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ECONOMIC AND TECHNOLOGICAL ASPECTS OF DISTRIBUTED ENERGY SYSTEMS BASED ON BIOMASS: A CASE STUDY OF A SMALL COUNTY IN POLAND

Abstract

The purpose of this article is to present the benefits of using renewable energy sources for generating electricity. Energy coming from renewable sources contributes to the advancement of technology, creates innovation, and establishes cross-sectoral cooperation in science, business and local governments. It also promotes the development of intellectual capital and technical knowledge. At the same time, it provides the opportunity to stimulate local development, especially in agricultural communities and rural areas. Therefore, the text presents the results of studies on the availability of biomass, its productivity, logistics and economic benefits for Daszyna County, who is a potential investor.

Key words

renewable energy sources, biomass, biogas, alternative energy sources, stimulating local development, development of agricultural communities and rural areas, technological progress, innovation, cross-sector cooperation

Introduction

The use of renewable sources for the construction of a distributed generation system in tri-generation (the production of electricity using heat and cold in combination) not only means energy security at the regional level, but provides the opportunity to stimulate local development, especially in agricultural and rural communities. Energy coming from renewable sources contributes to the advancement of technology, creates innovation, and establishes cross-sectoral cooperation in science, business and local governments. It also promotes the development of intellectual capital and technical knowledge.

However, the primary condition for achieving a significant increase in the use of renewable energy sources in Poland is to establish a favorable legal and economic environment that will enable the creation of an effective and comprehensive system of cooperation between enterprises, scientific and research entities, and institutions from the business environment. The hybrid micro power plant case study presented in this paper, developed by a multidisciplinary and international team of scientists, engineers, economists, biologists and the authorities of the small agricultural commune, can be a model of local development where renewable energy plays a key role.

The concept of a local biomass microelectric plant was created at the Pro-Akademia Research and Innovation Center, and an interdisciplinary Polish-German team of experts from the Lodz University of Technology and Kassel University was invited to design it, with the support of practitioners from Seeger Engineering. The potential investor, Daszyna, is a small municipality in Central Poland, and actively participated in works on the project. This article is a summary of preliminary fieldwork and analysis of the available statistics. The diagnosed land was mapped for the availability of biomass and its productivity and the logistic and economic aspects were analyzed.

Hybrid micro power plant - strategic assumptions

As the main raw material for the power plant, biomass is planned in the form of straw and wood chips. The planned investments are in line with the priorities of Poland's ecological policy and the requirements of the European Union. Promoting economic activities in the form of building a local biomass micro power plant will contribute to the principle of sustainable development and to the protection of the climate in the European space. Burning biomass in the form of straw and wood chips will reduce CO₂, NO_x, SO₂ and particulate emissions.

The model character of the hybrid power plant is that it will provide a multimodal technical, organizational and economic solution, which can be used in other European agricultural-type communes. The needs of rural and urban-rural communes in Poland, the European Union and the world in terms of securing the inhabitants with electricity, heat and cold are enormous, and they will grow. In the opinion of experts, implementing the development project "Conditions and mechanisms for rationalizing energy management in communes and districts" NR11 001506/2009, funded by the National Center for Research and Development, there are seven problematic situations that have significant energy aspects and need to be resolved by the energy management system in communes:

- Excessive use of electricity for municipal purposes and for households, agricultural entities and microenterprises.
- Unsatisfactory quality of power supply in communes and districts.
- Excessive heat consumption in communes, households, agricultural entities and microenterprises.
- Excessive emissions of pollutants into the environment.
- Danger of normal functioning of the commune under conditions of long-term failure of external power supply (up to three weeks).
- The threat of normal functioning of municipal and residential facilities in the event of a centralized heat source failure.
- Breaks in external supplies of liquid and gaseous fuels.⁸

The planned CHP plant provides the opportunity to solve or mitigate all the problems described above. In addition, during the implementation of the project, the assumption of the transfer of knowledge (philosophy transfer) and real cooperation of science, economy and local administration will be met.

The implementation of the project to build a local biomass power plant will enable the authorities of the Daszyna commune to realize the statutory obligation to secure the inhabitants with energy and heat and to develop so-called "green industries". The production of straw for the CHP plant will be carried out by the local farmers living in the commune. On the other hand, the organization of supply will be provided by local transport, providing additionally ironing services and pre-preparation of biomass bales.

