C. Description of the pilot area - Kraków

1. Infrastructural and socio-economic settings

Krakow City pilot project area covers the area within the administrative border of the city (Figure 1). Krakow is the second largest and one of the oldest cities in Poland with population of 762,448 (as on 30th of June 2016 – Table 1). Situated by the Wisla River in the Lesser Poland region, the city dates back to the 7th century. The city stretches from the North to the South ca. 18 km, whereas from the West to the East - ca. 31 km. Point of the highest elevation within the city limits - 383 m above sea level (The J. Piłsudski Mound). Point of the lowest elevation within the city limits – 188 m above sea level (mouth of the Potok Kościelnicki creek). The city of Krakow also happens to be crossed by the 50ºN parallel and the 20ºE meridian. The co-ordinates of the Adam Mickiewicz monument at Rynek Główny (Main Square) – 50º03'41"N and 19º56'17". Detailed statistical information on Krakow City is presented in table 1.

Table 1 The main geografic and demographic parameters of Krakow City pilot project area (after: Chełstowska, Czerwińska, Filip, 2015; krakow.stat.gov.pl, 2016)

Surface area: 326.9 km^2	Maximum temperature: 35.8˚C (September 1)
Location: coordinates of the Monument to Adam Mickiewicz in the Main Square – in the heart of the Old town – 50˚03'41"N and 19˚56'16"E; near the south-eastern border of the City (District X -Swoszowice) – at the intersection of parallel 50˚N and meridian 20˚E	Average temperature of the coldest month – February: 1.5˚C
Width from south to north: 18 km	Minimum temperature: -11.3˚C (January 7)
Width from west to east: 31 km	Annual total precipitation: 684.6 mm
Highest point: 383 m.a.s.l. – J. Piłsudski Mound	Maximum rainfall – August 16: 74.4 mm
Lowest point: 187 m.a.s.l. – mouth of the Kościelnicki creek	Number of days with snow cover: 26
Average air temperature in 2015: 10.7˚C	Number of days with sun > 0.1 h: 298
Average temperature of the hottest month – August: 21.9˚C	2015 was an exceptional year, especially with respect to the range of temperatures
Demographics issues	
Population: 762,448 (as on 30th of June 2016)	
Density: 2,327.7/km^2	

Krakow has traditionally been one of the leading centres of Polish academic, cultural and artistic life and is one of Poland's most important economic hubs. In 2000, Krakow was named European Capital of Culture. In 2013 Krakow was officially approved as a UNESCO City of Literature. The city hosted the World Youth Day in July 2016.

Krakow lies in the southern part of Poland, on the Wisla River, in a valley at the foot of the Carpathian Mountains (Figure 1), 219 m above sea level; halfway between the Jurassic Rock Upland (Polish: Jura Krakowsko-Częstochowska) to the north, and the Tatra Mountains 100 km to the south.

According to physical-geographical distribution of Polish by Kondracki (2002) the Krakow Agglomeration is located in a transitional zone between the valleys of: Auschwitz from the west and Sandomierz from the east and belongs to the geomorphological unit called the Krakow Gate. From the south, this area is bordered by the Wieliczka Foothills, and from the north by the Częstochowa Upland and Nida Trough. Area of Cracow Gate unit, within the Krakow agglomeration, is divided into subunits: Skawina Graben, Cholerzyn Depression and Krakow Bridge (Figure 1). The Krakow occupies vast area, which belongs partly to the Silesian-Krakow Monocline, partly to the Carpathian Foredeep and to the northern edge of the Flysh Carpathians. In the southern part of the City runs a front line of the Carpathian nappes overthrust. The base of overlap are built of the Miocene (molasse) sediments. Lowered zone extending in the front of the northern edge of the Carpathians is so-called Carpathian Foredeep (Figure 1). Krakow's Bridge structure forms a circuit of limestone hills and tectonic depressions, where flows the Wisla River. The main hills are as follow: Tyniec, Sowinec, Pychowice, Krzemionki, Wawel and Skalka Hill. Almost all of the geomorphological structure of the Krakow's Bridge is located within the agglomeration of Krakow, therefore a very large differentiation in the natural environmental conditions, mainly of anthropogenic origin can be observed. The main division of geomorphological units in the Krakow region is shown on figure 1.

