Geothermal Field and Geothermal Resources in Belarus, Country Update for Belarus

Vladimir Zui[1], Margrita Dubanevich[2], Elena Vasilionak[1]

[1] Belarusian State University, Nezavisiosti sq., 4, 220030 Minsk, Republic of Belarus

[2] Republican Unitary Enterprise "Research and Production Center for Geology", 7, Kuprevich str., 220141 Minsk, Republic of Belarus

email address zui@bsu.org.by

Keywords: Geothermics, geothermal energy, terrestrial temperature distribution, heat flow, geothermal resources, GSHP installations, country update.

ABSTRACT

The territory of Belarus is located in geographical center of Europe. In geologic respect it belongs to the western part of the East European Platform. The Precambrian crystalline basement is hidden under the platform cover within the whole area of the country. There are no visible geothermal manifestations such as geysers, fumaroles, mud volcanoes, etc.

Since the time elapsed after the European Geothermal Congress 2013 held in Italy the main efforts were directed to prepare the Geothermal Atlas of Belarus which was finished in December, 2015. The density of Geothermal resources were estimated for a number of geothermal horizons. They range from first dozens of kg.o.e./m^2 for shallow depths till a few t.o.e./m^2 in deep sedimentary layers of the Pripyat Trough. Some of these resources are exploited in a number of localities mainly using small heat pump geothermal installations irregularly distributed within the territory of the country.

During a few decades geothermal investigations were fulfilled there. In result of these works a number of geothermal maps were prepared covering the whole studied territory. Among them are temperature distribution maps compiled for the a number of depths starting from of 100 m till 4 km within the Pripyat Trough, which is the deepest sedimentary basin in the southeastern part of the country, maps of geothermal gradient, heat flow density and geothermal resourcs distribution maps.

Geothermal resources were estimated for several geothermal horizons. No high enthalpy geothermal steam was revealed within the platform cover. Very preliminary estimates show that a depths position at which it could be possible to reach temperatures of 150–180 ºC, necessary to construct geothermal power plants are inside the crystalline basement. They are over the economically acceptable limits. Therefore the geothermal electricity generation is not considered for the nearest future. The maximal temperature recorded at the base of the platform cover was around 140 ºC at the vertical depth of 6.4 km in the deepest in the region Predrechitsa-1 inclined borehole.

Around 150 geothermal installations were constructed and used all over the country starting from the middle of nineties of the past century and a few more geothermal heating systems are under construction now. All available installations are used for space heating and sometimes simultaneously to heat warm water. The biggest geothermal installation of 1 MW$_{th}$ was put into operation at the Greenhouse Complex "Berestye", located at the eastern suburb of Brest town not far from the Belarus-Poland state border. All heat pump installations excluding the latter one are using shallow depth intervals of the platform cover with rather low-enthalpy geothermal resources.

1. INTRODUCTION

The territory of Belarus is located in the geographical center of Europe, (fig. 1).

Figure 1: Belarus is located in the geographical Center of Europe.

The main area of the country belongs to the Precambrian East European Platform and is a junction of three major crustal segments: Fnnoscandia in its northern part, Volgo-Uralia in the east and Sarmatia in the south. The latter one includes the two Paleozoic sedimentary basins. They are the eastern part of the Podlaska-Brest Depression and the Pripyat Trough with its developed salt tectonics and the thickness of the platform cover up to 5–6 km in the deepest parts. The latter one represents the Pripyat-Dnieper-Donets Palaeorift extending southeast to the Caspian Sea, Gorbatschev and Bogdanova, (1993). The considered two tectonic structures have, at the background of rather cold Precambrian structures existing in Belarus, higher temperatures at same depths as well as heat flow values.

The Belarusian Anteclise is the main positive structure within the considered region. It occupies the central-west part of the country and is extending beyond its borders into eastern Poland, (Fig.2).

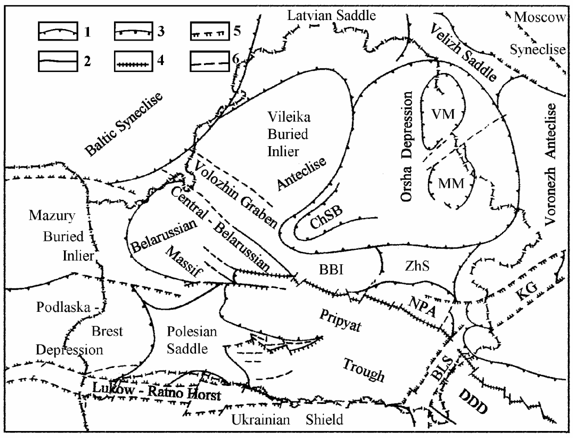

Figure 2: Main geologic units within the territory of Belarus.

Legend: 1 – the largest, 2 – large, 3 – medium-size platform faults: 4 – super regional, 5 – regional, 6 – sub regional and local faults. Abbreviations: DDD – Dnieper-Donets Depression; KG – Klintsy Graben; BLS – Bragin-Loev Saddle; NPA – North Pripyat Arch; BBI – Bobruik Buried Inlier; ZhS – Zhlobin Saddle; ChSB – Cherven Structural Bay; VM, MM – Vitebsk and Mogilev muldes, respectively.

Besides the Podlaska-Brest Depression and the Pripyat Trough in western and eastern parts of the country the Orsha Depression occupies its eastern part and is the third deep sedimentary basin.

The crystalline basement all over the country is hidden under sediments. Thin sedimentary cover overlies the crystalline basement of the Belarusian Anteclise. It ranges from 80–100 m within the Central-Belarusian Massif to ~500 m within other parts of this tectonic unit. Its thickness increases to 1.5–1.6 km within the Belarusian part of the Podlaska-Brest Depression and to 1.7–1.9 km within the Mogilev and Vitebsk muldes of the Orsha Depression, Aizberg et al. (2004). The deepest position of the crystalline basement up to 5–5.5 km was observed within the Pripyat Paleorift.

The Pripyat Trough is the best studied tectonic unit in geothermal respect comparable to other structures in the country. Hundreds of deep boreholes were drilled during oil prospecting works within its territory. In many of them were recorded thermograms in the process of their standard logging.

The active development of the Pripyat Trough, took place during the Devonian time Geology… (2001). In its eastern part the Devonian volcanism existed as well as explosion pipes, formed to the north of it within the Zhlobin Saddle, which is separated from the trough by the North-Pripyat Arm, (see Fig.2).

