above described processes, we cannot ignore the importance of water as a heat carrier.

Heat pumps as equipment utilizing waste heat are ideally suited for use in the meat processing industry. The heat source system of the pump can be powered by thermal power from the discharge water of the meat plant, warm air, or the heat acquired in the process of cooling milk, for example.

Industry and food processing

Plants producing frozen foods and other delicatessen products in Przeworsk use a heat pump to recover waste energy from the refrigeration equipment condensers. These plants have recovered waste energy with a heat pump since 1998. The electricity capacity of recovered heat is approximately 1320 kW/year. The total energy capacity in this plant is approximately 2340 kW/year. By using a heat pump and special heat exchangers the demand is reduced by 50%. Waste energy of the water used in the technological process can also be a source of heat for the applied pump, as well water from the cooling of machines, and partly the air from the production halls.

Horticulture and gardening

Heat pumps can be used in horticultural production (gardening), including heating of the substrate. The source of heat for this pump can be fulfilled by horizontal ground collectors.

Animal husbandry – heat recovery

One of the ways to use heat pumps in agricultural technology (animal husbandry) is the use of waste heat generated as a result of metabolic changes in animals. These solutions are used in Scandinavian countries, particularly in Denmark, where there are large farms of pigs and bovine. Simple systems of heat exchangers can be found there, placed under the ceiling (usually made of PVC pipes), which capture heat from the air.

Heat pumps can also be used to heat water in water tanks during the production of juvenile fish, or thermophilic fish. The source of heat for this pump can be: water from deep wells, the ground (horizontal or vertical exchangers), natural watercourses (rivers), and water discharged from geothermal installations.

By using heat pumps in agriculture for cooling milk after milking, it is possible to simultaneously heat domestic hot water to about 60°C. The economic advantages of heat pumps include the fact that at the expense of only small amounts of electricity, for example, consumed by a refrigerator with a capacity of 1 kW, to increase the water temperature, the coefficient of performance – 4-5 kW is achieved.

The use of biomass for heat supply

Using biomass, such as energy crops, crop processing waste, and agricultural residues to produce energy benefits the nation, especially rural areas. The national benefits include lower sulphur emissions (which contribute to acid rain), reductions in greenhouse gas emissions, and less dependence on fossil fuels. Rural benefits feature new sources of income for farmers, more jobs, and economic development – all achieved while preserving a high quality of life, local control, and a clean environment that help make rural areas a good place to live (*Figure 12*) (NREL 2000).

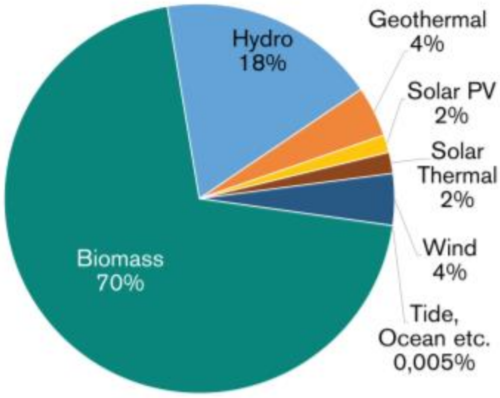

Figure 12. Total primary energy supply of all renewables in 2016

Source: (WBA 2018, p. 13)

Biomass energy systems not only offer significant possibilities for clean energy production and agricultural waste management, but also foster sustainable development in rural areas. The increased utilization of biomass wastes can be instrumental in safeguarding the environment, generating new job opportunities, as well as contributing to sustainable development and health improvement in rural areas (BioEnergy Consult 2019).

Biomass energy has the potential to modernize the agricultural economy and catalyze rural development. The development of efficient biomass handling technology, improvement of agro-forestry systems and the establishment of small, medium and large-scale biomass-based power plants can play a major role in rural development (BioEnergy Consult 2019).

In houses in the countryside fireplaces with a water jacket in which wood and biomass pellets are burned for heating are used increasingly more frequently.

Fireplaces can replace central heating boilers and in addition heating the house can be even half cheaper than that using gas (Roszkowski 2012, pp. 79-100; Goszczyński 2018, pp. 132-138).

Many people choose to heat their houses with modern fireplace inserts. That is caused by the increasing cost of gas, oil and electricity, as well as the aesthetic and ecological advantages of fireplace inserts. The smoke produced when combustion wood contains far fewer pollutants than the combustion gases from coal-fired boilers. Closed fireplace inserts differ from regular, open fireplaces by the fact that the vast majority of heat generated in them remains in the room, instead of leaving through the chimney. Fireplaces with a water jacket are modern devices equipped with heat exchangers (external or internal), circulation pumps, 3-way valves, and control units. Given the very low operating costs, they have become very popular. Until recently, the installation of a fireplace was mainly aimed at creating mood, or a relaxed family atmosphere that prevails at a natural fire, while today the main goal is to reduce the heating costs of the house and water heating (WNP.pl 2014, pp. 155-164).

A fireplace with a water jacket cooperates with traditional radiator or floor central heating installations, while maintaining the economic, aesthetic and ecological advantages of an ordinary fireplace. The exhausts in such a fireplace heat the air and water. The thermal power of such fireplaces varies from a dozen to 40 kW (Poskart, Szecówka, Radomiak 2006, pp. 950-952).