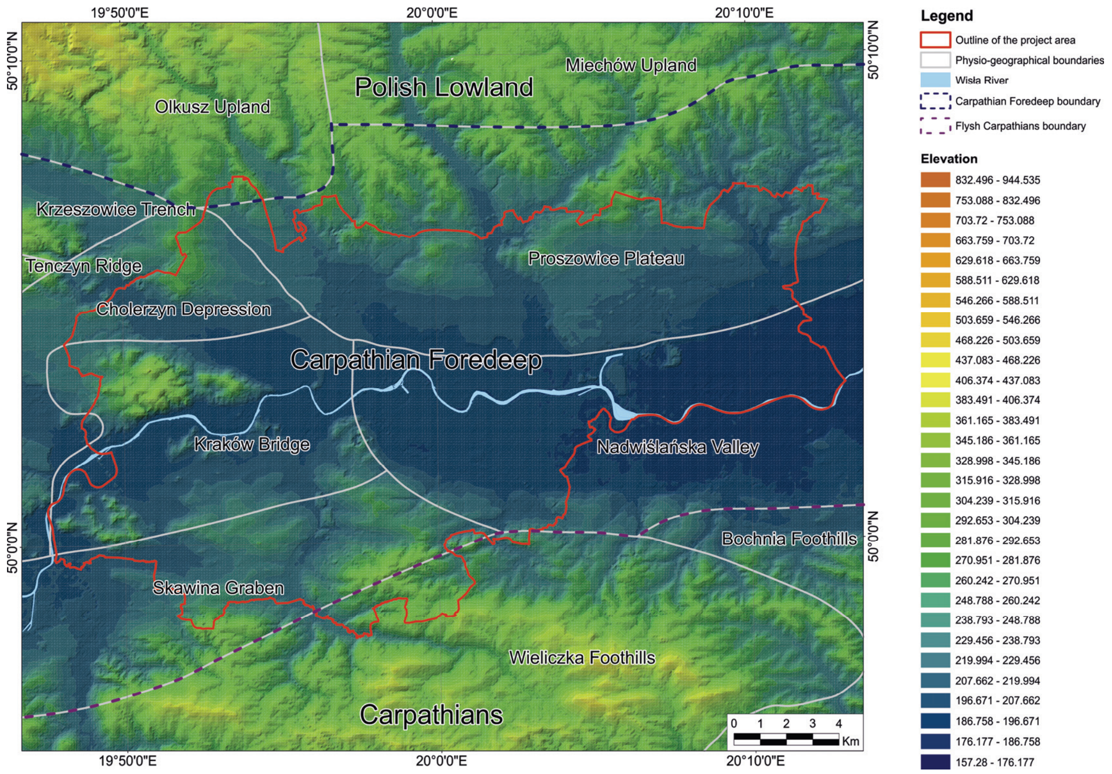

Figure 1 Layout of the main physio-geographical units of Krakow (after Kondracki, 2002)

2. Regional geological and hydrogeological characteristics

From geological point of view Krakow is located on the border of the Silesian-Cracow Monocline, Miechów Trough and the Carpathian foredeep. It's a region heavily tectonically disturbed, mainly with Neogene age tectonics. A few larger geological-structural units can be distinguished, eg.: Ojcow Plate, Krzeszowice

Graben, horst of Tenczyn bandwidth, Cholerzyn foreland and Sowiniec Horst (Rutkowski, 1993) (Figure 1). Location of selected geological boreholes and engineering-geological wells, with total depth above 30 m on topographic map of pilot project is shown on figure 2.