There are two salt layers (the Upper Salt and Lower Salt) within the platform cover of the trough, separated by terrigenous intersalt rocks. A base of the Lower Salt reaches the depth of 4.5–5.5 km depending on the individual basement block. Carbonate and terrigenous sediments underlie the lower salt complex, which contain highly mineralized brines. The complex geometry of salt bodies (diapirs, domes, swells) influences the terrestrial temperature field pattern.

A thickness of sediments within the Belarusian part of the Podlaska-Brest Depression varies from c.a. 0.5 km in its lateral parts till 1.7 km along the Belarus-Poland border. A few dozens of deep boreholes were drilled here with their irregular areal distribution.

The upper part of sediments within the whole territory of Belarus belongs to the zone of active water exchange, Kudelsky, et al., (2000) with its deepest parts up to 400 and in some localities up to 1000 m. Fresh water was also encountered in fractured uppermost parts of the crystalline basement within the Belarusian Anteclise in localities with thin sediments.

The content of dissolved chemicals in deep horizons in the Podlaska-Brest and Orsha depressions reach 25–40 g/dm^3. High salinity brines up to 400–420 g/dm^3 were observed in deep horizons of the Pripyat Trough.

2. TERRESTRIAL TEMPERATURE FIELD

Gradual accumulation of thermograms recorded in the process of boreholes logging occur after the second half of fifties of the last century when oil prospecting works were organized within deep sedimentary basins in Belarus. Since the end of sixties and beginning of seventies regular geothermal investigations were undertaken in a number of boreholes, reached the temperature equilibrium after the drill works were finished.

At present there are hundreds of thermograms of boreholes in the whole territory of the country. They were used to prepare a number of temperature distribution maps for selected depths and surfaces of several stratigraphic horizons, as well as geothermal gradient and heat flow density. Compiled geothermal maps were included into the Geothermal Atlas of Belarus. Its draft was finished in December of 2015. As new data were accumulated, it became evident that this, mainly Precambrian territory, has a contrast pattern of the terrestrial temperature field as well as geothermal gradients and observed heat flow density. The same concerns the density of geothermal resources distribution within the whole country which will be discussed below. A number of geothermal anomalies were revealed and shown at corresponding maps. Some of prepared maps are considered below.

A position of boreholes with available thermograms is shown in (Fig. 3).

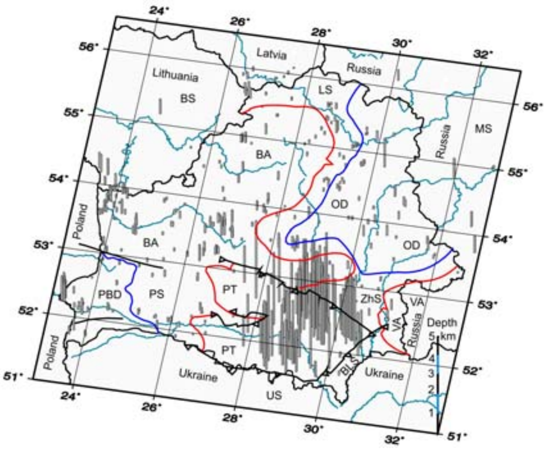

Figure 3: Location of boreholes within Belarus with available thermograms.

Legend: heavy black lines – deep penetrating platform faults; heavy blue lines – margins of negative structures; heavy red lines – margins of positive structures. Abbreviations: BA – Belarusian Anteclise; BLS – Bragin-Loev Saddle; BS – Baltic Syneclise; LS – Latvian Saddle; OD – Orsha Depression; ZhS – Zhlobin Saddle; PBD – Podlaska-Brest Depression; PS – Polesian Saddle; PT – Pripyat Trough; US – Ukrainian Shield; VA – Voronezh Anteclise; vertical lines and their lengths represent positions of studied boreholes with available thermograms and depths, reached thermometers during temperature measurements. The depth scale is shown in the right lower corner of the map.

The best studied in geothermal respect is the oil-bearing Pripyat Trough where hundreds of deep boreholes were drilled in the course of oil prospecting works. Other territories outside the Pripyat Trough: the Belarusian Anteclise with its Polesian, Zhlobin and Latvian saddles, Podlaska-Brest and Orsha depressions are less studied tectonic units. Mainly shallow boreholes were used there for geothermal measurements. Most of them were drilled for drinking water and were finished within the fresh water zone, which is the zone of active water exchange with a pronounced groundwater circulation.

Accumulated data base of thermograms was used to prepare temperature distribution maps for the whole country based mostly on reliable temperature records in boreholes only to the depths of 100-200 m. Using an extrapolation of recorded diagrams as well as some thermograms for shallow boreholes into deeper strata gave a possibility to compile temperature distribution maps for the whole country maximum to the depth of 500 m. Only for better studied Pripyat Trough it was possible to prepare such maps for deeper horizons. We consider some of them below.

Temperature distribution for the depth of 100 m. This map was re-compiled taking into account new thermograms recorded and collected during last years. Within the depth interval of 0-100 m there is a pronounced groundwater circulation. In result up to the depth of 100 m belong to the zone of active water exchange, containing fresh water in pores of rocks, (Fig.4).

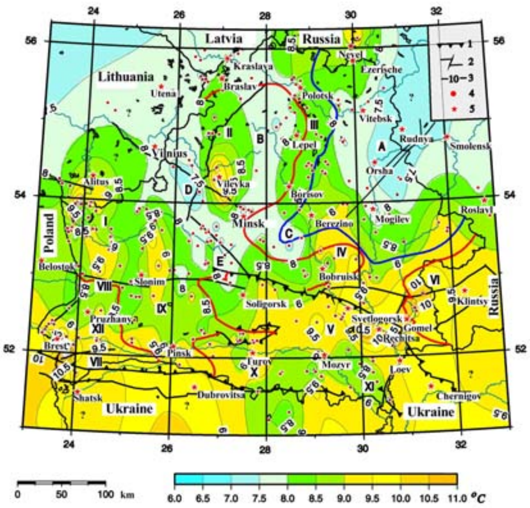

Figure 4: Temperature distribution map at the depth of 100 m within Belarus.