Biomass micro power plant - technological aspects

The planned biomass power plant with a capacity of 2 MW of thermal energy and 0.75 MW of energy will be supplied with a combination of plant raw materials consisting of straw, chips and hay. This fuel configuration is appropriate for the selected energy technology and thermodynamic circulation using the ORC (Organic Rankine Cycle) circuit. The ORC circuit is a type of steam circuit that uses the vapor of organic factors, which differs greatly in properties from water vapor. Their main advantage is having a low boiling point, which significantly increases the pressure in the whole circuit. In addition, these factors allow the turbines to scale to small dimensions.

In the proposed energy technology, the heat of circulation will be supplied by hot silicone oil heated by a biomass boiler. Currently, at the stage of conducting research analyses on the European market, there are not enough small steam boilers available that are heated with straw, which is a fuel of relatively low calorific value and significant volumes. Silicone oil evaporates at temperatures above 300°C, which requires to power the evaporator with a carrier of very high parameters like thermal oil. Thanks to the use of silicone oil, the oil vapors produced by the evaporator drives a less complex turbine than a professional steam turbine. Silicone oil, which practitioners expose, is a preservative, non-erosive, and mechanical-friendly medium for turbine blades. Overworked oil vapors are transported to the cooling system, fed to the condensation and circulated back to the evaporator.

⁸ Gospodarowanie energią w gminach – podstawy metodyczne, H. Rusak (ed.), Wyższa Szkoła Ekonomiczna, Białystok 2011.

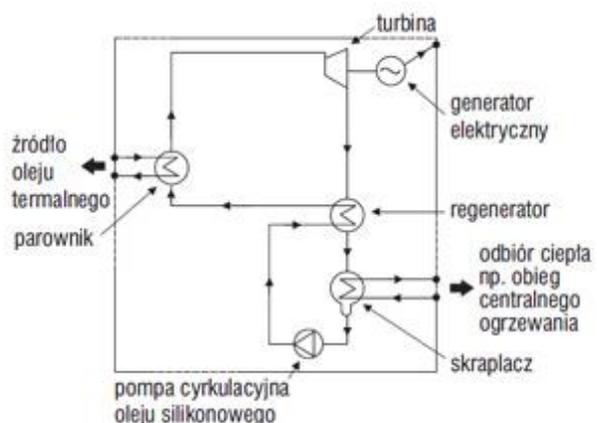


Figure 1. ORC circuit diagram.

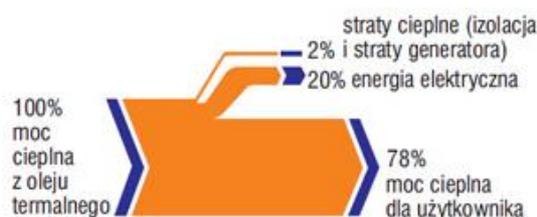


Figure 2. Balance of energy in the ORC circuit.

Source: Leszek Pacuła, www.rynekinstalacyjny.pl, 20.08.2011.

The above layout is characterized by very high reliability. The working time between renovations is about 50 thousand hours, and maintenance reviews take only a few hours a year.

Balance of biomass in the Daszyna Commune

The CHP will supply about 5000 tons of biomass per year (4500 tons of straw + 500 tons of wood chips, constituting an additional 10% to straw). This amount of biomass will allow the CHP to run all year, with full power, regardless of outdoor temperature, with an assumed average biomass value of 14,000 MJ/t.

The area of sowing in Daszyna Commune is shown in Table 1.

Table 1. Area of sowing in Daszyna Commune.

Wyszczególnienie	Ogółem	
	w ha	Ilość gospodarstw
pszenica		
- jara	1378,81	515
- ozima	1029,44	345
Żyto	518,05	325
jęczmień		
- jary	212,48	167
- ozimy	17,64	14
owies	142,23	146
pszenżyto		
- jare	79,56	70
- ozime	141,15	118
mieszanki zbóż		
- jare	259,24	238
- ozime	8,00	5
ziemniaki	433,44	603
kukurydza	156,02	120
buraki cukrowe	572,35	320
warzywa	790,60	562

Source: study "Update of the strategy for solving social problems in the Daszyna commune for the years 2009-2015", Daszyna, October 2010, p.28.