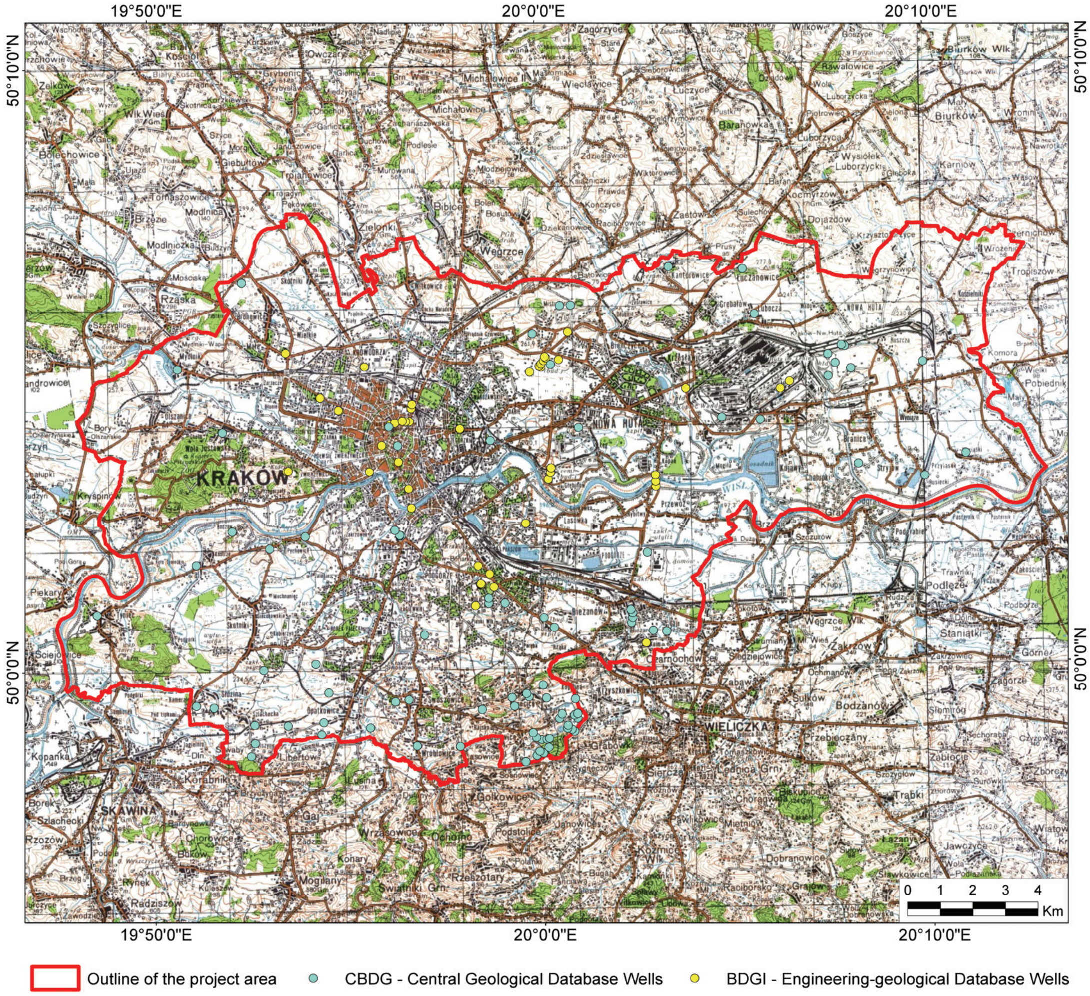

Figure 2 Outline of pilot area Krakow with topographic map and location of the main geological and engineering boreholes

In the southern part of the area a number of small horsts and grabens exist. They are built mainly of the Upper Jurassic limestones. Tectonic structure of horst constitute also the area of Krakow-Podgorze district and the area of Kurdwanow settlements as well. The Ojcow Plate is built of Oxfordian limestones downsloped to the NE towards the Miechow Trough underlying the Cretaceous sediments. The boundary between the Silesian-Cracow Monocline and the Miechow Trough runs within the Ojcow Plate tectonic structure and is assumed along the extent of Cretaceous formation outcrops (Rutkowski, 1993). Within the area of the Krakow city the Quaternary sediments fill the ancient valley of the Wisla River, creating a series of terraces and alluvial cones of Pradnik and Rudawa rivers (Duda et al., 1997). These sediments are mainly sand and gravel of fluvial and fluvioglacial origin.

From the hydrogeological point of view Krakow is located in the upper Wisla River watershed (the Baltic Sea catchment). In the area of Krakow groundwaters are reservoired within many stratigraphic units: Palaeozoic, Mesozoic, as well as Miocene, Eocene and Quaternary (Górecki [ed.], Hajto, et al., 2011).

In the city of Krakow groundwater occur within the water-bearing aquifers: Paleozoic and Jurassic (cracked and karstified limestones), Cretaceous (cracked marls and limestones), Miocene and Eocene (fine-grained sandstones and sands) and Quaternary (sand and gravel). The dominant role played in terms of aquifer levels are: Jurassic, Neogene (Bogucice sand) and Quaternary (Pleistocene).

Jurassic waters occur in different types of reservoirs related to cracked, fissured and karsted limestone, cut and shaped in the system of horsts and grabens, with a different hydraulic connection. Recharge area of the aquifer is located in the northern belt of the Krakow city.