Legend: 1, 2 – superregional and regional faults within the crystalline basement, 3 – isotherms, ˚C, 4 – studied boreholes, 5 – towns and settlements. Anomalies of increased temperature: I – Grodno, II – Molodechno-Naroch, III – West Orsha, IV – Chechevichi-Rechitsa, V – Pripyat, VI – western slope of the Voronezh Anteclise, VII – Podlaska-Brest, VIII – Mosty, IX – Lyakhovichi-Elnya, X – Turov, XI – Vystupovichi-Elsk, XII – Kobrin-Pruzhany. Low temperature anomalies: A – East-Orsha, B – eastern part of the Belarusian Anteclise, C – Cherven Structural Bay, D – central part of the Belarusian Anteclise, E – Central Belarusian Massif. Red heavy lines indicate margins of positive structures: Belarusian Anteclise, Polesian Saddle and the Voronezh Anteclise (their limits were outlined by 500 m isoline). The blue line shows margins of the Orsha Depression (outlined by –700 m isoline).

The influence of sub-vertical water filtration is reflected in shapes of thermograms. The typical form of thermograms in boreholes drilled at elevated form of relief: hills, uplands, watersheds have the concaved forms and convex ones within valleys. In results in a convective component of heat transfer, this is pronounced here, Zui, (2010).

After the data base of thermograms was extended, there were no dramatic changes in shapes of isotherms based on individual temperature values recorded in studied boreholes, Zui (2013). The isotherms were drawn within the territory of Belarus by means of an interpolation. Their contours outside the state border were received in result of an extrapolation into adjoining areas with small amount of thermograms.

Seasonal temperature variations at the ground surface propagate into depths within the described region depending on their lithologic composition comprising geologic cross-sections and downward or upward water filtration rates. These depths are typically range from 30 m to 70–90 m for areas with thin or absent impermeable layers of clays, mudstones, etc. Temperature at this depth ranges from 7 to 11.5 °C. Values above 8 ºC are typical for Palaeozoic geologic units: the Pripyat Trough and the Podlaska-Brest Depression.

The isotherm of 9 ºC has its continuation beyond the North Pripyat Fault into the North Pripyat Arch, Zhlobin Saddle and the western slope of the Voronezh Anteclise. At the depth of 100 m available thermograms of the Pripyat Trough, recorded in the course of standard logging, have low quality to be used in the temperature map for the depth of 100 m. A number of regional and local anomalies are shown in this map, (see Fig. 4). Low temperature anomalies exist in the eastern part of the Orsha Depression of 6.5–7.5 ºC. This area includes almost the whole Mogilev Mulde. No data to trace reliably this anomaly into adjoining area of Russia as there are very rare network of geothermally studied boreholes.

A strip of slightly increased temperature values of 8.5–10 ºC with the meridian orientation crosses the whole territory of the Orsha Depression from the Pripyat Trough and continues into Russia. Its northern continuation is unknown as only one thermogram was recorded near the stare border in the adjoining area of Russia.

As before isotherms of 9.0-9.5 ºC in the eastern part of the Podlaska-Brest Depression are traced through the Polesian Saddle along the Belarus-Ukraine border. They are continuing into the territory of Ukraine. The isotherm of 9.0 ºC of this anomaly has its continuation into the Pripyat Trough and then to the western slope of the Voronezh Anteclise, Zui (2010, 2013).

In the northwestern corner of the country the *Grodno anomaly* of increased temperature above 9 °C is stretched in the meridian direction and has its continuation into the territory of Lithuania.

Finally, the *Molodechno-Naroch anomaly* of elevated temperature above 8 ºC has the meridian orientation and in its northern part reaches the junction of state borders of Belarus, Lithuania and Latvia. It subdivides the anomaly of low temperature of the central part of Belarusian Anteclise into two parts. They are the *anomaly of the eastern slope of the anteclise* and the *anomaly of its central part*. The local *Kobrin-Pruzhany,* as well as the *Mosty* and *Lyakhovichi-Elnya* anomalies of elevated temperature, exceeding 9 ºC, has also the same meridian orientation.

Temperature distribution at the depth of 300 m. The number of available thermograms in the data base gradually reduces with for deeper horizons. In result only a few hundred of thermograms were used to compile the temperature distribution map for the depth of 300 m, (Fig. 5). To the number of temperature readings taken from recorded thermograms, dozens of them were added from extrapolated diagrams.

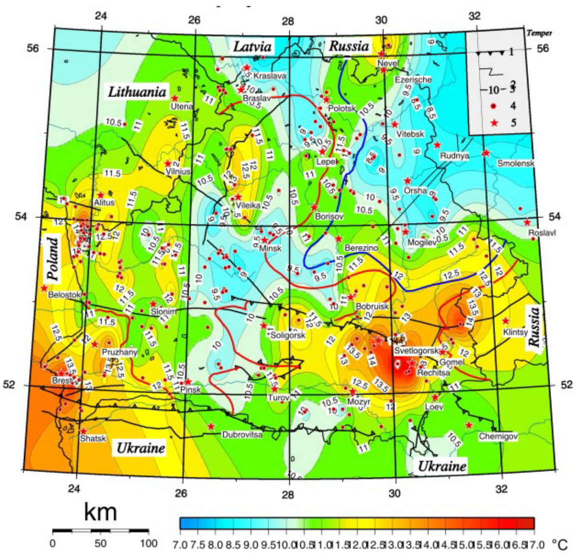

Figure 5: Temperature distribution map at the depth of 300 m within Belarus.

Legend: see in Fig. 4.

We will not discuss in details this map, but only mention some of its features. The available number of thermograms decreases for the depth of 300 m but it still remains around 250 including around 35-40 % of extrapolated temperature values. In result small detail disappear from the map and the shape of isotherms is slightly changing at the general background of increasing of temperature values with the depth. Minimal temperature values at the map for the depth of 300 m ranges from 8.0 till 17 ºC. The configuration of isotherms, especially at the last map is sufficiently changed. One of reasons is a lack of thermograms available for this depth for the Orsha Depression and adjoining blocks of the crust. As before, the main temperature anomalies with increased values are related to Paleozoic Pripyat Trough and the Podlaska-Brest Depression, considerably lower temperatures are typical for the Belarusian Anteclise and the Orsha Depression.

Actually all temperature anomalies, shown in the temperature distribution map for the depth of 100 m, exist also at the depth of 300 m with slightly changed shapes. Partly it is the result caused by ceased vertical component of the velocity of downward water filtration with depth. First of all, it concerns the Molodechno-Naroch, Kobrin-Pruzhany, Mosty and Lyakhovichi-Elnya anomalies. It is well known that the infiltration rate of groundwater results in many instances in the reduction of the convective component of heat transfer in loose sediments.