It should be noted that it is not constant and depends on the amount of fuel in the furnace and its heating phase.

The fireplace is constructed so that it can work in two systems: closed and open. It is possible thanks to the stainless steel built-in special exchanger. The exchanger does not only separate the open system from the closed one, but also prevents the condensation of water vapor contained in the combustion chamber during heating of the system at the walls of the fireplace, which significantly prolongs the service life of the device. This exchanger also improves the efficiency of the pump system and protects the pump from cavitation (the boiling point in an open system is 100°C and in a closed system it is dependent on pressure and can be between 105 and 115°C).

The heating process in the fireplace is supervised by a control unit equipped with a microprocessor, which controls the air turbine in the range of 20÷100%. The controller has a combustion support system at the moment when the set temperature has been reached and prevents the formation of carbon oxides in the furnace. It is also equipped with independent control of the central heating and domestic hot water circuit, and the ability to disconnect the heating circuit in the summer. A built-in special valve in the air turbine inhibits the combustion process at the moment when the desired temperature has been reached, and the design of the fireplace provides a minimum air flow so that carbon oxides are not created in the furnace. The combustion chamber is constructed so that the process of wood combustion is optimal. The turbine provides the primary air, which supports the process of heating and allows the combustion of wood-based materials with different parameters, and the secondary air, which is aimed at after combustion of the gases, increases the efficiency of the device. A fireplace can be used with other devices, while the built-in controller can turn off the operation of a gas, oil or electric boiler, or heat pumps after the minimal set temperature has been reached, taking control of the central heating and DHW circuit. As soon as the temperature drops below the set minimum, the functions of the boiler are restored. The controller is programmed for several time zones, or may cooperate with the room controller. It is possible to load the fireplace with wood to full and set the desired temperature, close the door and the controller will manage the combustion process so that the desired temperature is always reached. This does not require special supervision; the combustion process takes between 2 and 8 h, depending on the energy demand.

Coal stoves are increasingly more often replaced by furnaces for central heating in houses in the countryside also designed to burn pellets made of straw or wood waste. The difficulties associated with their implementations occur due to the following reasons:

– the lack of awareness of the large economic benefits associated with the production of electricity and thermal energy;
– the surplus of energy from fossil fuels and too low prices of conventional non--renewable fuels, not including the cost of pollution and risks for human health and life;
– the high price of green energy, which is not competitive compared to that of coal or gas;
– the large volume of biomass creates a problem of its storage;
– the difficult distribution of biomass;
– owners of biomass furnaces indicate problems with the lack of uniform operation of the furnace in the entire combustion cycle;
– too slow technical progress of new manufacturing technologies for heat and electricity from biomass, particularly high-energy;
– problems related to the sales of locally produced thermal energy;
– the lack of organizational experience concerning the possible implementation of renewable energy use in the forms of heat supply in rural communities.

Conclusions

Energy-balanced agriculture involves providing sustainable energy for the food sector and generating sustainable energy from the sector. There are three basic ways of making it energy-smart:

– increasing the efficiency of energy use;
– using more renewable energy as a substitute for fossil fuels;
– improving access to modern energy services.

The energy generated though renewable energy resources can be used directly by farms, fisheries and processing plants or be sold off-site to gain additional revenue. Much of the renewable energy could come from local resources. Energy generating facilities using wind, solar and hydro power can be built on rural lands with a negligible impact on agriculture. Biomass residues from primary production and food processing can also be used to generate energy. Raising awareness raising, developing the capacity and local technical support are essential if renewable energy projects are to be successfully established and implemented.

Investments in improving energy efficiency and establishing renewable energy projects are increasing throughout the entire food sector, from primary production to transport and food processing.

The combination of small-scale renewable energy systems and improved use of traditional biomass can provide access to reliable and affordable energy for many local communities. Renewable fuels may also be required to address energy poverty in rural areas. Where feasible, it would be preferable to jump directly to renewable energy systems to avoid investments in technologies that will lock users into fossil fuels for the foreseeable future. The potential co-benefits of renewable energy on livelihoods, employment, health, and rural development should be considered.

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ALTERNATYWNE SPOSOBY ZAOPATRZENIA W ENERGIĘ NA OBSZARACH WIEJSKICH

Streszczenie: Optymalizacja procesów produkcji energii cieplnej i elektrycznej z wykorzystaniem odnawialnych źródeł energii (OZE) jest niezwykle ważna dla gospodarstw rolniczych, ogrodniczych, produkcyjnych. Artykuł poświęcono poszukiwaniu najlepszych dostępnych technik optymalizacji procesu pozyskiwania energii cieplnej z OZE w celu zaspokojenia potrzeb energetycznych w rolnictwie polskim.

Przemysł spożywczy jest szczególnie energochłonny, wskutek czego podczas wprowadzania różnorodnych innowacyjnych procesów technologicznych silny nacisk kładzie się na racjonalne zużycie energii oraz minimalizację jej strat, a także na wtórne wykorzystanie ciepła odpadowego.

Bezpośrednim skutkiem zastosowania urządzeń OZE jest również redukcja emisji gazów cieplarnianych do powietrza.

Słowa kluczowe: odnawialne źródła energii, rolnictwo, biomasa