Proceedings World Geothermal Congress 2020
Reykjavik, Iceland, 24-30 April 2020
Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Geothermal Water and Energy Uses in Agriculture – Prospects in Poland

Robert Skrzypczak, Wiesław Bujakowski, Beata Kępińska and Leszek Pająk

Mineral and Energy Economy Research Institute, Polish Academy of Sciences
Wybickiego 7A Str., 31-261 Krakow, Poland
robskrzy@min-pan.krakow.pl, bkepinska@interia.pl (corresponding authors)

Keywords: geothermal energy, agriculture, development prospects, Poland

ABSTRACT

The agriculture presents one of the most prospective areas for direct geothermal applications. In many countries such uses have already been ongoing. Many new investments have also been observed. In case of agricultural market, the most dynamically growing is the segment of organic food – this fact creates an important argument that ecological geothermal water and energy shall be wider included in the chain of its production and processing. Also Poland has appropriate natural conditions and geothermal potential for agricultural development, as well as for applications related to agriculture.

First research and development works on geothermal water and energy applications in agriculture in Poland were carried out in early 1990s. In recent years this subject has been again raising a growing interest, also as an opportunity for sustainable development of agriculture and related activities in nature protected areas and their neighbourhoods. The paper presents current state of geothermal applications in Poland, and also suitable geothermal potential, circumstances, rationale, selected relevant estimations and proposed zones in the country for the deployment of geothermal water and energy uses in the agricultural sector of the country.

1. INTRODUCTION

The agriculture is one of the most prospective areas of economy for applications of geothermal waters and their energy. In many countries their resources are already used on a noticeable scale and new investments in this range are ongoing. The eco (organic) food market is the most dynamically developing agricultural market segment with high demand on it. These are some of the important arguments for ecological geothermal energy to have a contribution in its production and processing chain. Poland also has conditions and resource potential of geothermal waters and energy proper for their agricultural management in wide range of temperatures, in different ways and types of crops and also in similar to agriculture types of applications (biotechnology, aquacultures, etc.).

Current usage of geothermal energy in Poland takes place on little scale and includes six district heating plants (geoDH), usage of geothermal waters for spa purposes, over a dozen of recreational centres and other single applications. There is no practical application in agriculture on a significant scale yet, although the first research, development and implementation works in this range were performed many years ago (since the beginning of the 1990s) by the teams from Mineral and Energy Economy Research Institute PAS (e.g. Bujakowski et al., 2001) and Environmental Engineering Institute PAS (e.g. Rosik-Dulewska and Grabda, 2000). This subject again raises growing interest. The geothermal uses in agriculture might also take place as part of the cascade systems which would influence both the good quality food production and the improvement of energetic and economic efficiency of geothermal projects. It would also be an impulse for growth of local modern agriculture, agribusiness, advanced innovative biotechnologies and entrepreneurship accompanying them. It is also an interesting opportunity for protected natural areas and their direct neighbourhood.

2. CURRENT GEOTHERMAL ENERGY APPLICATIONS

Geothermal water resources in Poland are of low-temperature type. They are hosted mainly by Mesozoic sedimentary formations in the Polish Lowlands, and in the Inner Carpathians. Some prospects are connected with selected areas and locations in the Outer Carpathians, the Carpathian Foredeep and the Sudetes region. Their practical applications include heating, bathing, recreation and some minor uses. In particular – at the end of 2018 six geothermal district heating plants were operating in the country, twelve health resorts applying geothermal water for curative treatments and fourteen large recreation centres. Other single uses embraced large atlantic salmon farming (since 2015). Among remaining minor applications were a semi-technical wood drying, heating up a football pitch and walking paths (Kępińska, 2019).