Temperature distribution at the depth of 2 and 4 km. The number of available thermograms depends of the considered depth. For instance, when the depth increases, the number of used thermograms rapidly decreases as shown in fig. 6. For the depth of 0.5 km the number of recorded thermograms in boreholes of the Pripyat Trough and extrapolated ones (calculated temperatures) are almost equal. But for the depth of 3 km this ratio becomes 40/60 %. For the depths exceeding 4-5 km all thermograms as a rule were extrapolated.

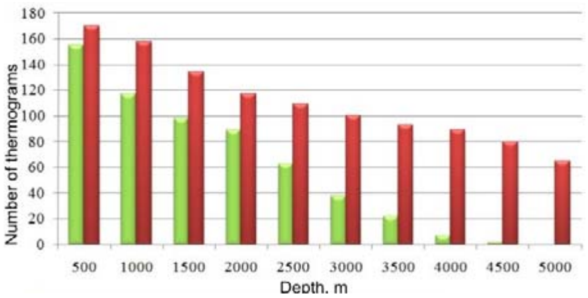

Figure 6: Number of used reliable thermograms for the Pripyat Trough.

A lack of thermograms didn’t allow compiling terrestrial temperature maps for depths deeper than 700–1,000 m for the whole territory of Belarus. Such thermograms are practically absent for the Belarusian Anteclise and only a few diagrams were available in deep boreholes within the Podlaska-Brest and Orsha depressions where temperature values at the sedimentary cover base reach 40–42 °C.

As thermograms for deep boreholes are mainly available for the Pripyat Trough, we consider its temperature field in more details. This is the best studied area in geothermal respect among other sedimentary basins of the country.

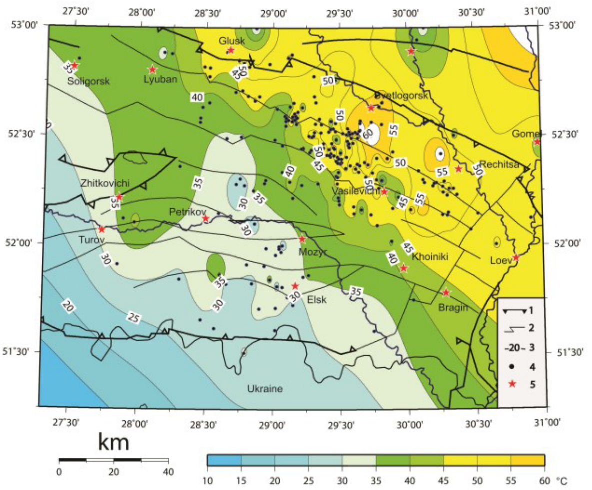

Figure 7: Temperature distribution at the depth of 2 km within the Pripyat Trough.

Temperature at the base of the platform cover in the northern zone here increases to 80–100 ºC, but for the depth of 4–5 km the number of reliable thermograms doesn’t exceed 20, which is not enough to compile detailed temperature maps based purely on results of measurements. The maximal temperature recorded, for instance, in the Barsuki 63 oil well, was 115 °C at the depth of 4 km and its maximal value around 140 °C at the depth of 6.4 km was recorded in the Predrechitsa-1 hole. New collected thermograms during last time allowed preparing more detailed map here. The temperature field pattern at the depth of 2 km is shown in (Fig. 7). There is a distinct asymmetry of the terrestrial temperature field within the whole structure. In the northern zone of the trough the temperature, in average, is two times higher than in its southern and western parts. A wide area of low temperature exists in southwestern parts of the though, it is the area to the left of the isotherm of 35 °C. Only a few thermograms were available in southwestern part, that’s why it was not possible distinguishing small details in the map. At this background the highest temperature exceeds 60–70 °C within the northern and north-eastern zones of the trough. The main exploited oil fields were encountered namely within this warm area, Zui (2013).

At the depth of 2 km the central part of the anomaly in the northern zone of the Pripyat Trough is limited by the isotherm of 50 °C. This zone is traced in the western direction till Luban town and continues to the southeast into the Gremyachy Buried Salient and the Dnieper-Donets Depression, the main part of the latter one is in Ukraine. In the northern direction the anomaly was traced into the North Pripyat Arch. Small anomalies exceeding 40 °C were observed within southern part of this geologic unit (the Elsk Graben and the Vystupovichi Step). The background temperature values here range from 35 to 40 °C.

The temperature distribution at the depth of 4km is shown in fig. 8.

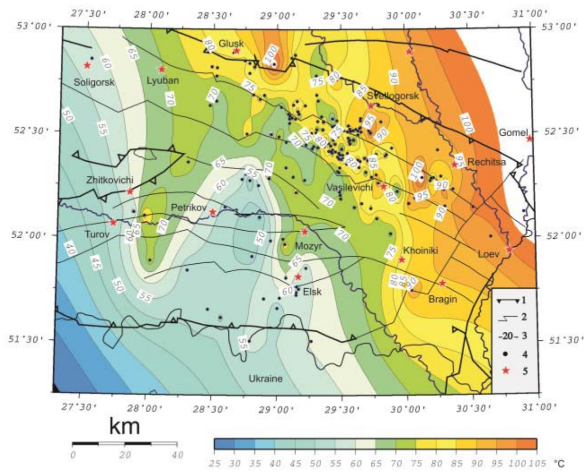

Figure 8: Temperature distribution at the depth of 4 km within the Pripyat Trough.

In the northern zone of the trough the temperature, in average, is two times higher than in its southern and western parts. A wide area of low temperature exists in western and southwestern parts of the structure. Only a few thermograms were available in southwestern zone, that’s why it was not possible distinguishing small details in the map. At this background the highest temperature exceeds 60–70 °C. When the depth increases to 4 km, small details in temperature distribution maps disappear, because the number of available thermograms also decreases. The terrestrial temperature field at the depth of 4 km is similar to those one shown at the depth of 2 km. The main differences are higher temperature values up to 90–100 °C in the northern zone of the positive anomaly and slight changes in shapes of isotherms.

3. HEAT FLOW

Investigations on heat flow density determinations were based on recorded thermograms and thermal conductivities of rock samples measured in laboratory conditions. These works were started since the very end of sixties and the beginning of seventies of the last century, Bogomolov et al., (1969), Bogomolov et al., (1970). Since that time regular heat flow investigations were organized in the Laboratory of Geothermics of the National Academy of Sciences of Belarus.

The heat flow density map, (Fig. 9), was compiled using all published data, which were accumulated in the heat flow catalogue, Zui, (2013). Available heat flow data from adjoining areas of foreign of Poland, Lithuania, Latvia, Russia and Ukraine were also used when compiling this map.

