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ANALYSIS OF THE POSSIBILITY OF ACHIEVING ENERGY SELF-SUFFICIENCY ON THE COMMUNAL LEVEL IN NORTH-EASTERN POLAND

***Tomasz Olkowski*[1], *Seweryn Lipiński*[2]**

[1]ORCID: 0000-0003-3783-1281
[2]ORCID: 0000-0001-9771-6897
Department of Electrical and Power Engineering,
Electronics and Automation
Faculty of Technical Sciences
University of Warmia and Mazury in Olsztyn

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Abstract

The pursuit of energy self-sufficiency is understandable, as there can exist many reasons standing behind such pursuit. When considering commune level, many factors can influence the possibility of achieving energy self-sufficiency, but one thing is certain – this idea can be achieved by utilizing local renewable sources of energy, saving energy, and using it more efficiently. Such approach allows dealing with both climate change and energy crisis and can be beneficial for the local population, environment, and economy. The main aim of the work is to answer the question whether it is possible to achieve energy self-sufficiency on the communal level in north-eastern Poland. Five communes were analysed in terms of achieving both electric and heat self-sufficiency. We also checked whether there is an impact of selected municipal parameters on the value of energy potential of local energy sources. The results of our study indicate that achieving self-sufficiency is easier in terms of electricity (in 2 out of 5 communes the potential is more than twice as high as the demand) than in terms of heat (in 4 out of 5 communes the potential is more than twice lower than the demand, only in one the potential is close to the demand). It should be emphasized, that differences in the results obtained for different communes indicate that local factors have great influence on energy potential of individual communes.

Correspondence: Seweryn Lipiński, Katedra Elektrotechniki, Energetyki, Elektroniki i Automatyki, Wydział Nauk Technicznych, Uniwersytet Warmińsko-Mazurski, ul. Oczapowskiego 11, 10-736 Olsztyn, e-mail: seweryn.lipinski@uwm.edu.pl.

Introduction

Communes strive for energy self-sufficiency is a noticeably phenomenon for at least last few years. This is quite understandable, as there can exist many reasons for such a striving. According to ENGELKEN et al. (2016), most important factors are environmental awareness, tax revenues and greater independence from private utilities. However, this study indicates also that citizens, the political environment, the mayor's political power, and his/her financial resources are relevant factors for a municipality striving for energy self-sufficiency. Similar conclusions can be drawn from other works. For example, BALCOMBE et al. (2015) and WOCH et al. (2017) analyse i.a. the importance of involving the region inhabitants in the process and their premises for its support, BALEST et al. (2019), similarly as HAUBER and RUPPERT-WINKEL (2012), describe the whole process of moving towards renewable energy self-sufficiency as a socio-technical change and underline the importance of local decision-makers of the energy sector, while RAE and BRADLEY (2012) review all the issues of energy autonomy in sustainable communities, identifying a number of problems which are regarded as being of critical importance.

The other factor, often playing the crucial role, is inconvenient localisation – difficulties in energy supplies can be great motivation for attempts to achieve "energy independence" (RAE, BRADLEY 2012), including alpine regions (ABEGG, 2011), hard-to-reach islands (IGLESIAS, CARBALLO 2011) and remote or off-grid communities (REZAEI, DOWLATABADI 2016). On the other hand, there are also regions in which local conditions, like location favourable for acquiring energy from renewable sources (BERTSCH et al. 2017, BIERANOWSKI, OLKOWSKI 2016), the presence of plants producing waste that can be used for energy purposes (LIPIŃSKI et al. 2018, GU et al. 2017), or possibility of using tidal stream power (RAMOS et al. 2014), make it easier to achieve energy self-sufficiency.

Regardless of local factors driving the pursuit of energy self-sufficiency, one thing is certain – this idea can be achieved by utilizing regional renewable sources of energy, saving energy, and using it more efficiently (RAE, BRADLEY 2012, WOCH et al. 2017). Such approach allows dealing with both climate change and energy crisis and can be beneficial for the local population, environment, and economy (HAUBER, RUPPERT-WINKEL 2012, RAE, BRADLEY 2012, ENGELKEN et al. 2016).

