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Geothermal water as a raw material for the agricultural sector in Poland

Introduction

Agriculture is one of the most prospective areas for applications of geothermal waters. In many countries their resources are already used on a noticeable scale and new investments in this range are ongoing. These are some of the important arguments for geothermal water to have a contribution in agricultural production and processing chain. Poland also has conditions and promising resource potential of geothermal waters proper for their agricultural management in different ways and types of crops and also in types of applications similar to agriculture.

The thus far usage of geothermal waters in Poland takes place on a moderate scale and predominantly includes their energetic applications for six district heating plants. Geothermal waters have been also applied for spa purposes in twelve health resorts, in fourteen recreational centers and other single applications (e.g. one case of semi-technical wood drying).

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However, there is no practical use 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) in the Podhale Region by the Mineral and Energy Economy Research Institute PAS (e.g. Bujakowski et al. 2001) and Environment Engineering Institute PAS (e.g. Rosik-Dulewska and Grabda 2000). This subject is again sparking interest. The geothermal waters' uses in agriculture might also take place as part of the multipurposed (cascaded) systems which would influence both the good quality food production and the improvement of the efficiency of geothermal projects. Such applications in agriculture – if taking place after the earlier use of geothermal waters for energetic or other purposes – would exemplify in practice the idea of the closed cycle economy.

This could also be some impulse for the growth of local modern agriculture, agribusiness, advanced innovative biotechnologies and entrepreneurship accompanying them. This is also an interesting opportunity for agricultural development in protected natural areas and their direct neighborhoods.

1. Geothermal water applications in agriculture in the world and in Poland – a review

In agriculture and related activities, geothermal water is used as a raw material for various purposes, namely (in brackets: relevant temperature intervals according to the IGA Information Brochure 2001): food processing (100–140°C), drying, processing of cereals and feed (50–120°C), drying of vegetables and fruits (40–90°C), greenhouses (30–80°C), heating of livestock buildings (25–60°C), heating of the growing ground under covers (15–40°C), irrigation of crops (15–40°C), aquacultures (15–40°C).

Globally, according to the state of 2014 (the year from which the latest comprehensive data from about 80 countries stems; Lund and Boyd (Lund and Boyd 2016), among the several main groups of different types of direct geothermal waters' applications, the leading ones were their uses for heating purposes, mainly in district heating (33.6%), followed by bathing and swimming (15.7%). The agricultural sector (greenhouses) was in third place (10.2%). Fourth place went to the needs of fish farms and others aquacultures (4.6%). Among the fields related to agriculture, the needs of drying (including drying agricultural products) accounted for 4%. In total, the use of geothermal waters for the needs of agriculture and related fields amounted to nearly 19% in the world (from the total amount of 262,758 TJ heat of geothermal waters used for various applications in 2014). These statistics do not include the amount (volume) of these waters that were implemented in specific agricultural applications. Other direct applications of geothermal waters in the world were at the level of up to 1%. In the given year:

- the use of geothermal water to heat greenhouses and cultivations under cover (and irrigation in some cases) took place in 31 countries. The leaders were: Turkey, Russia, Hungary, China and the Netherlands. The main crops were vegetables and flowers

(including roses in cases of Kenya and Tunisia, exported, among others, to European markets);

- aquaculture using geothermal water was carried out in 21 countries. The leaders were: the US, China, Iceland, Italy, Israel. One should also mention that, large fish farms based on geothermal water have been operating in Vrbov (for over 40 years) and in the region of Banska Bystrica in Poland's neighbor – Slovakia. Thermophilic fish species (e.g. African catfish, tilapia) are bred, but also salmon, trout, oysters, shrimp, mussels, and even alligators in the US and Japan;
- drying of cereals, vegetables and fruits with heat extracted from geothermal waters took place in 15 countries. The leaders were: China, the US and Hungary. Dried products were, among others, seaweed (Iceland), onion (USA, Brazil), wheat and other cereals (Serbia), tomatoes (Greece, Italy), fruits (El Salvador, Guatemala, Mexico), alfalfa (New Zealand), coconuts (Philippines), wood (New Zealand, Mexico, Romania).