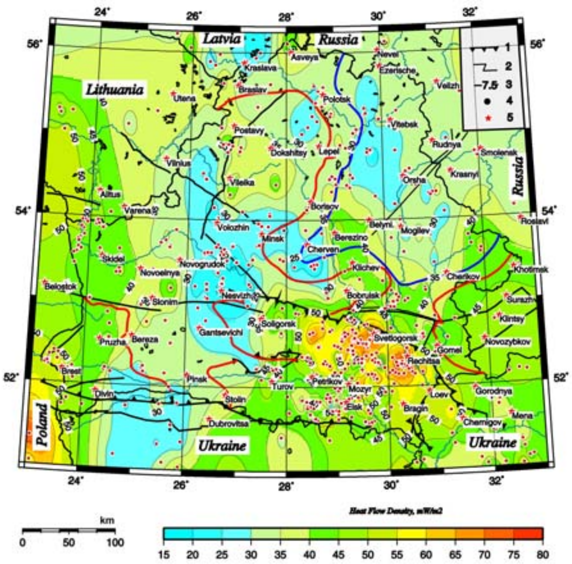

Figure 9: Heat flow density map for Belarus. Legend see in Fig. 4.

Heat flow density distribution is rather differentiated within the considered area. A chain of low heat flow anomalies below 30 mW/m^2 is stretched from SW (Lvov Palaeozoic Depression) through the Belarusian Anteclise to NE (Orsha Depression). They cross the whole territory of the country. At a background of low values (30–40 mW/m^2), positive anomalies are well distinguished within the Podlaska-Brest Depression (50–55 mW/m^2) and the Pripyat Trough where heat flow exceeds 60 mW/m^2 in its northern zone.

Heat flow density within the Pripyat Trough ranges from less than 40 mW/m^2 to more than 100 mW/m^2 within nuclei of salt domes., Tsybulya, Levashkevich, (1990); Zui et al., (1991); Zhuk et al., (2004). The geometry of salt tectonics is good studied within the Pripyat Trough both by drilling and by geophysical methods. Geothermal measurements and heat flow determinations were fulfilled in most of boreholes drilled through salt domes and swells. Heat flow vectors deflect of vertical direction in the vicinity of such salt bodies, as rock salt has 2–3 times higher thermal conductivity comparing to surrounding terrigenous sediments and distorts sub horizontal course of isotherms.

In the upper part of the geological section within so-called "above-the-salt" sediments interval heat flow values are typically lower in result of the groundwater circulation phenomenon. Therefore, heat flow calculated in shallow boreholes resulted in its lower values comparing to adjoining areas of the trough with deep boreholes. That's why; it was observed that interval heat flow values are dependent on the depth. This fact is the result of many factors: thermal conductivity variations for rocks comprising the platform cover, groundwater filtration, varying tectonic conditions, etc., Zhuk et al., (2004).

Besides the main orientation of heat flow density isolines along the North Pripyat Fault, it is clearly distinguished another direction with heat flow of 50–60 mW/m^2, traced along the line joining Mozyr – Rechitsa towns. It is orthogonal to the main stretching of the anomaly in the north zone and follows the Perga crustal fault, penetrating into the upper mantle.

Heat flow density of 40–50 mW/m^2 was observed also within local anomalies of the Belarusian Anteclise (areas with granite intrusions in the crystalline basement), Orsha Depression, North Pripyat Arch, Zhlobin Saddle, and the western slope of the Voronezh Anteclise.

As it was mentioned above, all oil fields were revealed within areas of positive geothermal anomalies. All exploited oil fields of the Pripyat Trough are located within areas with heat flow above 55 mW/m^2, Gribik, Zui, (2009) and the most of them fall inside the area limited by the isoline of 60–75 mW/m^2. Only less than 10 of them are located inside the area of 55–60 mW/m^2. A zone of 65–75 mW/m^2 corresponds to two condensate accumulations. They are: the Krasnoselskoye and West-Aleksandrovskoye fields.

Heat flow density values below 30 mW/m^2 form a chain of small anomalies, partly located along the Volyn – Orsha – Krestsy Paleodepression, Paleotectonics, (1983), having as a rule, the longitudinal orientation. One of them, covering the largest area, is traced from the northern part of the Polesian Saddle and the Mikashevichi – Zhitkovichi Salient to the northern part of the Belarussian Anteclise in the direction of Gantsevichi – Nesvizh towns. At the latitude of Minsk the strip has a tongue into the Cherven Structural Bay and the Osipovichi Uplift. Low heat flow is typical for the Central Belarussian Massif.

The Grodno and the Podlaska Brest anomalies are joined by the isoline of 40 mW/m^2 with heat flow values in their central, parts exceeding 50 mW/m^2. This anomaly is continued into the territory of Lithuania in its northern part and probably joins with the high heat flow area in western Lithuania and the Kaliningrad Enclave of Russia. A lack of thermograms in the territory of Lithuania doesn’t allow tracing it in more details.

Heat flow density values within the adjoining area of Poland were studied only in a few boreholes near the Belarus-Poland border. Therefore the pattern of heat flow isolines adjoining the Belarus-Poland boundary should be considered as preliminary one. Same concerns their configuration along both sides of state borders with Lihuania, Latvia and Russia.

4. GEOTHERMAL RESOURCES

Recoverable geothermal resources were calculated on the basis of widely used approach, namely according to Hurter and Haenel (2002).

Resources of geothermal energy were estimated for both shallow horizons within the country and deep ones exceeding 1 km in the Pripyat Trough and the Podlaska-Brest Depression. They vary in a wide range from 10–20 kilograms of oil equivalent per square meter (kg.o.e./m^2) within crustal blocks with thin sedimentary cover to 200–300 kg.o.e./m^2 in the Podlaska-Brest Depression. The highest density of resources, exceeding 1 t.o.e./m^2, was observed in deep complexes of the Pripyat Trough, but these horizons have high content of dissolved chemicals up to 350–420 g/dm^3.

4.1 Geothermal resources in the depth interval of 100–200 meters

Fresh ground waters are encountered till the depth of 200 m almost in the whole territory of Belarus. Only within relatively small areas their mineralization slightly exceeds 1 g/dm^3. Therefore using these waters for heat recovery from shallow horizons of the platform cover is a favorable condition from technologic point of view as it is not necessary to drill additional pumping wells. Moreover, there are no scaling problems when exploiting such waters for geothermal energy recovery. To be able to obtain comparable results all over the whole territory of the country for a density of recoverable geothermal resources, it was decided to calculate them for the interval of 100–200 m.