The above analysis was our motivation to perform this study. The main aim of the work is to answer the question whether it is possible to achieve energy self-sufficiency on the communal level in north-eastern Poland. For that purpose, we analysed five communes in terms of achieving both electric and heat self-sufficiency. We also checked whether there is an impact of selected municipal parameters (e.g., total area, population, land use structure) on the value of energy potential of local energy sources.

Materials and Methods

Characteristics of the studied communes

Our study covered five communes located in north-eastern Poland. Two of them, i.e., Żuromin and Myszyniec are located in the northern part of the Mazovia province. The three remaining communes – Ostróda, Olecko, and Kozłowo – are in the Warmia-Mazury province. The locations of the studied communes are shown in Figure 1.

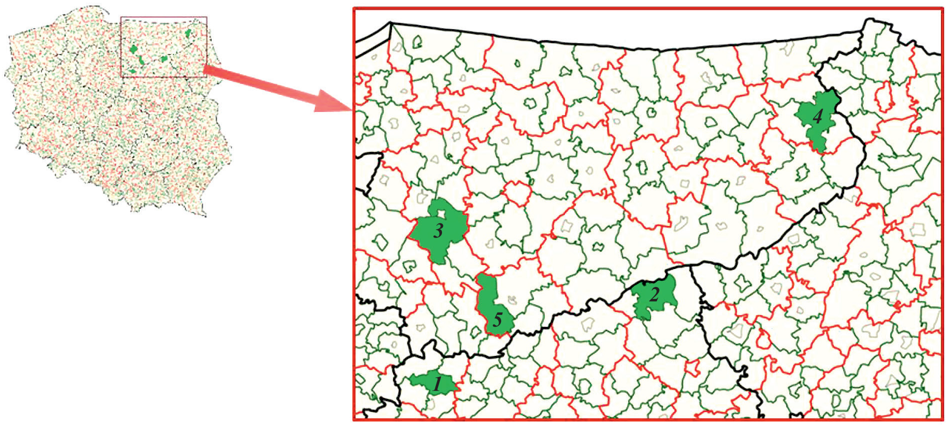

Fig. 1. Location of the analysed communes on the map of Poland:
1 – Żuromin, *2* – Myszyniec, *3* – Ostróda, *4* – Olecko, *5* – Kozłowo
Source: based on AOTEAROA (2013), added colours and numbers, CC BY-SA 4.0.

Żuromin, Myszyniec and Olecko are urban-rural communes, i.e., with the headquarters in the town with urban rights, while Kozłowo and Ostróda are rural communes. Tables 1 and 2 present data on the type, area, number of localities, population, and structure of land use in the analysed communes. The main source of information for the data on the studied communes was the Central Statistical Office of Poland (CSO) (2019); missing data was supplemented based on information being received directly from the communes' offices.

As it can be seen in Table 1, Ostróda commune has the largest area (401 km^2), while the smallest commune is Żuromin (133 km^2). Olecko commune has the largest population (about 22,000), and Kozłowo the smallest (about 600). The differences in population and area lead also to quite big disparity in population density (from 17 people per km^2 in Żuromin commune to 83 people per km^2 in Olecko). It should be also noted, that Ostróda (i.e., analysed area of Ostróda rural commune, not the city itself, which is considered as a separate commune) and Myszyniec communes have no existing heating systems.