The Daszyna Commune Council has confirmed the validity of the data presented in Table 1 as of 25.05.2012, supplementing that the sown grain straw is about 4000 ha. In addition, the Commune Council has supplemented the above data with an area of 200 ha from which hay can be harvested, a complementary input material for the CHP plant, and identified possible wood pulp from the commune's area in the amount of 5000 tons per year.

Determining the number of tons of straw obtained per hectare is relatively complex; it depends on the grading class of each crop field, the weather conditions in a given year, the variety of grain and the use of blade twigs. Sources say that it is between 1 t/ha and 4.5 t/ha, with some analyses giving levels up to 6 t/ha.⁹ For the calculations in this analysis, the value below the average (3 t/ha) amounting to 2.5 t/ha has been assumed to be appropriate for investment decisions.

To meet the supply of 4,500 tons of straw to the CHP plant, assuming the acquisition of 2.5 tons per hectare, 1,800 hectares of corn fields are needed. The best quality straw comes from about 2,726 hectares, which includes the value of the reduction of acreage related to the supply of straw to the already existing small biomass boiler (see data in Table 1). Considering only the area of wheat and rye cultivation in the Commune, this means that 1,800 ha of cereal crops and harvesting of straw required for the CHP plant constitute 66% of the total available area of wheat and rye fields. On the other hand, the total available area from which straw can be obtained is about 3,700 ha, which is the value 4,000 ha reduced by about 300 ha associated with the supply of straw to the already existing small boiler houses in the commune. The demand for the area is approximately 49% of the total available area of fields in the Commune. The above calculations indicate that there is sufficient area potential in the commune that meets the demand of CHP plants for straw.

The Daszyna Commune has a wood chip production potential of 4,500 tons, with a calorific value of 14,000 MJ/t.¹⁰ The CHP plant needs 500 t. This means that the Commune has much greater wood chip production possibilities needed for the CHP plant (4,500 t production compared to 500 t of demand).

In addition, the Commune has a stock of hay coming from about 200 ha, which means it can generate on average about 1,600 tons of hay with a calorific value of 8,000 MJ/t¹¹. The above mass of hay corresponds to a mass of straw equal to 900 tons. There is a technical and logistical possibility of mixing straw, wood chips and hay in certain technological scopes. It should be emphasized that the above calculations are made with the assumption of the CHP operating at maximum power throughout the year, even in the summer, which is a strongly redundant assumption, but guarantees the reliability and safety of the CHP plant operating at the investment and operating stage.

Method of obtaining biomass

Daszyna Commune, where the planned CHP plant will be built, covers an area of less than 81 km² (see Map 1).

As shown on the map, the maximum distance from the approximate location of the CHP plant to the point at the border of the commune, the furthest away, is about 13 km by road, which gives about 26 km in both directions.

Bales of straw, depending on their size and the devices making them, weigh from 10-30 kg for bales (0.5x0.5x1 m) and up to 450kg for large so-called Hesston bales (1.2x1.3x2.4 m).¹² In the application it is assumed that bales with an average weight of about 150 kg will be delivered to the planned CHP plant. Such bales measure 0.8x0.8x1.7 m or have a diameter of 1.2 m and 1.1 m high.