In case of agriculture the first experimental system of geothermal water and energy uses in Poland was launched in the Podhale region by MEERI PAS in 1992/1993. It included a cascaded system: breeding thermophilic fish; greenhouse heating; heating the substrate in crops under foil cover; wood drying. Also in case of aquaculture: referring to the-above-mentioned salmon farm, it was opened in Janowo close to the Baltic coast in 2015. It applies geothermal water both for culturing and for heating the farm's facility. In 2018 an experimental algae production using geothermal water started in the premises of geothermal district heating plant in Poddębice town, Polish Lowlands (first application of geothermal water and heat in biotechnology).

It results from this short review that the use of geothermal energy in agriculture and related sectors has so far taken place on a very small scale in Poland. It is to be hoped that this situation will change due to both prospective geothermal resources, market demand and other circumstances.

3. GEOTHERMAL WATERS AND ENERGY – CONDITIONS AND PROSPECTS FOR THEIR AGRICULTURAL APPLICATIONS

The fragments of geothermal reservoirs hosted by Lower Cretaceous and Lower Jurassic rock formations on the Polish Lowlands, and some regions of the Carpathian Foredeep and the Carpathians are thought to be the most prospective for the needs of agriculture in Poland (Fig. 1). Those fragments are outlined by the isotherm 30°C and (on the Polish Lowlands) also by the isotherm 60°C. An exemplary cross-section through central part of the Polish Lowlands and location of Lower Cretaceous and Lower Jurassic geothermal reservoirs (including parts prospective for agriculture) is shown on Fig. 2.

In case of part of reservoirs in the Polish Lowlands outlined by the isotherm 30°C, the mineralization of geothermal water hosted by Lower Jurassic formations is in the range of 10–210 g/dm^3 (predominantly 50–100 g/dm^3). Geothermal water flow rates are (or were estimated for) 10–380 m^3/h (predominantly 150–250 m^3/h. Taking into account mineralization of geothermal water hosted by Lower Cretaceous formations is in the range of below 1 to 110 g/dm^3 (predominantly 1–50 g/dm^3. Geothermal water flow rates are (or were estimated for) 20–310 m^3/h (predominantly 40–150 m^3/h). These values were given acc. to Górecki [sc. ed.], Hajto et. al. (2006).

When it comes to the Polish Lowlands it is worth pointing out that the Cretaceous reservoirs locally contain geothermal waters of drinking quality. In reference to the fragments of reservoirs outlined by the isotherm 60°C it may positively affect development of various methods of using those resources on farms. This also applies to the locations where the geothermal waters are used for heating purposes already. In case of higher mineralization of geothermal waters some methods of their agricultural uses would require prior demineralization (e.g. via reverse osmosis method proposed for geothermal waters by Tomaszewska and Szczepański, 2014).

Relatively less beneficial geothermal conditions are in the south of Poland due to rather small potential water flow rates from the wells (except of the Podhale region – aquifers in the Middle Triassic host rocks). Within the Carpathian Foredeep (also beneath the Carpathian Overthrust) the possibility of using it for the benefit of agriculture concerns small parts of Jurassic and Triassic reservoirs. Similarly in the Carpathians: on the west – in small reservoirs hosted by Flysch, Cenomanian and Middle Jurassic formations; on the east – mostly in Miocene reservoir, vast as for the Carpathian conditions (Statutory work, 2016).

Especially in mentioned areas, and moreover also in the areas where there are geothermal waters at temperatures lower than 30°C, their various methods of their agricultural APPLIdevelopment are possible (Table 1).

Considerations about potential management of geothermal resources for agricultural needs should include, among others, soil types in areas where the geothermal reservoirs are located. For this purpose one shall use the Polish soil maps (e.g. http://2.bp.blogspot.com). Farms structure should be planned in reference to these information with taking into account the soil needs of plants which would be grown there. In relation to planned crops, changes in soil humidity in long-term periods, including specific changes during the year, should be included – the service http://www.agrometeo.pogodynka.pl maps analysis will be useful in this area. The values of soil moisture indicators relevant for the growth of plants root systems are presented on them. These maps illustrate at the same time spatial tendencies which are periodically repeatable. They partially result from soil construction. They are also dependent on precipitation duration and intensity. Deficit areas for water retention occur periodically on Polish Lowlands. These information should also be followed up by the analysis of meteorological observations concerning periods of drought (portal maps www.iung.pulawy.pl posted since 2009) especially in reference to the legumes crops, fruit bushes and potatoes. With reference to the observations above systems of periodical supplemental soil irrigation with geothermal waters of appropriate parameters for the cultivated crops can be analysed.