In the case of Europe, in 2014 geothermal waters, as a raw material or as a heat source, were used in agriculture (on a different scale) in 37 countries. When they were used as a heat carrier, the leading ones were: Iceland, Hungary and the Netherlands, followed by Austria, Greece, France, Slovakia, Italy, Germany, North Macedonia, Serbia and Switzerland (Lund and Boyd 2016). It can be assumed that the information from 2014 is largely up-to-date, and even some ways of using geothermal waters in agriculture are further progressing in some countries. It is worth paying attention to the dynamic development in recent years in the Netherlands – where geothermal waters started to be applied for about 20 large complexes of greenhouses and crops under cover (as raw material, heat). Further projects in this area are being implemented.

In Poland practical applications of geothermal water embrace heating, bathing, recreation and some minor uses including those related to agriculture. In particular six district heating plants have been operating in the country, twelve health resorts applying geothermal water for curative treatments and fourteen large recreation centers. Other single uses include a large Atlantic salmon farm (since 2015). The remaining minor applications include semi-technical wood drying, heating up a football pitch and walking paths (Kępińska 2019).

In the case of agriculture the first experimental system of geothermal water and energy uses in Poland was launched in the Podhale region in 1992/1993, as mentioned before (Bujakowski et al. 2001; Rosik-Dulewska and Grabda 2000). It included a cascaded system: breeding thermophilic fish; greenhouse heating; heating the substrate in crops under foil cover; wood drying. Also in the case of aquaculture: the-above-mentioned salmon farm 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, experimental algae cultivation using geothermal water started in the premises of the geothermal district heating plant in Poddębice, in the Polish Lowlands (the first application of geothermal water and heat in biotechnology). In recent years vegetable processing started (at present on a small scale) – i.e. pickling vegetables (in Pyrzyce and Uniejów) using geothermal water.

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

2. Methodology for the purposes of this study

The analysis of the global geothermal water resources usage for agricultural sector and their parameters leads to the assumption that there also are geothermal water reservoirs useful for the given purposes in Poland. Their fragments are primarily defined by an isotherm of at least 30°C in the tops of those reservoirs. Such fragments were indicated by the authors on the working map of Poland, using information from several geothermal atlases (Górecki [sc. ed.] et al. 2006, 2011, 2012, 2013). Then, the ranges of those fragments (contoured with the given isotherm) were transferred to selected thematic working maps, important in the authors' opinion, when initially considering the future potential locations of geothermal installations which would be used also or exclusively in the agricultural industry. The thematic maps selection was made based on the analysis and systematization of publicly available cartographic materials (maps) created for various separate detailed purposes.

Thematic working maps – the source of basic data – were arranged by the authors to present the following facts that occur in Poland:

- soil conditions (soil types, exemplary soil saturation with water, exemplary threats of hydrological droughts),
- potential collisions among the proposed geothermal installations for agriculture and other important functions of the natural environment (like the areas of strategic drinking ground water reservoirs and their protection zones, areas of natural value, including forests, and their protective systems),
- selected elements of current agricultural management (distribution of orchards, vegetable field crops, vegetable crops under cover, locations of the so-called demonstration farms).

Attention was drawn to the fact that within the parts of geothermal water reservoirs favored for agriculture, greenhouse systems (sometimes relatively large) had already been operating but with no use of geothermal waters' potential. The analysis of the collected data also showed that the areas especially suitable for the agricultural purposes could be, in particular, protection zones around large protection systems of natural resources, or selected enclaves within such resources, or the vicinity of already operating geothermal installations with currently different specific objectives. A preliminary synthetic image of such zones on a Polish scale was developed by the authors and presented in this paper.

3. Conditions and prospects of geothermal water applications for agriculture in Poland

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 (selected areas of Outer and Inner Carpathians) are thought to be the most prospective for the needs of agriculture in Poland. These fragments are outlined by the isotherm 30°C on Figure 1.