Table 1

Type, area, number of localities, population, and population density in the analysed communes

Commune	Type	Area [km^2]	Number of localities	Population	Population density [people/km^2]
Żuromin	urban-rural	133	29	14,507	17
Myszyniec	urban-rural	228	22	10,471	46
Ostróda	rural	401	79	16,031	40
Olecko	urban-rural	270	45	22,130	83
Kozłowo	rural	254	36	6,200	24

Table 2

Structure of land use in the analysed communes

Type of land	Commune									
	Żuromin		Myszyniec		Ostróda		Olecko		Kozłowo	
	area [km^2]	share [%]	area [km^2]	share [%]	area [km^2]	share [%]	area [km^2]	share [%]	area [km^2]	share [%]
Farmland, including:	11,493	86.35	15,925	69.80	22,565	56.06	17.982	67.60	19,171	75.26
arable land	7,459	64.90	6,558	41.18	17,296	76.65	12,795	71.20	15,579	81.26
orchards	8	0.07	19	0.12	56	0.25	80	0.40	16	0.08
grasslands	4,026	35.03	9,348	58.70	5,213	23.10	5,107	28.40	3,576	18.60
Forests	714	5.37	5,485	24.04	12,597	31.30	4,841	18.20	3,929	15.42
Land under water	n.d.	n.d.	75	0.33	1925	4.78	1,330	5.00	478	1.88
Other lands	1,102	8.28	1,330	5.83	3 165	7.86	2,447	9.20	1,894	7.44
Total	13,309	100	2,814	100	40 252	100	26,600	100	25,472	100

n.d. – no data

The data on the land use structure, given in Table 2, shows that analysed communes have similar characteristics, i.e., in each of the communes under study, the agricultural lands, i.e., arable lands, orchards and grasslands, have the largest share of area. Differences in population, area, and population density, combined with the fact that all analysed communes have similar structure of land use, make the conclusions drawn from the study representative, as they will be obtained for communes with similar characteristics, but also appropriately diversified in terms of population.

Methodology of research on energy self-sufficiency of communes

In each of the analysed communes, the analysis was carried out in four steps.

Step 1 – determination of the energy demand of the commune. The need for electricity and the heat demand were considered separately. For this purpose, data on the consumption of energy carriers (fuels), the consumption of electricity drawn from the grid, or the consumption of heat collected from the heating system (if such a system existed in the area), was collected. The collected data covered the period of one calendar year in each case.

Step 2 – identification of energy sources available in the given commune. Electricity sources and heat sources were analysed separately. Among the identified sources, it was possible to distinguish between sources that are already exploited, as well as those potentially available.

Step 3 – determination of the energy potential of the previously identified local energy sources (taking into account the energy conversion efficiency). The calculations of the energy potential concerned only biomass sources. The potential of other sources, such as wind, sun, or water, was determined based on data obtained from installations already operating in a given area. For biomass, only the technical energy potential was considered. It is this part of the total potential that can be obtained within the framework of specific technologies, considering the energy efficiency of devices converting biomass into usable energy. In our calculations, we did not consider the potential of those biomass resources that are used for non-energy purposes, such as food, feed or industrial. We decided that only the surplus of biomass resources in each area can be treated as an energy resource.

The methodology of calculating the energy potential of biomass depended on the method of converting a given type of biomass into a given type of usable energy. In the case of heat production technology by direct combustion of biomass, the energy potential of its various types was determined based on the knowledge of the mass and calorific value and assuming that the efficiency of biomass boilers is 80%. The value of the technical energy potential was calculated considering the technology of simultaneous production of electricity and heat in CHP systems – first the available biomass resources that can be subjected to methane fermentation were determined, then the amount of biogas possible to obtain in this way was calculated, taking into account its calorific value, as well as the conversion efficiency to a given type of energy (35% for electricity, 50% for heat).

Step 4 – drawing up the energy balance. As a result, obtained is the answer, what are the possibilities of covering the energy demand of a given commune with the maximum use of local energy sources. Moreover, if the potential of local energy sources was insufficient to cover the demand, then the amount of energy from conventional sources (i.e., fossil fuel energy) needed to complement the balance was determined.

In the analysis, energy sources that are installed mostly by individual users (heat pumps with ground heat exchanger, thermal solar collectors, etc.), were not included. Thus, our work should be treated as a sort of a worst-case analysis.