Different methods of geothermal waters uses in agriculture should also include the locations of main underground waters reservoirs (GZWP) – strategical freshwaters reservoirs in Poland (Map PIG-PIB GZWP, 2016). Considering this it would be the best for agricultural purposes to use the geothermal water resources outside those strategic freshwater reservoirs and their protection zones. Potential applications of geothermal waters in agriculture do not necessarily have to be in a conflict (like GZWP) with the objects of legal protection system of natural goods (www.gis-suppot.pl), NATURA 2000 system (http://misjanatura.fwie.pl), ECONET-PL system and with ecological corridors connecting them (https://ekorytarz.pl). Performed analysis (Statutory work, 2016) points out that the use of geothermal resources could concern laggings (buffer zones) of a few landscape parks situated on Polish Lowlands and in Eastern Carpathians, and a few national parks.

The management of geothermal resources in agriculture should be located outside the natural bird habitats and sanctuaries provided by the NATURA 2000 system, and also outside forest areas and ecological corridors (https://www.lasy.gov.pl).

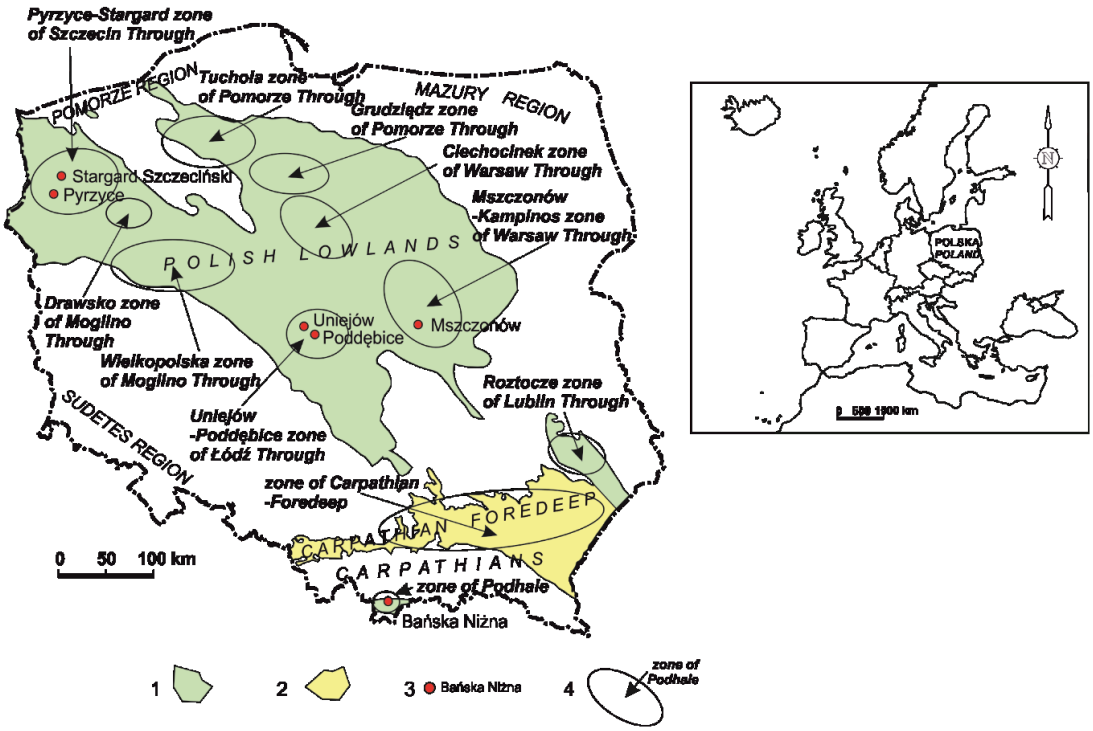

Figure 1: Map of geothermal reservoirs attractive for agricultural applications in Poland and proposed particularly favourable zones