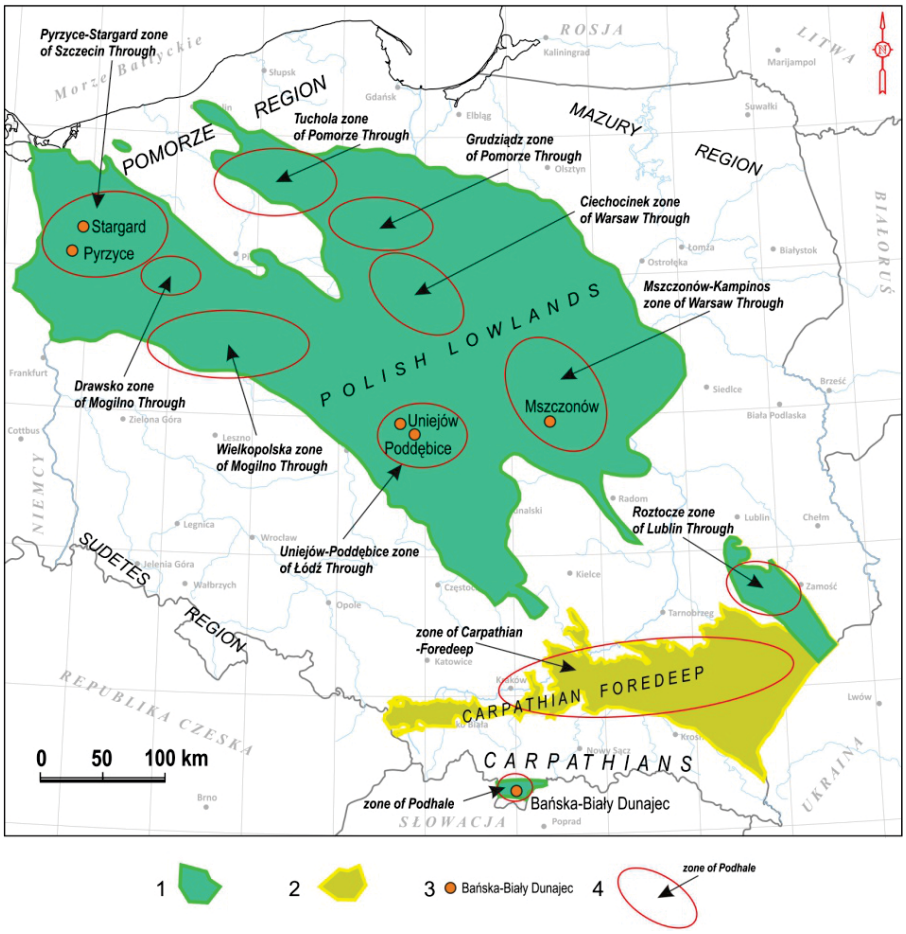

Fig. 1. Map of geothermal water reservoirs prospective for agricultural applications in Poland and proposed particularly favorable zones (Statutory work 2016. Ranges of geothermal reservoirs with temperatures > 30°C acc. to maps in Górecki [sc. ed.] et al. 2006, 2011, 2012, 2013)
1 – geothermal reservoirs (>30°C, efficient for agriculture), 2 – geothermal reservoirs (>30°C, less efficient), 3 – geothermal heating plants (locality name),
4 – preferred zones for geothermal water uses in agriculture (zone name)

Rys. 1. Mapa zbiorników wód geotermalnych w Polsce perspektywicznych dla zastosowań w rolnictwie i preferowane szczególnie odpowiednie strefy

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

In the case of 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 this may positively affect the development of various methods of using those resources for agricultural needs. This also applies to the localities where the geothermal waters are already used for heating purposes. In the case of the higher mineralization of geothermal waters some methods of their agricultural uses would require prior demineralization (e.g. via the 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 low potential water flow rates from the wells (except of the Podhale region). Within the Carpathian Foredeep (also beneath the Carpathian Overthrust) the possibility of geothermal waters' uses in agriculture concerns small parts of the 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).