Within Neogene aquifer the two main water-bearing layers are present. The first one consists of the *Bogucice* sandstones and sands leading freshwater. Optimal recharge conditions exist at the outcrops of *Bogucice* sands and through infiltration of surface water flowing from areas outside the boundary outcrop of *Bogucice*. The second Neogene water-bearing layer is related to gypsum sediments, provides mineralized water, curative waters of "Swoszowice", with the composition of the SO_4-HCO_3-Ca-Mg, H_2S.

Separate Paleogene water-bearing layers are related to deep pours sand bodies filling sinkholes located in Jurassic limestone. This water, with the composition of the SO_4-Cl-Na-Mg-Ca, H_2S, is widely used for treatment purposes in curative house (SPA) of "Mateczny".

Within the Quaternary strata the main aquifer level is related to Quaternary/Pleistocene, occurring mainly in the ancient valley of the Wisla River and represents by the complex gravel-sandy sediments. The aquifer is characterised mostly with free water table (unconfined aquifer), but sometimes also under low pressure. A natural drainage basis of this level is the Wisla River and its tributaries, especially in the lower sections of the riverbed eg.: Rudawa, Bialucha, Dlubnia, Koscielnicki stream and Wilga River. The Quaternary aquifers are recharged directly through the rainfalls and infiltration of surface water (Wisla and tributaries) and from Jurassic water-bearing layers.

A fresh groundwaters occurs within hydrostratigraphic units creating usable groundwater levels. Area characterized with the most abundant reserves constitute the main groundwater reservoirs - GWB. In the area of the Krakow city three main parts of groundwater reservoirs can be distinguished (Figure 3):

- Wisla River Valley (GWB No. 450) - quaternary aquifer porous nature within the Pleistocene sand and gravel, includes the valley of the Wisla River and its tributaries within the limits of the City of Krakow. Water intake based on this vessel characterized by varying depth (from several to several tens of meters) and generally higher yields;

- Subreservoir Bogucice (GWB No. 451) – Neogene aquifer, porous nature within the complex Neogene waterbearing sands *Bogucice*, encompasses the south eastern part of Krakow, and outside the City of large areas in the municipalities of Wieliczka, Niepolomice and Klaj. Groundwater was recognized by dozens of wells, ranging from 60 to 200 m depth;

- Czestochowa (E) (GWB No. 326) – small section of the large documented Jurassic aquifer located north of Krakow. The aquifer are built of fractured and karsted limestones. It covers an area of the Upper Jurassic outcrops and occurs in diversified layouts, mostly under overlying, permeable Quaternary sediments.

Groundwater of GWB's are generally of good quality and can complement the needs of the City. Quaternary water level are recognized for urban water supply (in Mistrzejowice, consisting of three teams drilled wells), and for the purposes of social and living – Arcelor Mittal Poland S.A. (the so-called "Passage A" and "Passage D"). For these water intakes, the decisions of the Governor of the Krakow the protection zones have been established, in which the restrictions, prohibitions and injunctions arise directly from the Water Act and administrative decisions.

Groundwater is also a source of emergency supply system of Krakow. The system consists of wells that draw water from the Quaternary aquifer and a few intakes of Neogene and Jurassic. In addition, the groundwater are a source of supply for residents on the outskirts of town, with no water supply system. Groundwater in the area of the City of Krakow are poorly insulated from the ground, and therefore very non-resistant to the passage of contaminants from the surface. Quality and effective protection of groundwater resources is one of the most important tasks and problems taken into account in the preparation of local development plans. Location of selected hydrogeological wells, with total depth above 30 m in the background of the main hydrogeological units is shown on figure 3.