Results

Balances of heat and electricity in analysed communes

Both demands (i.e., for heat and electricity) in studied communes are given in Table 3, the potentials of individual energy sources that are available in each commune are presented in Tables 4 (electricity) and 5 (heat), while Figures 2 and 3 show juxtapositions of heat and electricity potentials with demands, i.e., energy balances of each commune with distinction between heat and electricity.

Table 3

Energy demand in the analysed communes

Commune	Żuromin	Myszyniec	Ostróda	Olecko	Kozłowo
Electricity demand [MWh/yr]	20,088	16,761	26,475	40,000	9,030
Heat demand [GJ/yr]	438,414	338,200	632,693	955,533	190,113

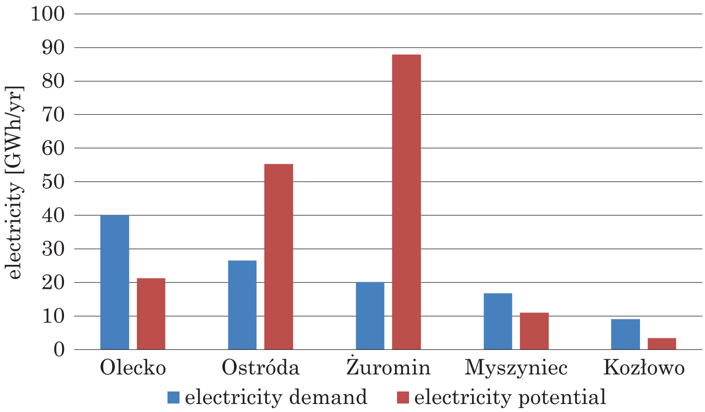

Fig. 2. Electricity balance in the analysed communities (communes are sorted by with respect to electricity demand)

Table 4

Potential of electricity sources available in the analysed communes; amount [MWh/yr]

Commune	Żuromin	Myszyniec	Ostróda	Olecko	Kozłowo
Wind energy	46,104	–	–	1,820	–
Solar energy	–	–	516	–	–
Water energy	510	–	–	27	–
Biogas from sewage treatment plants	137	34	128	–	36
Agricultural biogas	41,112	11,010	54,677	19,377	3,379
Total (share in demand)	87,863 (437%)	11,044 (66%)	55,321 (209%)	21,224 (53%)	3,415 (38%)

Table 5

Potential of heat sources available in the analysed communes; amount [GJ/yr]

Commune	Żuromin	Myszyniec	Ostróda	Olecko	Kozłowo
Wood biomass from forests	1,406	12,874	28,935	18,465	1,027
Wood biomass from orchards	8	19	53	54	24
Roadside biomass	381	1 069	481	519	410
Straw	54,182	55,175	16,096	167,496	143,314
Hay	11,015	39,262	16,046	114,397	3,706
Energy crops	1,030	2,753	1,183	2,880	30,497
Biogas from sewage treatment plants	279	69	260	–	73
Agricultural biogas	83,902	22,469	111,986	56,993	6,895
Total (share in demand)	152,203 (35%)	133,690 (40%)	175,040 (28%)	360,804 (38%)	185,946 (98%)

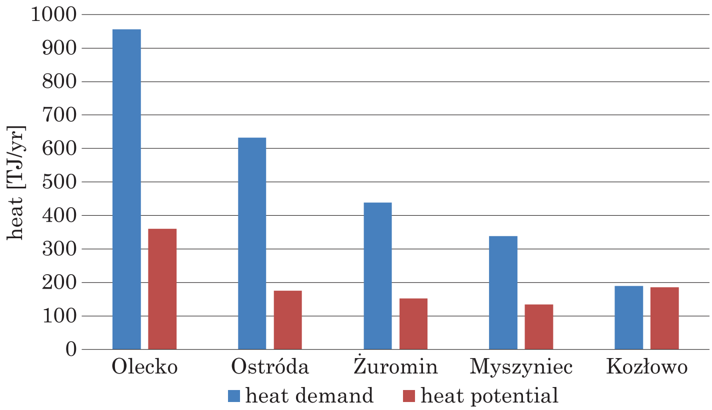

Fig. 3. Heat balance in the analysed communities
(communes are sorted by with respect to heat demand)