Their various agricultural applications are possible especially in mentioned areas and moreover also in areas where there are geothermal waters at temperatures below 30°C (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. The Polish soil maps (e.g. http://2.bp.blogspot.com) will be used for this purpose. Farms' structure should be planned in reference to this information while taking the soil needs of plants which would be grown there into account. In relation to the 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. At the same time these maps illustrate spatial tendencies which are periodically repeatable. They partially result from the soil structure. They are also dependent on precipitation duration and its intensity. Deficit areas for water retention occur periodically on the Polish Lowlands. This 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

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

Tabela 1. Perspektywiczne zastosowania wody geotermalnej w sektorze rolniczym w Polsce (przedziały temperatur wg IGA Information Brochure 2001)[1]

Medium	Method of agricultural use (water mineralization), temperature interval
Geothermal water	Irrigation of crops (field crops, greenhouses, foil tunnels) (freshwaters), 15–40°C
	Aquacultures (freshwaters and low mineralized waters), 15–40°C
Geothermal water's heat	Heating of protected crops (foil tunnels), 15–40°C
	Heating of livestock buildings, 25–60°C
	Greenhouse heating food processing drying and processing of grains and forages, 30≥60°C, especially >60°C

[1] In the case of Poland according to legal regulations "thermal water is an underground water which on the outflow from the intake has the temperature not less than 20°C" (Art. 5.1.2.2, the Act of 9 June 2011. Geological and Mining Law (Act of June 9, 2011. Geological and Mining Law (Journal of Laws of 2017, item 2126, codified text)). The synonymous of the formal name "thermal water" is the name "geothermal water".

supplemental soil irrigation with geothermal waters of appropriate parameters for the cultivated crops can be considered.

Different methods of geothermal waters uses in agriculture should also take the locations of Main Ground Water Reservoirs (MGWR) – strategical freshwaters reservoirs in Poland (Map of MGWR 2016; Mikołajków and Sadurski 2017) into account. 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 MGWR) with the objects of the legal protection system of natural goods (www.gis-suppot.pl), the NATURA 2000 system (http://misjanatura.fwie.pl), ECONET-PL system and with ecological corridors connecting them (https://ekorytarz.pl). The 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 applications of geothermal waters 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).

4. Premises for geothermal water applications in agriculture

The structure and arrangement of gardening centers are among the main premises for using the geothermal water in agriculture in Poland. 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 the case of protected crops the indicator is a size of the area relative to 100 ha of agricultural land in the municipality (Kulikowski 2007).

The 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%.

The spatial distribution structure of field vegetables crops with onions, cabbage and carrots (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%.

The spatial distribution structure of protected crops (greenhouses, foil tunnels). Within the prospective geothermal reservoirs, municipalities in which share of these crops was higher than 250 m^2/100 ha agricultural land dominate in approx. 25–30%. Major centers in the Polish Lowlands stand out, where this share exceeded even 3000 m^2/100 ha of agricultural land.

The other premise for the 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 (Eurostat 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),
- Austria (21 843).

The total sale value of organic farming products in Europe reached a level of approx. EUR 23.4 billion at the time. The annual increase of this sale was then at the level of 6%. The biggest markets in this regard were Germany (EUR 7.6 billion), France (EUR 4.4 billion) and Great Britain (EUR 1.1 billion). In Poland however (according to the Main Inspectorate of the Trade Quality of Agricultural and Food Products – https://www.cdr.gov.pl/aktualnosci) 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 totaled 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 demonstration organic farms (https://www.cdr.gov.pl/aktualnosci). Many of such farms have been operating in e.g. the Polish Lowlands, including some which are situated within the areas that have prospective geothermal water resources. In some of them the usage of geothermal waters could be possible. This concerns twelve out of sixteen voivodships (administrative regions) in the country. Sometimes there is a possibility of cooperation among operating geothermal heating plants or other installations.

5. Results – prospective zones for geothermal water applications in agriculture in Poland

Some zones particularly attractive for geothermal waters' uses in agriculture including organic farming in Poland were proposed (Figure 1; Statutory work 2017) taking the conditions presented in the above chapters and other premises into account. These zones are as follows:

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

- Southern Poland:
  - wide zone of the eastern part of the Outer Carpathians and Carpathian Foredeep – in reference to Cenomanian and Miocene geothermal water reservoirs (in the case of Outer Carpathians the Cenomanian and Miocene reservoirs are located within their basement),
  - Podhale region – zone in reference to the existing geothermal heating plant and natural resources of this region.

On a moderate scale various agricultural uses are also possible outside the zones indicated on Figure 1. This applies to the Outer Carpathians and some regions in Pomorze, Mazury and in the Sudetes region.