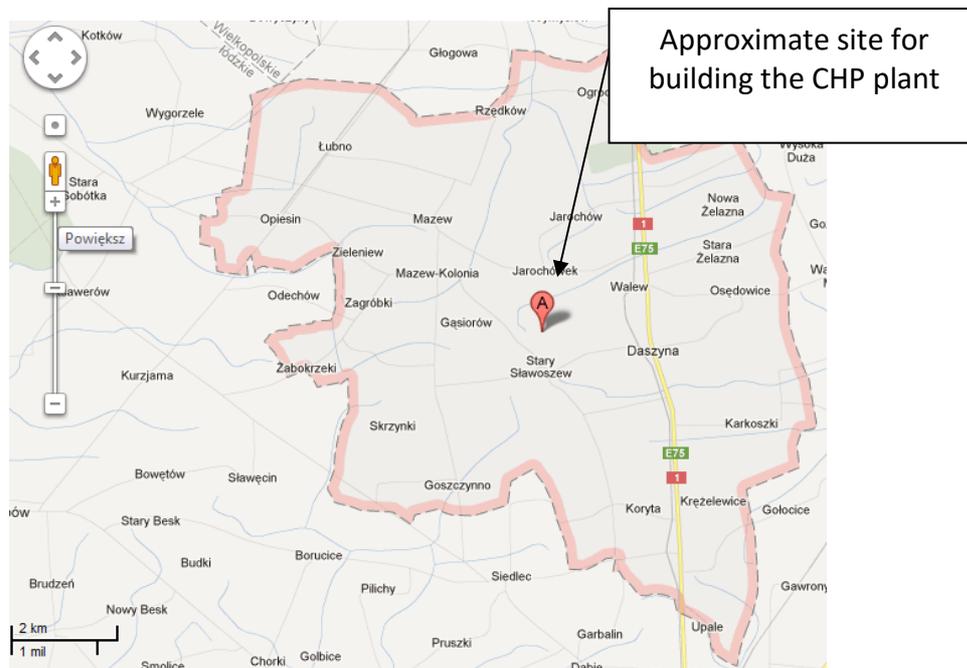
Assuming that the CHP plant works year-round with full power of 2 MW, 12.33 tons of straw per day should be delivered plus about 1.37 tons of wood chips per day. As demonstrated in the previous analysis, the production and availability of the above quantities is not a problem. By converting the daily straw demand in tons to the number of straw bales with a weight of 150 kg, the power plant should be delivered about 83 bales per day; at a weight of 120 kilograms, approx. 103 bales should be delivered per day.

⁹ See: W. Denisiuk, Słoma – potencjał masy i energii, "Inżynieria Rolnicza" 2008/2(100), p.26.; Brykiety ze słomy, Zachodniopomorski Ośrodek Doradztwa Rolniczego w Barzkowicach, Barzkowice 2010.; <http://www.brykieciarki.fora.pl/sloma,11/ile-ton-slomy-z-hektara,276.html>

¹⁰ Update of the strategy for solving social problems in the Daszyna commune for the years 2009-2015

¹¹ http://fluid.wme.pwr.wroc.pl/~spalanie/dydaktyka/spalanie_wyklad/PALIWA/BIOMASA.PDF

¹² http://www.kape.gov.pl/EN/Achievements/Programmes/ProgrammesInternational/1996_2000_a/pliki/sloma/sloma_2.htm



Map 1. The boundaries of the Daszyna commune and approximate site for building the CHP plant.

Source: own materials.

Straw bales will be delivered daily to the warehouse, which will be a covered roof of about 12x12 m in size and a height of about 4 m, located in the immediate vicinity of the CHP plant. In addition, as a buffer for supplies to the CHP plant, in the case of unforeseen circumstances, a 500-bale warehouse existing in the commune can be used, weighing about 75 tons. This is enough for about 5 days to power the CHP plant with full power.

Companies producing straw transport platforms have a trailer with a load capacity of over 13.7 tons (e.g. T026 from Pronar¹³). They have a loading platform measuring 2.43 x 10.77 m, which makes it possible to place on the trailer, with 3 bales stacked on each other (height), 54 cubic bales (8.1 tons) of the size and weight intended for delivery to the CHP plant. So, to meet the daily straw demand for the planned CHP plant in Daszyna, in one transport there will be two trailers needed with the dimensions given above, connected one following the other and towed by one vehicle. An example of this is shown in Figure 3.



Figure 3. Method of realization of transport deliveries to the planned CHP plant in Daszyna.

Source: www.metaltech.com.pl

To meet the daily delivery of straw in one transport, the field should have a specific surface area of at least 30.83 ha (assuming a yield of 2.5 t/ha). Another solution to ensure the implementation of one transport per day is to collect straw from several fields smaller than 30.83 ha adjacent to each other, or lying along a transport path of a certain length.