(Statutory work, 2016. Ranges of geothermal reservoirs with temperatures > 30°C acc. to maps in Górecki [sc.ed.] et al. (2006, 2011, 2012, 2013))

1 – geothermal reservoirs (>30°C, efficient for agriculture), 2 – geothermal reservoirs (>30°C, less efficient), 3 – geothermal heating plants (locality name), 4 – preferred zones for geothermal uses in agriculture (zone name)

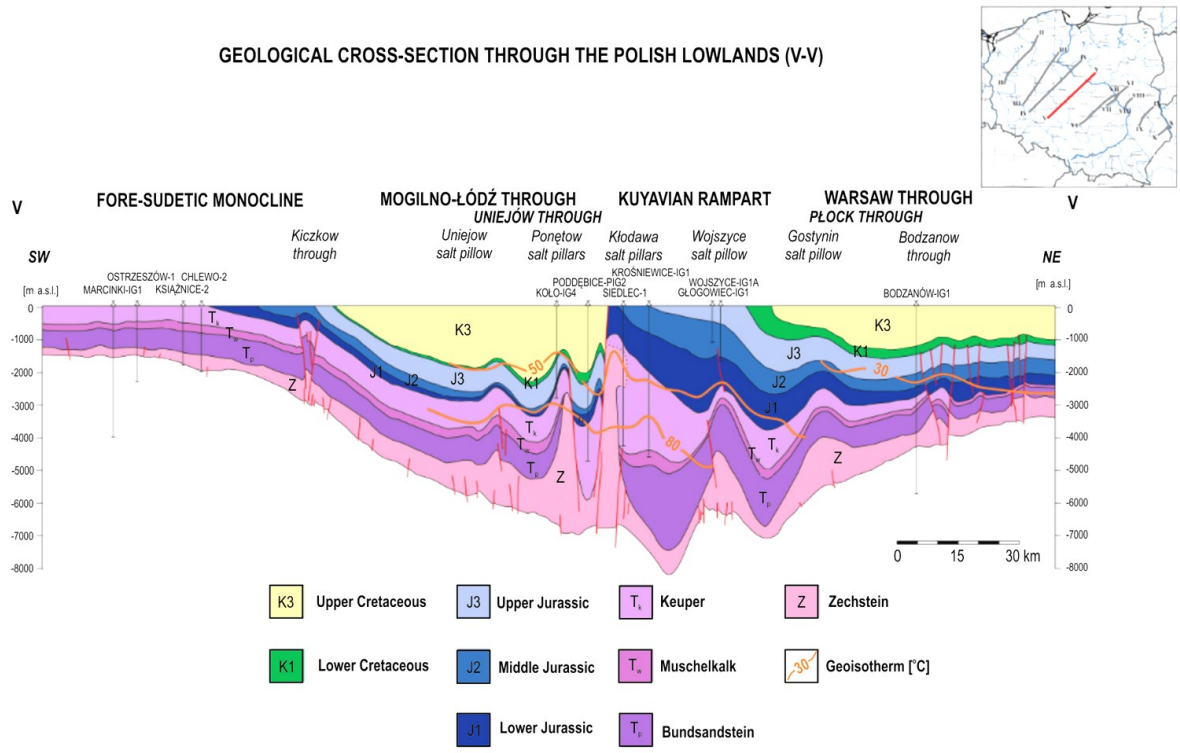

Figure 2: Exemplary cross-section through central part of Polish Lowlands showing the location of Lower Cretaceous and Lower Jurassic that host geothermal waters prospective for their applications in agriculture

(source: Górecki [sc. ed], Hajto et al., 2006)