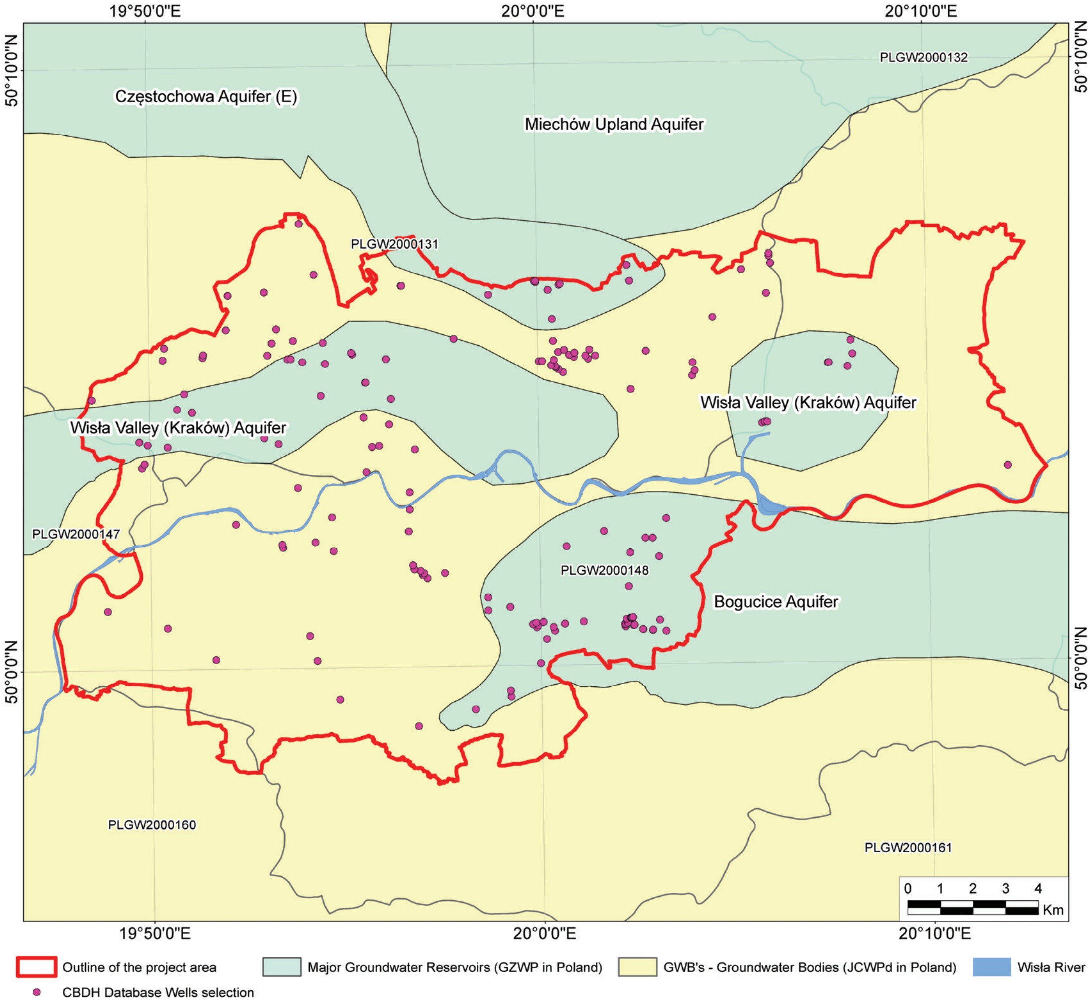

Figure 1 Location of Krakow pilot project area in the background of the main hydrogeological units (Ground Water Bodies) and location of hydrogeological wells

3. Market situation and existing shallow geothermal use

Heat pump market in Poland is comparatively young and dynamically developing. It appears in one of the highest in EU year-over-year heat pumps sales percentage increase, while characterising comparatively low total amount quantities. Such situation is indicating, that Polish heat pumps market is emerging and very prospective one. In Poland, at the moment, there is no central information system and statistic on the geothermal heat pumps (GHP), including their location, depth of boreholes, type of applied technology (open or closed system), installed power capacities and other data. For this reason, it is not possible to give a reliable, comprehensive data on existing GHPs for Poland as a whole country.

According to Summary of EGC 2016 Country Update Reports on Geothermal Energy in Europe (Antics et al., 2016 after Kępinska, 2015), in Poland during 2015 about 5,000 new ground-source heat pumps were sold, which is 11.1% of all operational GSHPs in the country. The EGEC Members edition Market Report 2015 (Angelino et al., 2016) presents data based on WGC 2015, which show clearly outstanding quantitative market size (beside other countries from Central and Eastern Europe Region), comparable with Austrian and Switzerland markets, whilst permanently growing.

PORT PC assessed that number of operational heat pump installations amounts to in significantly less than 100,000 units, nevertheless more and more popular are air/water heat pumps, as their installation is comparatively cheap. Since recent winters were mild, main advantages of ground-source heat pumps do pale in comparison to initial money savings. In 2015, sale of air/water heat pumps was 70% bigger than in 2014, whilst quantitatively for space heating applications brine/water (ground and water source) are dominating (sold slightly less than 5,000 pieces vs. about 4,000 sold air/water HPs). The number of sold heat pump units per year in Poland, including their type is presented on figure 4.