¹³ http://www.pronar.pl/przyczepy/___t026_.html

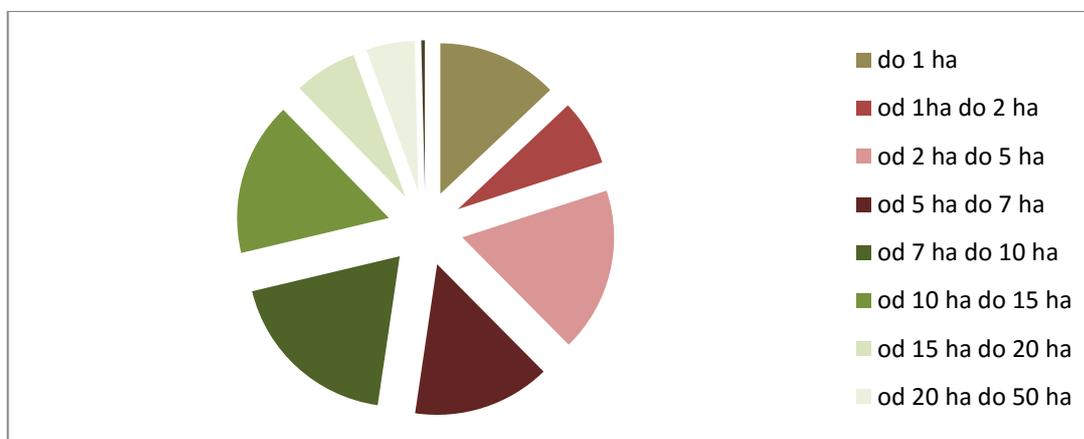
Table 2. Agrarian structure in Daszyna commune.

Grupy obszarowe użytków rolnych	Liczba gospodarstw
Ogółem	777
do 1 ha	100
od 1 do 2 ha	55
od 2 do 5 ha	137
od 5 do 7 ha	114
od 7 do 10 ha	147
od 10 do 15 ha	128
od 15 do 20 ha	52
od 20 do 50 ha	40
od 50 do 100 ha	0
pow. 100 ha	3

Source: Study "Update of the strategy for solving social problems in the Daszyna commune for the years 2009-2015", Daszyna, October 2008, p.26-27.

A separate analysis will require the optimization of the biomass supply chain and reduction of carbon footprint in biomass. Depending on the investor's final decision on the delivery of biomass, the following logistics solutions are possible:

- collecting the raw material obtained from direct manufacturers in unprocessed form and transporting it to the CHP plant, where further works will be carried out in biomass treatment for energy purposes;
- collecting pre-processed biomass from suppliers and delivering them in a "just-on-time" mode;
- warehousing as an intermediate operation will be included in the logistics process.



Graph 1. Agrarian structure in Daszyna commune.

Source: Study "Update of the strategy for solving social problems in the Daszyna commune for the years 2009-2015", Daszyna, October 2008, p.26-27.

With the increasing use of biomass by the commune, the optimization of delivery logistics to the local CHP plant will require proper planning, organization and management of both the supplier base and fleet of delivery vehicles or other means of transport. An important aspect of future research should be the so-called carbon footprint in the life cycle of biomass. The carbon footprint is calculated over the entire life cycle of biomass - from the production of vegetable energy resources, including CO₂ emissions, due to land use change in agricultural production for biomass production, through logistics, transport, warehousing and processing and combustion technologies. To minimize the carbon footprint while minimizing transportation and logistics costs, it is important to organize biomass production and delivery at the closest possible distance from the planned CHP plant. The preliminary calculations show that the maximum radius of biomass to the CHP plant will be 26 km, and considering the agrarian structure in the Commune, presented in Table 2 and in Graph 1, a distributed

system of production and delivery of biomass should be expected. The data in Table 5 indicate that 3 farms occupy an area of over 100 ha and about 25 farms between 30.83-50 ha. Therefore, there is a real danger that the 1,800 ha needed to provide annual straw deliveries to the CHP plant will not be collected (assuming the use of fields above 30.83 ha, which provides the daily straw requirements). Therefore, the straw supplier will probably have to additionally organize the collection of biomass from the small adjacent fields, or from fields along one transport route of a certain length.