Table 1: Prospective geothermal water and energy applications in agricultural sector in Poland
(temperature intervals acc. to IGA Information Brochure, 2001)[1]

Medium	Temperatures [ºC]	Method of agricultural use (water mineralization)
Geothermal water	15 – 40	irrigation of crops (freshwaters)
		aquacultures (freshwaters and low mineralization waters)
Geothermal energy	15 – 40	heating of protected crops
	25 – 60	heating of livestock buildings
	30 – >60 especially >60	greenhouse heating food processing drying and processing of grains and forages

[1] In case of Poland acc. to formal regulations " thermal water is an underground water which on the outflow from the intake has the temperature not less than 20ºC" (Art. 5.1.2.2, the Act of 9 June 2011. Geological and mining law; (Dz. U. 2017 item 2126; unified text). The synonymous of the formal name "thermal water" is the name "geothermal water".

4. RATIONALE FOR AGRICULTURAL USE OF GEOTHERMAL WATERS' POTENTIAL

One of the essential premises for using the geothermal potential in agriculture in Poland is the structure and arrangement of gardening centres. According to percentage of area in 2002 this structure included respectively (Kulikowski, 2007): orchards – 53.2%, field vegetables – 33.7%, fruit bushes – 10.4%, protected crops – 1.2%, nurseries of fruit trees and shrubs – 0.9%, flowers and ornamental plants – 0.6%, other types of crops – 1.0%. From the viewpoint of potential geothermal usage in agricultural production and processing, the orchards and field vegetables crops, especially protected crops, are crucial. Their spatial arrangement is worth comparing with the arrangement of prospective geothermal water reservoirs. In reference to orchards and field vegetables crops the spatial arrangement is defined by areas of municipalities. They are described by the indicator expressing percentage share of a given crop in total agricultural area of municipality. In case of protected crops the indicator is a size of area in relative to 100 ha agricultural land in the municipality (Kulikowski, 2007).

Spatial distribution structure of apple orchards (to a much lesser extent of cherry-tree, plum-tree and other fruit trees). In the geothermal reservoirs areas prospective for agriculture, municipalities with a share of orchards higher than 1% are dominating in approx. 75%. In some parts of these reservoirs this share exceeded even 10%.

Spatial distribution structure of field vegetables crops with onion, cabbage and carrot (to a much lesser extent with cucumbers, beetroots, tomatoes, cauliflowers and other field vegetables). In the geothermal reservoirs areas prospective for agriculture, municipalities with a share of these crops higher than 1% are dominating in approx. 50%. In centres created by municipalities groups this share exceeds even 6%.

Spatial distribution structure of protected crops (greenhouses, foil tunnels). Within the prospective geothermal reservoirs, municipalities in which share of these crops were higher than 250 m^2/100 ha agricultural land are dominating in approx. 25-30%. Major centres in Polish Lowlands are standing out, where this share exceeded even 3000 m^2/100 ha of agricultural land.

The other premise for possible use of geothermal waters potential and their energy in Poland is a special organizational form of agricultural production known as *organic farms*. According to Eurostat data (2013) in 2012 leading European countries in terms of quantity of organic farms were subsequently: Italy (48 852), Spain (30 462), France (24 425), Greece (23 433), Germany (23 032) and Austria (21 843). Total sale value of organic farming products in Europe reached a level of approx. 23.4 billion Euro at the time. Yearly increase of this sale was then on the level of 6%. The biggest markets in this regard were Germany (7.6 billion Euro), France (4.4 billion Euro) and Great Britain (1.1 billion Euro). In Poland however (according to Main Inspectorate of Trade Quality of Agricultural and Food Products) in 2011 there were 23 847 registered organic producers including 23 449 organic farms and 270 processing plants. The area of crops used in accordance with regulations on organic farming totalled 605 519 ha. Thus Poland occupied a prominent place in Europe in terms of the quantity of organic farms, presumably the third.