This interval is composed of rocks with different age and lithology. As there are a lot of hydrogeological windows in this interval, it was decided, as the first approach, to consider this interval as a “single aquifer”. It gives a possibility to determine and compare recoverable resources within different geologic units of the country. Moreover, shallow boreholes or horizontal circulation loops are typically used for small geothermal installations in the country. From this point of view there was a sense to assess the geothermal resources density in shallow horizons.

Figure 10 shows a distribution of recoverable geothermal resources for Belarus contained within permeable rocks with fresh water in the depth interval of 100–200 m.

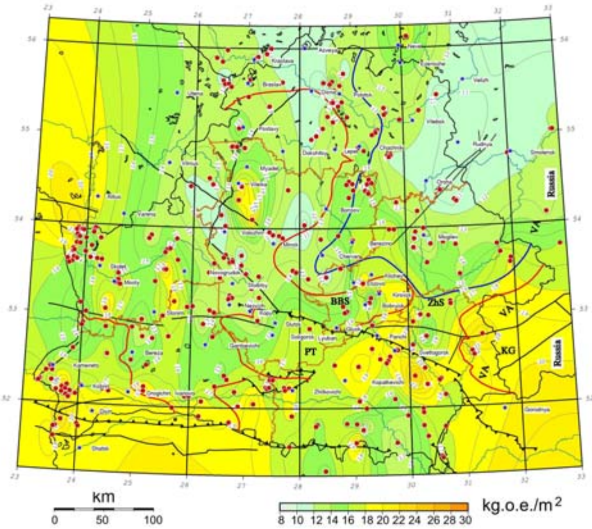

Figure 10: Recoverable density of geothermal resources from the interval of 100–200 m within the territory of Belarus.

Legend: BBS – Bobruisk buried Salient, KG – Klintsy Graben, VA – Voronezh Anteclise, PT – Pripyat Trough, ZhS – Zhlobin Saddle. Red heavy lines indicate margins of positive structures: Belarusian Anteclise, Polesian Saddle and the Voronezh Anteclise (their limits were outlined by minus 500 m isoline). The blue line traces margins of the Orsha Depression (outlined by –700 m isoline).

The density of recoverable geothermal resources ranges from 10 to around 25–28 kg.o.e/m^2. Values above 18 kg.o.e/m^2 are typical for southwestern part of the country. In geologic respect it corresponds to the Podlaska-Brest Depression and the Polesian Saddle. A wide area of a positive anomaly exists within the northern part of the Pripyat Trough, extended into the western slope of the Voronezh Anteclise and continued beyond the North Pripyat Fault as a narrow strip of increased values, stretched in northern direction along the line crossing through towns and settlements: Stetlogorsk – Parichi – Kirovsk – Elizovo. Small anomalies exist in between Molodechno – Naroch, Volozhin – Vileyka, Slonim – Pruzhany towns. Another anomaly was traced in the vicinity of Grodno, its margin is open into the territory of Lithuania and probably they reach the positive anomaly existed within the west Lithuania and the Kaliningrad Enclave of Russia.

Several areas of low values of geothermal resources 10–12 kg.o.e/m^2 were observed within northern and northeastern parts of the country. The area of the widest one corresponds to the northern part of the Orsha Depression. It was practically not studied in adjoining territory of Russia. In deep horizons of the

Orsha Depression the estimated density of geothermal resources reaches up to 50 kg.o.e./m^2. All isolines were drawn by interpolation inside the territory of Belarus. They were extrapolated into adjoining areas beyond the state border as preliminary ones.

The density of geothermal resources was calculated also for different water-bearing complexes, developed within Belarus. They are the Cretaceous, Middle Devonian, Paleogene deposits, etc. not discussed here.

4.2 Geothermal resources within deep horizons of the Pripyat Trough

The Pripyat Trough belongs to geologic units with higher heat flow in comparison to Precambrian blocks of the crust. Geothermal resources were calculated here for several geothermal horizons using the standard approach, Hurter and Haenel (2002). These horizons are: (a) Jurassic deposits, (b) Carboniferous, (c) Devonian sediments overlying the Upper Salt Formation (d) the Intersalt sediments, (e) Devonian thickness underlying the Lower Salt Formation (terrigenous and carbonate strata), (e) the Upper Salt complex and (f) the Lower Salt thickness. The underlying the Lower Salt complex has very high mineralization of brines up to 420–450 g/dm^3 and even higher in some localities. There are no the world practice to utilize such brines to recover geothermal resources.

Here we consider only a few of them. The density of geothermal resources for several horizons of the Pripyat Trough was discussed earlier, Zui, (2010). They range from 0.25 to 1 t.o.e/m^2 in the Intersalt Complex of the Pripyat Trough, (Fig.11).

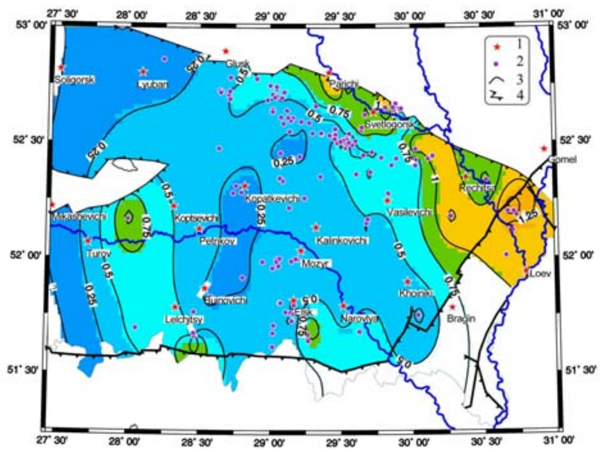

Figure 11: Density of Geothermal resources within the Intersalt Complex of the Pripyat Trough (t.o.e/m^2)**.**

Dozens of abandoned deep wells were drilled in the course of oil prospecting works in the Pripyat Trough beyond the water-oil boundaries, later they were plugged. These abandoned boreholes represent the interest for geothermal energy extraction. They could be opened, repaired and put into operation to extract warm and hot geothermal liquids and return them to underground after the heat of brines will be used.

The feature of the Pripyat Trough is rather high salinity of brines. Because of high mineralization of them it is possible to use these drilled wells to create borehole heat exchangers without direct extracting of brines itself. Using the old abandoned boreholes will allow reducing of expenses to construct corresponding geothermal systems.