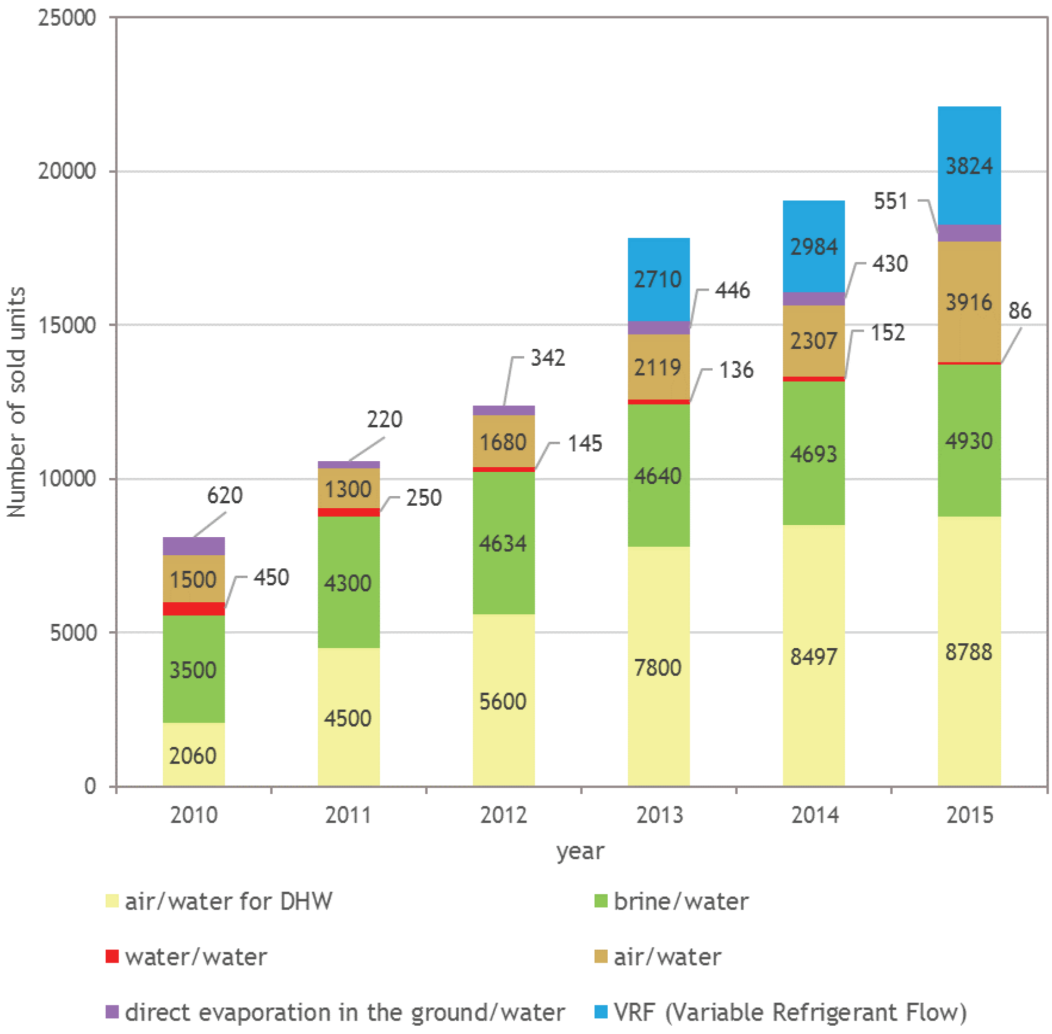

Figure 4 Heat pump sales development by type of heat pump in Poland (after EHPA, 2016)

In 2015, power of shallow ground-source heat pump installed in Poland was equal to 500 MW, provided by about 45,000 devices producing 714 GWh_t per year (Kepinska, 2015; Antics et al., 2016). Average power per unit was about 11 kW indicating that vast majority of ground-source heat pumps installed in Poland are dedicated for residential purposes (in Poland heat power demand for a detached house is usually not higher than 15 kW), if applied in big structures – working in a cascade system. Precise data is not available, though. It seem that there are two main groups of ground-sourced heat pumps installations.

First, owners of detached houses with capacities of about 10 kW and another – administrators of big buildings, mainly owned by local authorities of different level (schools, hospitals etc.), but also commercial or sacral buildings (hotels, shopping moles, churches).