Among organic farms the separate category in Poland is represented by *demonstrational organic farms* (https://www.cdr.gov.pl/aktualnosci). In some of them usage of geothermal waters could be possible. It concerns 12 from 16 voivodeships (administrative regions) in the country. Sometimes there is a possibility of cooperation between functioning geothermal district heating plants or other installations.

In addition to open agricultural crops, significant prospects of geothermal uses in agriculture are connected with greenhousing and cultivations under plastic covers.

5. EXAMPLE – BASIC PREDICTED ENERGETIC AND ECONOMIC PARAMETERS OF GEOTHERMALLY-HEATED GREENHOUSES

As mentioned above, among various possible uses of geothermal water and energy in agriculture, one of the most popular would be their using in greenhouses. Table 2 shows sample results of basic energy and economic calculations for big greenhouse object and a group of seven small greenhouses, which would be powered by geothermal heat. It was assumed that these objects would be situated in Central Poland. The calculations assumed:

- own energy source (geothermal water of temperature 60°C) for the needs of greenhouses in terms of central heating and volumetric preparation of domestic hot water,
- location in so-called II climatic zone for project calculations according to *PN-EN 12831* standard (it includes the central part of Polish Lowlands geothermal reservoirs; project parameters: outside temperature - 18ºC, average yearly outside temperature 7.9ºC),
- object interior temperature approx. 26°C and air humidity 65%,
- external partitions of greenhouse object providing heat transfer factor on the level of 0,5 W/(m^{2}·K),
- the intensity of air exchange in the object approx. 0.3 volume/h.

In order to get energetic effect at the supply temperature lower than 60°C (indicated in Table 2) one could alternatively:

- increase heating elements surface, which at their lower temperature would bring similar heating effect,
- apply supporting air heating to increase the amount of heat transfer factor (by heated air) from heating elements surface,
- increase the flow of working medium (thus raising the temperature of its return), which would have increased the average heating elements surface temperature.

Table 2: Example – energetic and economic evaluations for large greenhouses and group of seven small greenhouses assumed to be powered by geothermal heat. Central part of the Polish Lowlands, Uniejów-Poddębice zone
(Statutory work, 2017)

Parameter	Unit	Recipient (type of object)	
		Large greenhouse	Small greenhouses (7 objects in total)
Cubature	[m^3]	225 000	98 000
Usable area	[m^2]	15 000	1 400
Height	[m]	15	7
Capacity of central heating	[kW]	2 400	361,2
Capacity of warm water preparation	[kW]	16	18,9
Energy demand (central heating, warm water)	[GJ/yr]	21 800	3 745
Design parameters of the heating installation	[°C]	70/50	70/50
Design parameters of installation for warm water preparation	[°C]	60/20	60/20
Investment expenditures	[PLN][1]	2 416 000	380 100
Fixed costs (assumed technical lifetime of the installation: 20 yrs)	[PLN/yr]	120 800	19 005
Variable costs	[PLN/yr]	1 454 420	249 155
Total costs	[PLN/yr]	1 575 220	268 160

[1] 1 PLN (Polish złoty) ~ 0.25 Euro (June 2019)

6. PREFERRED ZONES FOR THE USE OF GEOTHERMAL RESOURCES IN AGRICULTURE

Some zones particularly attractive for agricultural development including organic farming in Poland were proposed (Fig. 1; Statutory work, 2017). Conditions presented in above chapters and other premises were taken into account. The locations of existing geothermal heating plants and other objects using geothermal energy were also included. These zone are as follows:

Polish Lowlands:
- Szczecin Through – zone in reference to existing geothermal heating plants in Pyrzyce and Stargard towns,
- Mogilno Through – zones in reference to laggings of Drawieński and Wielkopolski National Parks,
- Pomorze Through – zones in reference to: lagging (buffer zone) of Bory Tucholskie National Park and geothermal balneotherapeutic centre in Marusza near Grudziądz,
- Warsaw Through – zones in reference to: reputable balneotherapeutic centre in Ciechocinek, Kampinoski National Park, orchard traditions in Skierniewice region and geothermal heating plant in Mszczonów,

- Łódź Through – zone in reference to geothermal heating plants in Uniejów and Poddębice,
- Lublin Through – zone in reference to lagging (buffer zone) of Roztoczański National Park.