Another possibility is to use geothermal horizons overlying the Upper Salt Complex, where the salinity of warm brines is much lower. For instance, the Carboniferous deposits (fig. 12) or overlying them horizons containing mineral or even fresh waters with lower geothermal resources, but still acceptable for their practical utilization.

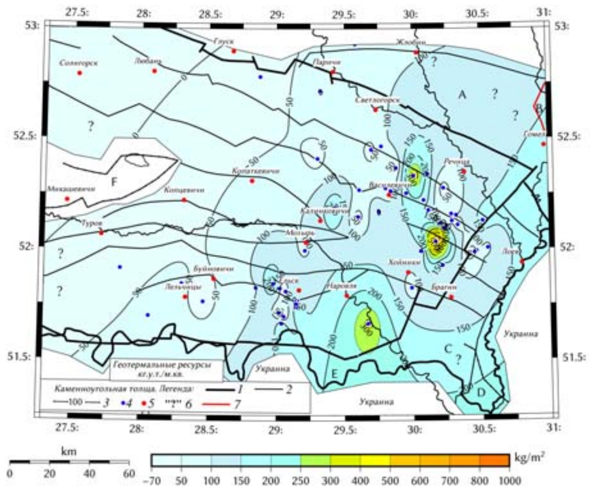

Figure 12: Density of Geothermal resources within the Carboniferous Complex of the Pripyat Trough, (kg.o.e/m^2)**.**

Density of geothermal resources within the Carboniferous sediments ranges from less than 50 kg.o.e/m^2 in the western part of the Pripyat Trough up to approximately 500 kg.o.e/m^2 in some localities of the northern and eastern parts of the trough.

5. GEOTHERMAL INSTALLATIONS

Existing regulations in the country don't require registering geothermal installations in the Ministry of Mineral Resources and Environmental Protection. Therefore their exact number could be only estimated. The very first small heat pump system was installed for heating of waterworks and sewage header buildings mostly in the Minsk District in 1997.

At present the total number of geothermal installations all over the country is estimated to be around 150, (Table 1). The biggest installation exists at the Greenhouse Complex "Berestye" in Brest. It uses fresh warm water pumped out from a borehole of 1000 m deep. Water temperature at the well mouth reaches of 24 ºC, the well flow rate is around 42 m^3/hour. Two heat pumps Daikin EWWD 440MBYN, with heat output of 505 kW each, are used there, (Fig.13), Zui, Pavlovskaya, (2012).

Table 1: Some existing geothermal installations, Zui, Pavlovskaya (2012)

Location	Primary heat source	Heat capacity, kW_{th}
Greenhouse Complex “Berestye”, Brest	Ground water	2 x 505
Waterworks “Vitskovshchina”, Minsk District	Ground water	43
Sewage header building No.9, Minsk District	Ground water	45
Waterworks “Vodopoy”, Minsk District	Ground water	40+390
Sewage header building No.19, Minsk District	Ground water	122
Sewage header building No.24, Minsk District	Ground water	330
River waterworks, Novopolotsk town	River water	230
Waterworks “Mukhavets”, Brest	Ground loop	3x60
Frontier point “Novaya Rudnya”, Elsk District	Ground water	273
Hospital, Nesvizh town	BHE	375
Waterworks “Drozdy”, Minsk District	Ground water	36
Sewage header building No.46, Minsk district	Ground water	156
Water purification station, Minsk	Ground water	165
Pump plant “Uruchye”, Minsk	Ground water	48
Pump plant “Sosny”, Minsk	Ground water	40
Waterworks “Felitsianovo”, Minsk District	Ground water	29
Waterworks No.11, Minsk District	Ground water	80
Waterworks “Sokol”, Minsk	Ground water	150
Rowing channel, Gomel	Ground water	2x46
Waterworks in Rechitsa town	Ground water	≈50
Church near Braslav town	BHE	≈40
Office building, Vitebsk	BHE	≈40
Waterworks in Gorki town, Mogilev region	Ground water	≈140
Cottages	?	≈1500 (?)

Other heat pump installations use an open circulation loop with pumping out of fresh water or closed loop systems with horizontal or vertical heat exchangers. The main consumers of the underground heat are: a frontier point Novaya Rudnya at the Ukrainian border, a church, dwellings, etc. with the total number of installed heat pumps around 150 with their heat capacity approaching to 7 MW_{th}. We assume these figures are underestimated.

Figure 13: Heat pumps Daikin EWWD 440MBYN at the Greenhouse Complex “Berestye”.

Additionally several dozens of small heat pump systems were installed in private cottages within and around the main towns and cities (Brest, Gomel, Grodno, Mogilev, Vitebsk and Minsk) with total heat capacity around 1.5–2 MWth. Most of installations use cold groundwater taken from shallow boreholes with ambient temperature of 8–10 ºC as a primary energy source or have closed horizontal circulations loops. One installation is based on the utilization of the river water.

6. CONCLUSIONS

Both studied temperature and heat flow values have a contrast pattern within the territory of Belarus. Variations of them are especially pronounced within areas with developed salt tectonics, like salt swells and domes of the Pripyat Trough.

The terrestrial heat is a perspective renewable and ecologically clean resource of energy available in the country. Its utilization represents an important national goal for the economics of Belarus. Low-enthalpy geothermal energy could be used within the whole territory of the country.

The density of geothermal resources varies in a wide range from 10 to more than 1000 kg.o.e./m^2. Low values are typical for the main part of the Belarusian Anteclise and adjoining Latvian, Polesian and Zhlobin Saddles. These values are slightly higher for deep horizons of the Orsha Depression (up to 50 kg.o.e./m^2). The density of geothermal resources within the Intersalt Complex of the Pripyat Trough ranges on average from 0.1 to 1.75 t.o.e./m^2. The Pripyat Trough and Podlaska-Brest Depression are the most promising areas in Belarus for the geothermal energy utilization. A construction of a pilot geothermal station using warm brines would be useful to stimulate the practical utilisation of geothermal resources of deep horizons within the Pripyat Trough.

Dozens of abandoned deep wells, drilled within the Pripyat Trough for oil prospecting were plugged as nonproducing ones. Their reanimation will increase the economic feasibility of such projects.

There is no utilization of geothermal resources in Belarus for power generation. All existing geothermal installations use heat pumps to extract low-enthalpy geothermal resources.

A number of geothermal maps were compiled in the process of preparation of Geothermal Atlas of Belarus. Its draft was finished in December 2015.