The only official source of information on GHP in Poland are the district (county) offices. They are obliged to issue opinions on the projects submitted by the investors aimed to perform geological works “in order to use the heat of the Earth” (i.e. use of shallow geothermal energy by means of GHP), and later to collect the post-completion documentations.

The estimates shows that in Krakow (NUTS: PL213) ca. 40 GSHP (closed loop system technology with ground heat exchangers mounted in the vertical borehole) and respectively only ca. 4 WSHP (open loop systems) have been installed so far. The estimates gives totally ca. 44 HP within the whole extent of Krakow City area, as it was reported in the documentation of deliverable D.T2.1.2 of GeoPLASMA-CE project, which will be published soon. It must be emphasis that most of HPs installations in Krakow were constructed for the needs of the single-family houses with individual energy power ranging to several, approx. 20 kW.

According to the information gathered by personal contacts with representatives of HPs manufacturers, distributors and installers associated with the PORT PC, there are three/four larger plants exist within the area of Krakow City. The largest HP’s installations in Krakow are located in the: John Paul II Centre in Krakow, located in the south part of Krakow, with a total installed geothermal capacity of operating GSHPs is equal to 1.5 MW (after Tetlak T. – Vatra PLC). The second largest are installation of closed loop, WSHP with ca. 400 kW of installed capacity, that supply heat to production hall (after www.vatra.pl). The third one ground source heat pumps of 320 kW installed capacity is set up in the central-north part of Krakow in the Monastery of Discalced Carmelite Fathers (mounted in 2008). The following one is set up in the John Paul II Hospital in Krakow, located in central part of the city, with installed capacity of ca. 220 kW. Another GSHP is operating in the border west part of the City in Tyniec settlement, where four compressor heat pumps draw heat from several vertical ground heat exchanger with a depth of 100 m each and supply heat for the buildings of ancient Monastery (after PORT PC). The Abbey is situated in charming place, on a limestone hill above the Vistula River. Total installed capacity equal to 200 kW.

The ground source heat pumps installation of ca. 150 kW is also located in the central part of the City, and heat selected buildings of the Faculty of Animal Sciences of the University of Agriculture in Krakow (nearby AGH UST). The GSHPs are also installed at the AGH UST, e.g. at the Faculty of Drilling, Oil and Gas, where the Laboratory of Geoengineering was established. They operate two ground source heat pumps with total installed capacity of 26 kW used mainly for research purposes.

4. Main challenges and needs for shallow geothermal use

The city Krakow as the only city in Poland where They pay special attention on environmental issues, including air protection, where in 2011 the Krakow City Council announced (proclaimed) resolution on the adoption of “Low Emission Reduction Program for the City of Krakow”. The project assumed total coal-smoking ban at the city. Hazardous air quality is a common problem particularly during the colder months when many residents use solid fuels (mostly coal) for household heating. On 15th of January, 2016 the Malopolska Regional Assembly adopted so called “antismog resolution” (ODMV, 2016). This means that in the whole of Krakow Municipality a total ban of heating coal and wood, as well as use of fireplaces will be introduced. The new regulations are expected to contribute to a significant improvement in air quality in the city. The resolution enter into force on 1st of September, 2019. In the framework of “Low Emission Reduction Program”, the City Office of Krakow proposes subsidies to replace heating from coal to electric, gas, oil, based on renewable energy sources (solar or heat pump) or the connection to the central heating network operated by the Municipality owned heat supply company (MPEC). Parallely with introduction of new legal conditions, Krakow authorities try to provides financial support to reduce low emission e.g. through dedicated programs of financial incentives. Accordingly, in 2016 one could get up to 100% of the investment costs, but not more than 900 PLN (ca. 210 €) for each kW, in 2017 grants will be awarded to 80%, in 2018 to 60% of the incurred eligible costs respectively.