Southern Poland:
- wide zone of the eastern part of Outer Carpathians and Carpathian Foredeep – zone in reference to Cenomanian and Miocene geothermal reservoirs,
- Podhale region – zone in reference to the existing geothermal heating plant and other natural resources of this region.

On a small scale various agricultural uses in agriculture are also possible outside the zones indicated on Fig.1. It applies to Outer Carpathians and some regions in Pomerania, Masuria (Mazury) and in Sudetes region.

SUMMARY

1. Agriculture, specially organic agriculture, presents a very prospective sector of numerous countries' economy. Its share in agriculture grows in general. Poland also has a chance to become a significant organic food producer both for domestic and export market. The presence of areas free of pollution (among others national and landscape parks laggings) speaks for it. The key element in eco food production chain should be the use of ecologically clean energy sources e. g. geothermal.

2. Geothermal waters resources in Poland are in most cases prospective for the agricultural needs including organic farming. The most useful would be waters with low mineralization and proper physicochemical composition, which could be used directly to heat the growing medium (including irrigation) or aquacultures (in this case it could be also poorly mineralized waters). These waters are present in Polish Lowlands in relatively efficient Lower Cretaceous reservoir (locally freshwater) and in Lower Jurassic reservoir. Whereas geothermal waters and heat might also be used for heating livestock buildings, greenhouses, in food processing, drying or processing of grain, forages etc.

3. Geothermal water and energy usage in agriculture in Poland would result in increased healthy food production and sustainable agriculture development, effective prevention of civilization diseases, improving the quality of health and life of the society, etc.

4. The selection of new object locations for the needs of various geothermal resources usage in agriculture should consider among others:
   - geothermal reservoir conditions,
   - the farms specifics dependent among others on types of soil, cultivated plants, variability of hydrological conditions,
   - rather not forest terrains,
   - the need of protection of main strategic underground freshwaters reservoirs (GZWP),
   - the need of preserving essential natural functions in systems of: legal protection, ECONET-PL, NATURA 2000 and in ecological corridors network.

   New organic farms – well designed and situated (e. g. in national and landscape parks laggings) and well prospering – could also support and promote the protective and didactic mission of particular natural areas (especially national parks).

5. Several regional zones for the development of organic farming in Poland, in which geothermal waters and energy can be used, were indicated. Within Polish Lowlands these are: Pyrzyce-Stargard zone of Szczecin Through, Drawska and Wielkopolska zones of Mogilno Through, Tuchola and Grudziądz zones of Pomorze Through, Ciechocinek and Mszczonów-Kampinos zones of Warsaw Through, Uniejów-Poddębice zone of Łódź Through and Roztocze zone of Lublin Through. Whereas in south of Poland these are: Carpathian-Foredeep zone and Podhale zone. On a small scale agricultural using of geothermal resources could also develop in the other parts of Outer Carpathians, in Sudetes region, in Pomerania and Mazury.

Acknowledgements. The paper presents selected results of statutory works done by POZE IGSMiE PAN in 2016 and 2017.

REFERENCES

Bujakowski, W., Barbacki, P., Długosz, P., Graczyk, S., Hołojuch,G., Kazanowska, A., Kępińska, B., Ney, R., Pająk, L., Tarkowski, R., and Uliasz-Misiak, B.: Wykorzystanie ciepła wód geotermalnych do intensywnej produkcji warzywniczej i chowu ryb (The application of geothermal water's heat for intensive vegetable production and fish farming). [in] Ney, R. [sc. ed.] et al.: Wybrane problemy wykorzystania geotermii II. (Selected problems on geothermal applications II). IGSMiE PAN Pbs. Kraków (in Polish, English abstract) (2001).