REFERENCES

Aizberg, R.E., Garetsky, R.G., Kudryavets, I.D., Starchik, T.A. On tectonics of the Orsha Depression and its correlation with basement structures. *Doklady of the National Academy of Sciences of Belarus*. **48**, Minsk, (2004), 88-92. (in Russ.).

Bogomolov, G.V., Lyubimova, E.A., Tsybulya, L.A., Kutasov, I.M., Atroshchenko, P.P. Heat flow within the Pripyat Depression. *Vesti of the Academy of Sci. of BSSR. Series of Physics-Technical Sciences*. No.2, Minsk (1970), 97 – 103 (in Russ.).

Bogomolov, Yu.G., Shpakov, O.N., Atroshchenko, P.P. Heat flow in the southern slope of the Belarusian Crystalline Massif. *Vestnik of the Moscow State University*. No.6, Moscow (1969), 95 – 98 (in Russ.).

Geology of Belarus. Makhnach, A.S., et al (Eds.), *Institute of Geological Sciences*, Minsk, (2001), 815 pp. (in Russ.).

Gorbatcshev, R. and Bogdanova, S.: Frontiers in the Baltic Shield, *Precambrian Research*, **64**, Amsterdam, (1993), 3-21.

Gribik, Ya.G., Zui, V.I. Features of geothermal field within the Pripyat Trough. *Contemporary Problems of Geology. University Geological Readings devoted to 60th Anniversary of a discovery of the Starobin Potassium Deposit*, Minsk, 3–4 April, 2009, E.A. Vysotsky et al., (Eds.), Minsk, (2009), 41 – 43 (in Russ.).

Hurter S., Haenel R. (Eds.). Atlas of Geothermal Resources in Europe. Leibnitz Institute for Applied Geosciences (GGA), Hannover, Germany, (2002), 91 pp + 89 plates.

Kudelsky, A.V., Pashkevich, V.I., Karabanov, A.K., Pavlovskaya, I.E., Korkin, V.D. Hydrosphere of Belarus at the latest tectonic stage, *Doklady of the National Academy of Sciences of Belarus*. **44**, Minsk, (2000), 79–83 (in Russ.).

Paleotectonics of Belarus, Garetsky R.G. et al. (Eds.). Nauka i Tekhnika, Minsk, (1983), 182 pp. (in Russ.).

Zhuk, M.S., Tsalko, P.B., Zui, V.I. Heat flow of the Pripyat Trough, *Lithosphere*, No. 1 (20), Minsk, (2004), 122–130 (in Russ.).

Zui, V.I. Geothermal Resources and their Utilization in Belarus, *Proceedings* World Geothermal Congress 2010, Bali, Indonesia, 25-29 April (2010), paper #0170, 1-12.

Zui, V.I. Thermal Field within the Platform Cover of Belarus. *Econompress*, Minsk, (2013), 256 pp. (in Russ.).

Zui, V.I., Pavlovskaya, O.A. Examples of geothermal resources utilizations in Belarus, VI University Geological Readings “Innovations in Geology and Utilization of Entrails”, Minsk, 6 – 7 April, 2012, V/N/ Gubin et al., (Eds.), Minsk, Belarusian State University, (2012), 17 – 19 (in Russ.).

Table A: Present and planned geothermal power plants, total numbers

Table B: Existing geothermal power plants, individual sites

No geothermal power plants in Belarus.

Table C: Present and planned geothermal district heating (DH) plants and other direct uses, total numbers

Table D1: Existing geothermal district heating (DH) plants, individual sites

Table D2: Existing geothermal direct use other than DH, individual sites

No District Heating plants (for towns, settlements, villages, etc.) in Belarus. Some of individual geothermal installations are listed in the Table 1 in the main text.

Explanation to table E: ‘Shallow geothermal’ installations are considered as not exceeding a depth of 400 m and (natural) geothermal source temperatures of 25 °C. Installations with geothermal source temperatures >25 °C and depth >400 m should be reported in table D1 or D2, respectively. Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings are not considered geothermal DH *sensu strictu*, and should be reported in table E also.

Table E: Shallow geothermal energy, ground source heat pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2015 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2015 *	~150 *est.*	7.0 *est.*	3.57 *est.*	2 *est.*	0.2 *est.*	2 *est.*
Projected total by 2018	160 *est.*	7.5 *est.*	3.8 *est.*			

* If 2014 numbers need to be used, please identify such numbers using an asterisk

Comments to the Table E: All figures are estimated ones. No detailed information available. Existing geothermal installations are based on fresh water pumping from boreholes, using borehole heat exchangers (BHE) and not many of them use horizontal circulation loops.

Table F: Investment and Employment in geothermal energy

	in 2015 *		Expected in 2018	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	No	No	No	No
Geothermal direct uses	No*	No*	No	N/A
Shallow geothermal	0.2*	No*	0.5 – 1.0	N/A
total	**0.2***	**No***	**0.5 – 1.0**	**N/A**

* If 2014 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Comments to the Table F: *) – Estimated data. All installations available are for the use of geothermal energy by heat pump installations, at the same time all they are "shallow geothermal" (usually they use the fresh water pumping out, or the BHE technology). 2) Typically there are no separate personell to exploit these installations; they are served by users themselves.

Table G: Incentives, Information, Education

	Geothermal el. power	Geothermal direct uses	Shallow geothermal
Financial Incentives – R&D	No	No	Same ~25 000 €/ year (Estimated)
Financial Incentives – Investment	No	No	Same ~250 000 €/year (Estimated)
Financial Incentives – Operation/Production	No	N/A	N/A
Information activities – promotion for the public	No	No	Publications in public media (newspapers, magazines).
Information activities – geological information	No	No	Publications in geological journals.
Education/Training – Academic	No	No	We have 1 Prof. and 1 PhD specialists in Geothermics. Now we have 2 magisters and 1 PhD student too.
Education/Training – Vocational	Lectures are delivered for students of the Belarusian State Univ. in Geothermics & Geothermal Energy since 2011.	Lectures are delivered for students of the Belarusian State Univ. in Geothermics & Geothermal Energy since 2011.	Lectures are delivered for students of the Belarusian State Univ. in Geothermics & Geothermal Energy since 2011.

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)

Final comments: If something in the tables A – G are not understandable, or should be extended, or erroneously filled in, please contact Vladimir Zui zui@bsu.by (Belarusian State University, Minsk, Belarus) to discuss these items. Mob. +375 29 6634851.