Summary and conclusions

1. Agriculture, especially organic agriculture, presents an important and prospective sector of numerous countries' economy. Poland also has a chance to become a significant organic food producer both for the domestic and export market. The presence of areas free of pollution (among others national and landscape parks laggings) attest to this. The key element in the organic food production chain should be the use of ecologically clean water and energy resources, e.g. geothermal waters as raw materials and heat sources.
2. Geothermal water resources in Poland are in some cases prospective for the agricultural needs including organic farming. The most useful would be waters with low mineralization and a proper physical and chemical composition, which could be used directly to irrigate the growing medium (in field crops, greenhouses, foil tunnels), for aquacultures (in this case it could be also poorly mineralized waters) or for heating needs. These waters are present in the Polish Lowlands in the relatively efficient Lower Cretaceous reservoir (locally freshwater) and in the 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 usage in agriculture in Poland would result in increased healthy food production and sustainable agriculture development, effective prevention of civilization diseases, improved quality of health and life of the society.
4. The selection of new object locations for the needs of various uses of geothermal waters' resources in agriculture should consider among others:
   - geothermal water parameters,
   - the farms specifics dependent among others on types of soil, cultivated plants, variability of hydrological conditions,
   - rather not forest terrains,
   - the need to protect the strategic main ground water reservoirs (MGWR),
   - the need to preserve essential natural functions in systems of: legal protection, ECONET-PL, NATURA 2000 and in the ecological corridors network.

New organic agricultural 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 (as raw material or by extraction of their heat) can be used, were indicated. Within Polish Lowlands these are: the Pyrzyce–Stargard zone of the Szczecin Through, the Drawska and Wielkopolska zones of the Mogilno Through, the Tuchola and Grudziądz zones of the Pomorze Through, the Ciechocinek and Mszczonów-Kampinos zones of the Warsaw Through, Uniejów–Poddębice zone of the Łódź Through and Roztocze zone of Lublin Through. Whereas in the south of Poland these are: the Carpathian–Foredeep zone and the Podhale zone. On a small scale, the agricultural use of geothermal waters could also develop in the other parts of the Outer Carpathians, in the Sudetes region, in Pomorze, and Mazury regions.

The paper presents selected results of statutory works done by the Renewable Energy Sources' Department MEERI PAS in 2016 and 2017.

REFERENCES

Act of 9 June 2011. Geological and Mining Law (Journal of Laws of 2017, item 2126; codified text) (*Ustawa z dnia 9 czerwca 2011 Prawo geologiczne i górnicze (Dziennik Ustaw 2017, poz. 2017, tekst jednolity*). Warszawa (*in Polish*).

Bujakowski et al. 2001 – Bujakowski, W., Barbacki, P., Długosz, P., Graczyk, S., Hołojuch,G., Kazanowska, A., Kępińska, B., Ney, R., Pająk, L., Tarkowski, R., and Uliasz-Misiak, B. 2001. The application of geothermal water's heat for intensive vegetable production and fish farming. [In:] Ney, R. [sc. ed.] et al.: Selected problems on geothermal applications II *(Wybrane problemy wykorzystania geotermii – II). Studia, Rozprawy i Monografie* no 92. (*in Polish*, English abstract). 65 pp.

Eurostat 2013 – Eurostat regional yearbook 2013 – European Commission. [Online] ec.europa.eu›eurostat›documents› KS-HA-13-001-EN [Accessed: 2020-09-04].

Górecki, W. (sc. ed.) and Hajto, M., et al. 2006. *Atlas of geothermal energy resources in the Polish Lowlands. 1. Mesozoic formations*. Kraków: AGH-UST, NFEP&WM, 485 pp.

Górecki, W. (sc. ed.) and Hajto, M., et al. 2011. *Atlas of geothermal water and energy resources in the Western Carpathians*. Kraków: AGH-UST, NFEP&WM, 774 pp.

Górecki, W. (sc. ed.) and Sowiżdżał, A., et al. 2012. *Geothermal atlas of the Carpathian Foredeep*. Kraków: AGH-UST, NFEP&WM, 418 pp.

Górecki, W. (sc. ed.) and Hajto, M., et al. 2013. *Geothermal atlas of the Eastern Carpathians*. Kraków: AGH-UST, NFEP&WM, 796 pp.