Discussion

The obtained results of the energy potential of local energy sources for the individual communes are relatively strongly diversified. These differences may put forward for consideration that local factors have fundamental influence on energy potential of individual communes. Generally, obtained results suggest that achieving self-sufficiency is easier in terms of electricity (in 2 out of 5 communes the potential is more than twice as high as the demand; in Żuromin commune the potential is four times greater than the demand) than in terms of heat (in 4 out of 5 communes the potential is more than twice lower than the demand, only in Kozłowo commune the potential is close to the demand, but still lower, i.e., equal to 98%). In the context of the one commune, where the demand for heat is close to the potential, it is worth noting that Kozłowo is at the same time the commune with the least possibility of self-covering the demand for electricity.

Below given is the rest of the discussion, split between electrical and heat self-sufficiency.

Electricity

The level of demand for electricity and demand for heat is similar in individual communes, starting from the commune of Olecko, in which the demand for both types of energy is the highest. This is clearly seen in Figures 2 and 3. In addition, Figure 2 shows that two communes (Ostróda and Żuromin) can achieve energy self-sufficiency in terms of electricity. In the commune of Ostróda, the source with the greatest potential for electricity is agricultural biogas, which would be used to drive gas engines of cogeneration aggregates. In the Żuromin commune, biogas of agricultural origin is one of the available sources with significant electricity potential, as in the commune of Ostróda. The wind farm, which already exists in this area, is another more resource-rich source of electricity in this commune. The annual production of electricity by wind farms from the commune is 46,104 MWh/yr and it is over 2 times higher than the demand for this type of energy in the commune. Other municipalities, i.e., Olecko, Myszyniec and Kozłowo, will not be able to achieve energy self-sufficiency for now. In each of these communes, the greatest energy potential lies in agricultural biogas, but it is not high enough to fully cover the demand for this type of energy. Perhaps locating wind farms in these communes would improve the balance of electricity, but there is a lack of data on the area available for the construction of such wind farms.

Heat

On the other hand, analysing the potential of heat sources in relation to the demand for heat in the examined communes (Fig. 3), none of the communes achieves energy self-sufficiency in this respect. However, it cannot be clearly stated that achieving energy self-sufficiency in heat is not possible at all. An example of this is the Kozłowo commune. In this commune, the heat potential from local energy sources accounts for 98% of the heat demand. This potential may, in fact, be higher, because it should be mentioned that when determining the energy potential, the most pessimistic scenario was adopted, i.e., it was examined what the minimum amount of energy can be obtained in a given area. In the case of the Kozłowo commune, cereal straw is the biggest source of heat. Straw is also the most energetic source of heat in the communes of Olecko and Myszyniec. In these communes, hay also has considerable energy potential. In other communes, the most important source of heat is agricultural biogas for use as fuel in the cogeneration process. One can also pay attention to the significant heat potential contained in biomass of energy plants in the Kozłowo commune and the forest biomass heat potential in the communes of Ostróda, Olecko and Myszyniec. Other identified sources of energy in the examined communes are marginal and do not have a significant impact on the total value of energy potential.

Conclusions

Given below are the most important conclusions that can be drawn based on the whole analysis:

1. Achieving energy self-sufficiency is easier in terms of electricity than in terms of heat.
2. Local factors play crucial role when considering reasons of differences in the energy potential of individual communes.
3. Energy balance, both in terms of electricity and heat, can be additionally improved thanks to individual efforts and investments of the communes' inhabitants.
4. However, it is worth emphasizing that since unconventional energy sources are inherently limited, e.g., due to seasonality or dependence on the weather, even in communes where the obtained results indicate the possibility of achieving energy self-sufficiency, total cutting off from fossil fuels would be a major risk.

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