According to the latest urban air quality database (WHO, 2016), as many as 33 Polish cities are among the 50 most polluted cities in the EU, considering PM2.5. Krakow is ranked at 11 position cities for levels of both PM10 and PM2.5 accordingly and Walbrzych took 178 position when considering PM10 and 156 position (PM2.5) respectively. Krakow experiencing 188 days each year above the EU's target levels for air pollution (PM10).The current standard of PM10 dose is up to 50 µg/m^3, and can not be exceeded more than 35 days a year (EC, 2008). According to European Environmental Agency statistics (EEA, 2016) premature deaths in Poland attributable to PM2.5, was estimated to 48,270 of beings. The fact that 10 percent of City dwellers are not connected to the municipal heating network should be seen as a considerable defeat in Krakow's development. Yet the problems of funding and enforcement remain. Krakow has had a programme subsidising the replacement of solid fuel furnaces for many years, but it is proceeding very slowly. One way to reduce of low emission, pointed out even by the Krakow Authorities, is the use of heat pumps. The market of shallow geothermal energy in the City of Krakow is still poorly recognized. Many of private investors assembles a heat pumps for heating their private houses, but the information on the location and installed thermal power is not properly registered. These disadvantages were also raised during bilateral meeting at the Krakow City Office last year in the framework of GeoPLASMA-CE project implementation.

The Krakow City is located within the extent of several underground aquifers provides an important source of fresh tap water and supply not only residents of the City but surrounding suburb community as well, thus beyond the GSHP, the application of WSHP in Krakow, should also be considered. Unfortunately possible increasing numbers of applications, may influence on conflicts use and cause thermal overload of the shallow groundwater bodies. The Polish Water Act (PWA, 2001) focuses on the use of groundwater, especially the drinking water supply. All possible energetic uses of the groundwater are regulated by another regulations (e.g. Polish Geological and Mining Law, ACT of 9th of June 2011, as amended). At the current stage of development and application of heat pumps, we are primarily interested on promotion of the technology itself, including the use of high efficient WSHP (open loop systems) in Krakow, considering the risks associated with the unreasonable management of groundwater heat, to avoid in future, arising from excessive densities of water intakes problems on energetic use of the groundwater body, that are facing currently e.g. in Vienna (within the groundwater body Marchfeld).

Another challenge is to support promotion of geothermal heat pump utilization in Krakow, where the use of HP is recommended not only by a society of professionals, manufacturers and installers, but first of all by the city authorities. Strengthening public awareness about the benefits of GHPs use and delivery of scientific and technical support aimed to enhance their wider applications in Krakow is the most important challenge of the GeoPLASMA-CE. The concept of increasing the use of heat pumps is also included in the draft plan of "Low-carbon economy" developed in order to the Municipality of Krakow, Krakow City Office in 2015 (LCE, 2015), which assume the potential of renewable energy by particularly use of the HPs to 100 MW and possible production of ca. 150,000 MWh/year of thermal energy.

Another issues are related to overcome still existing conviction that use of heat pumps is economically unfeasible, that of course may happen when HP system was badly designed and constructed.

A great challenge of the project for Krakow will be also connected with providing of reliable qualitative information on conflicts arising from a multiple use of the subsurface and use of groundwater below the city as a main drinking water resource, in a form of user friendly tools and maps, that could be a solid base for planning and designing geothermal systems, which is still awaiting for both the average consumer, specialist and local authorities, as well, issuing relevant permits, licenses, etc.

5. Project objectives

The objectives of the project in the Krakow pilot area is to support the city of Krakow with information on possible use of shallow geothermal energy and integrate this information into development and management strategies of the city. Quantification of shallow geothermal potential for utilisation with both ground source heat pumps (GSHPs) and water source heat pumps (GWHPs) as well for heating and cooling purposes will be the main challenge of the project implementation.

Despite several decades of geological, engineering and hydrogeological development done within the Krakow city, aimed to identify the technical conditions for infrastructure development and the possibility of use of groundwater to supply the inhabitants of Krakow, no attempt to develop a coherent 3D digital geological model have been taken so far. The construction of such model can also be a great scientific and research achievement itself. All geoscientific data will be used to establish a geothermal potential map for both open loop systems and for ground source heat pumps as well.

Collection and integration of overall geological and hydrogeological data will also constitute a great challenge of our activity within the framework of GeoPLASMA-CE project. The database will be used to set-up calibration and validation of 2D/3D models which will enable estimation of geothermal potential for the use and simulation of periodical behaviour of the aquifer, including estimation of potential hydraulic and thermal mutual impact of existing and planned geothermal use. Results will be elaborated and presented in the form of user friendly 3D viewer tool that will be used by local stakeholders, including the authorities for management of shallow geothermal use in Krakow pilot area.

Another GeoPLASMA-CE project task, will be focused on detailed information about these installed GHPs also with some help provided by the Polish Organization of Heat Pump Technology Development.

The outputs of the project area will be made available to the interested public via the GeoPLASMA-CE web portal.

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