IGA Information Brochure. 2001.

Kępińska, B. 2019. Geothermal Energy Use – Country update for Poland, 2017–2018. *Proceedings, European Geothermal Congress 2019.* 11–14 June. Hague (the Netherlands), pp. 1–9.

Kulikowski, R. 2007. Gardening in Poland. Distribution, crop structure and role in agricultural production (*Ogrodnictwo w Polsce. Rozmieszczenie, struktura upraw i rola w produkcji rolniczej*). *Przegląd Geograficzny* 79, 1, pp. 79–98 (*in Polish*).

Lund, J.W. and Boyd, T.L. 2016. Direct utilization of geothermal energy 2015 worldwide review. *Geothermics* 60, pp. 66–93.

Map of Main Groundwater Reservoirs (November, 2016) – Warszawa: Polish Geological Institute – National Research Institute. [Online] https://www.pgi.gov.pl/en/phs/tasks/8878-gzwp-major-groundwater-reservoirs.html [Accessed: 2020-09-04].

Mikołajków, J. and Sadurski, A. (sc. ed.) et al. 2017. *PHS Guidebook Main Underground Water Reservoirs in Poland (Informator PHS Główne zbiorniki wód podziemnych w Polsce)*. Warszawa: PGI-NRI, 413 pp. (*in Polish*).

[Online] http://agrometeo.pogodynka.pl [Accessed: 2020-09-04].

[Online] http://misjanatura.fwie.pl/n2000kompendium/images/natura%202000%20pl.jpg [Accessed: 2020-09-04].

[Online] http://susza.iung.pulawy.pl [Accessed: 2020-09-04].

[Online] http://2.bp.blogspot.com/-Ivi5nIJc5Fg/VQ3AZXdouSI/AAAAAAAA0k/oY5ioKupXI4/s1600/mapa.jpg (Map of Polish soils) [Accessed: 2020-09-04].

[Online] https://ekorytarz.pl/2014/07/24/spojnosc-europejskiej-sieci-obszarow-chronionych-natura-2000/ [Accessed: 2020-09-04].

[Online] https://www.cdr.gov.pl/aktualnosci/57-cdr-informuje/569-demonstracyjne-gospodarstwa-ekologiczne [Accessed: 2020-09-04].

[Online] https://www.lasy.gov.pl/pl/informacje/publikacje (Report on the state of forests in Poland 2010) [Accessed: 2020-09-04].

[Online] http://www.oodr.pl/informacja.php?id=2015-12-11_-_9:01:41&kategoria=dane_liczbowe&dzial=rolnictwo_ekologiczne&on=tak) [Accessed: 2020-09-04].

[Online] www.gis-suppot.pl (map by Dorota Kwaśny 12.05.2012) [Accessed: 2020-09-04].

[Online] www.iung.pulawy.pl [Accessed: 2020-09-04].

PN-EN 12831. *Heating installations in buildings. The method of calculating the design heat load. 2016* (*Polska Norma PN-EN 12831. Instalacje ogrzewcze w budynkach. Metoda obliczania projektowego obciążenia cieplnego 2016*) (*in Polish*).

Rosik-Dulewska, C. and Grabda, M. 2000. Geothermal waters as a clean source of energy needed for plant production (*Wody geotermalne jako czyste źródło energii dla potrzeb produkcji żywności*). *Chemia i Inżynieria ekologiczna* 3, pp. 263–271 (*in Polish*, English abstract).

Statutory work 2016 (Praca statutowa 2016). *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.* (*Badania parametrów energetycznych OZE na przykładzie wybranych stref z uwzględnieniem aspektów racjonalnego zarządzania energią – Analiza parametrów zasobów geotermalnych w wybranych rejonach Polski pod kątem ich wykorzystania w rolnictwie ekologicznym w warunkach racjonalnego gospodarowania energią. Część 1*). Collective work RES Department MEERI PAS. Arch. MEERI PAS. Kraków, 64 pp. (*in Polish*, English abstract).