Górecki, W. [sc. ed.], Hajto, M., et al.: Atlas of geothermal energy resources in the Polish Lowlands. 1. Mesozoic formations. AGH Pbs. Kraków (2006).

Górecki, W. [sc. ed.], Hajto, M., et al.: Atlas of geothermal water and energy resources in the Western Carpathians. AGH-UST Pbs. Kraków (2011).

Górecki, W. [sc. ed.], Sowiżdżał, A., et al.: Geothermal Atlas of the Carpathian Foredeep. AGH-UST Pbs. Kraków (2012).

Kępińska, B.: Geothermal Energy Use – Country Update for Poland, 2017-2018. Proceedings, European Geothermal Congress 2019. Hague (the Netherlands). Paper CUR-21 (electronic version) (2019).

Kulikowski, R.: Gardening in Poland. Distribution, crop structure and role in agricultural production: Map of orchards. Agriculture generally, 2002; Map of field vegetables. Individual farming, 2002; Map of protected crops. Total agriculture, 2002. Geographical Review,79, 1 (in Polish) (2007).

Rosik-Dulewska Cz., and Grabda M.: 2000: Wody geotermalne jako czyste zrodlo energii dla potrzeb produkcji zywnosci (Geothermal waters as a clean source of energy needed for plant production). Chemia i Inzynieria ekologiczna 2000; 3 (in Polish, English abstract) (2000).

Tomaszewska, B., and Szczepański, A.: Possibilities for the efficient utilisation of spent geothermal waters. Environmental Science and Pollution Research (21), str. 11409-11417 (2014).

Statutory work: Research the energetic parameters of renewable energy sources on a basis of selected areas including rational energy management's aspects – Analysis of geothermal resources' parameters in selected Polish regions in terms of their use in organic farming and energy efficiency. Part 1. Collective work POZE IGSMiE PAN. Arch. IGSMiE PAN. Kraków (in Polish, English abstract) (2016).

Statutory work: Research the energetic parameters of renewable energy sources on a basis of selected areas including rational energy management's aspects – Analysis of geothermal resources' parameters in selected Polish regions in terms of their use in organic farming and energy efficiency. Part 2. POZE IGSMiE PAN. Arch. IGSMiE PAN. Kraków (in Polish, English abstract) (2017).

Act of June 9, 2011. Geological and Mining Law (Journal of Laws of 2017, item 2126, codified text).

Eurostat, 2013.

IGA Information Brochure (2001).

Main Inspectorate of Trade Quality of Agricultural and Food Products, 2011.

Map of the main underground water reservoirs – PIG-PIB Warszawa (2016).

PN–EN 12831. Heating installations in buildings. The method of calculating the design heat load (in Polish) (2016).

The World of Organic Agriculture – statistics & Emerging Trends 2015. FIBL and IFOAM (http://www.oodr.pl/informacja.php?id=2015-12-11-_9:01:41&kategoria=dane_liczbowe&dzial=rolnictwo_ekologiczne&on=tak) (2015).

http://agrometeo.pogodynka.pl

http://misjanatura.fwie.pl/n2000kompendium/images/natura%202000%20pl.jpg

http://susza.iung.pulawy.pl

http://2.bp.blogspot.com/-Ivi5nIJc5Fg/VQ3AZXdouSI/AAAAAAAA0k/oY5ioKupXI4/s1600/mapa.jpg (Map of Polish soils)

https://ekorytarz.pl/2014/07/24/spojnosc-europejskiej-sieci-obszarow-chronionych-natura-2000/

https://www.cdr.gov.pl/aktualnosci/57-cdr-informuje/569-demonstracyjne-gospodarstwa-ekologiczne

https://www.lasy.gov.pl/pl/informacje/publikacje (Report on the state of forests in Poland 2010).

http://www.oodr.pl/informacja.php?id=2015-12-11_-_9:01:41&kategoria=dane_liczbowe&dzial=rolnictwo_ekologiczne&on=tak)

www.gis-suppot.pl (map by Dorota Kwaśny 12.05.2012).

www.iung.pulawy.pl