The maximum distance from the CHP plant to the furthest points on the border of the commune is about 26 km on the existing roads. If it is assumed that the average distance on which the straw will be delivered "back and forth" will be 20 km and one transport per day with straw to the CHP plant, the annual number of kilometers traveled by the transport system will be about 7300 km/year, and combustion of 40 L of diesel fuel on 100 km, the transport system will burn 2970 L of diesel fuel per year for delivery purposes. This corresponds to roughly the amount of diesel fuel used by about 4 passenger cars driving an annual average of 100,000 km. Thus, the environmental burden will be negligible, mainly due to the short distances from which straw will be supplied.

In the case of a shortage of straw in the commune, it can be bought and brought from adjacent areas, especially to the east. Possible distances in this direction outside the municipality for possible delivery of straw will also be small.

The commune has experience in obtaining biomass from the adjacent communes. The cost of delivery of straw and 10% of wood chip additive on a long-term contract and a large tonnage of 5,000 tons/year is estimated at an average of 150 PLN/t.¹⁴ This gives an annual amount of about 750,000 PLN per year (62,500 PLN monthly). These are acceptable amounts for the commune's budget.

The contracted company will be obliged to deliver 12.33 tons of straw per day in a single transport, amounting to 83 bales of straw at an assumed single bale weight of about 150 kg. The requirement for a transport company to deliver the above straw mass with one transport will be entered into the rules of competitiveness. Minimizing the number of delivery routes is an expression not only of rationalizing costs, but above all of concern for the environment.

The Daszyna Commune has experience in the delivery of biomass to the already functioning small straw boiler houses and in the preparation of specific contracts with companies, together with appropriate records that work in practice (these agreements are included in this document).

Conclusion

The analyses forming the subject of the study authorize the following conclusions:

- Daszyna Commune has the necessary area of grain fields to meet the delivery of 4,500 tons of straw to the planned CHP plant. The commune also has the possibility to deliver 4,500 tons of wood chips, which exceeds the demand of CHP 9 times. In addition, the commune has the possibility of supplying 1,600 tons of hay, which corresponds to about 900 tons of straw.
- The distances from which straw, wood chips and hay will be delivered and the way in which it is delivered will cause minimal environmental stress and the carbon footprint will be insignificant.
- The commune has extensive experience in contracting the supply of straw to an already existing small boiler plant for straw. It has prepared and developed contracts for this type of service. After minor changes to account for the maintenance of the straw parameters and the method of delivery, it can be used for the planned CHP plant.
- The average cost of supplies of straw and chips is estimated at 62,500 PLN per month.
- It should be emphasized that all the values presented in this analysis assumed that the CHP plant will operate at full capacity throughout the year, including the summer, which is a very redundant assumption, thus guaranteeing the safety and economic efficiency of biomass deliveries while maintaining the highest environmental concerns.

¹⁴ http://www.kape.gov.pl/EN/Achievements/Programmes/ProgrammesInternational/1996_2000_a/pliki/sloma/sloma_8.htm#8.3

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**EKONOMICZNE I TECHNOLOGICZNE ASPEKTY ROZWOJU ROZPROSZONEJ ENERGETYKI OPARTEJ O BIOMASĘ
NA PRZYKŁADZIE MAŁEJ GMINY**

Abstrakt

Celem artykułu jest zaprezentowanie korzyści wynikających z wykorzystania źródeł odnawialnych dla wytwarzania energii elektrycznej. Wynika to z faktu, iż energetyka bazująca na odnawialnych źródłach przyczynia się do postępu technologicznego, kreowania innowacyjności, nawiązywania współpracy międzysektorowej: nauki, gospodarki i jednostek samorządu terytorialnego, sprzyja rozwojowi kapitału intelektualnego i technicznego. Jednocześnie stwarza możliwość stymulowania rozwoju lokalnego, zwłaszcza gmin rolniczych i terenów wiejskich. W związku z tym w tekście przedstawiono wyniki badań pod kątem dostępności biomasy, jej produktywności, logistyki i korzyści ekonomicznych, u potencjalnego inwestora – Gminy Daszyna.

Słowa kluczowe:

biomasa, współpraca międzysektorowa, stymulowanie rozwoju lokalnego, rozwój gmin rolniczych i terenów wiejskich, postęp technologiczny, alternatywne źródła energii, biogaz, innowacyjność, odnawialne źródła energii