Statutory work 2017 (Praca statutowa 2017). *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* (*Badania parametrów energetycznych OZE na przykładzie wybranych stref z uwzględnieniem aspektów racjonalnego zarządzania energią – Analiza parametrów zasobów geotermalnych w wybranych rejonach Polski pod kątem ich wykorzystania w rolnictwie ekologicznym w warunkach racjonalnego gospodarowania energią. Część 2*). Collective work RES Department MEERI PAS. Arch. MEERI PAS Kraków, 66 pp. (*in Polish*, English abstract).

The World of Organic Agriculture – statistics & Emerging Trends 2015. FIBL and IFOAM. [Online] (http://www.oodr.pl/informacja.php?id=2015-12-11-_9:01:41&kategoria=dane_liczbowe&dzial=rolnictwo_ekologiczne&on=tak) [Accessed: 2020-09-04].

Tomaszewska, B. and Szczepański, A. 2014. Possibilities for the efficient utilisation of spent geothermal waters. *Environmental Science and Pollution Research* 21, pp. 11409–11417.

GEOTHERMAL WATER AS A RAW MATERIAL FOR THE AGRICULTURAL SECTOR IN POLAND

Keywords

geothermal water, raw material, agriculture, application, prospects, Poland

Abstract

Direct applications in agriculture are among the most prospective development lines of geothermal water and energy. In many countries such uses have already been ongoing. Poland also has suitable natural conditions and geothermal waters' potential for agricultural development as well as for applications related to agriculture. Moreover, such applications in agriculture – if taking place after earlier use of geothermal waters e.g. for energetic or other purposes – would be the realization of the idea of the closed cycle economy. The first research and development works on geothermal waters and energy applications in agriculture in Poland were carried out in the early 1990s. In recent years this subject has once again sparked a growing interest. The paper presents geothermal water resources potential as well as circumstances, rationale, selected relevant estimations and proposed zones in the country for their uses (as raw material and heat source) in the agricultural sector of the country.

The use of geothermal waters in agriculture would be an important element in the chain of agricultural production and agri-food processing, contributing to the increase in the use of locally available natural resources, as well as reducing emissions when using these resources for energetic purposes.

The topic is presented against the background of a brief review of the state of geothermal water applications in agriculture in the world and in Europe, which convinces the legitimacy and need for the development of such use of geothermal water as a raw material for agriculture also in Poland.

WODA GEOTERMALNA JAKO SUROWIEC DLA ROLNICTWA W POLSCE

Słowa kluczowe

Polska, zastosowanie, rolnictwo, surowiec, woda geotermalna

Streszczenie

Bezpośrednie zastosowania w rolnictwie należą do perspektywicznych kierunków wykorzystania wody geotermalnej. W wielu krajach takie zastosowania mają już miejsce. Również Polska posiada odpowiednie warunki naturalne i potencjał wód geotermalnych dla ich rolniczego wykorzystania, a także zastosowań związanych z rolnictwem. Co więcej – zastosowania w rolnictwie, jeśli miałyby miejsce po wcześniejszym wykorzystaniu wód geotermalnych np. do celów energetycznych – byłyby realizacją idei gospodarki o obiegu zamkniętym. Pierwsze prace badawczo-rozwojowe nad zastosowaniami wód geotermalnych w rolnictwie w Polsce przeprowadzono na początku lat dziewięćdziesiątych XX w. W ostatnich latach temat ten ponownie budzi coraz większe zainteresowanie. W artykule przedstawiono potencjał zasobów wód geotermalnych oraz uwarunkowania, przesłanki, wybrane

istotne szacunki, a także proponowane perspektywiczne strefy dla ich wykorzystania (jako surowca i źródła ciepła) w sektorze rolniczym kraju.

Wykorzystywanie wód geotermalnych w rolnictwie stanowiłoby ważny element w łańcuchu produkcji rolnej i przetwórstwa rolno-spożywczego, przyczyniając się do wzrostu wykorzystania lokalnie dostępnych zasobów wód podziemnych, a także zmniejszania niskiej emisji, jeśli te zasoby byłyby stosowane także do celów energetycznych.

Temat przedstawiono na tle krótkiego przeglądu stanu zastosowań wód geotermalnych w rolnictwie na świecie i w Europie, co przekonuje o zasadności i potrzebie rozwoju takiego wykorzystania wód geotermalnych jako surowca dla rolnictwa także w Polsce.