C. Description of the Wałbrzych / Broumov area

1. Infrastructural and socio-economic settings

The transboundary Wałbrzych / Broumov pilot area, being investigated during GeoPLASMA-CE project covers a total area of ca 1,245 km^2, including Polish part - i.e. Wałbrzych area – of ca 767 km^2 and Czech area of 478 km^2 (Figure 1 A). The selection of such a range of the examined area resulted from the need to include the whole Wałbrzych district and the northern part of the Nachod district. For technical reasons, related with 3D modelling to be performed during the project, the research area is increased by special buffer zone, which enlarges the total area to 1,536 km^2. Geographically, the main part of the Wałbrzych / Broumov area is located in Central Sudety Mts. This area is morphologically very differentiated and includes fragments of several mesoregions (Figure 1 B).

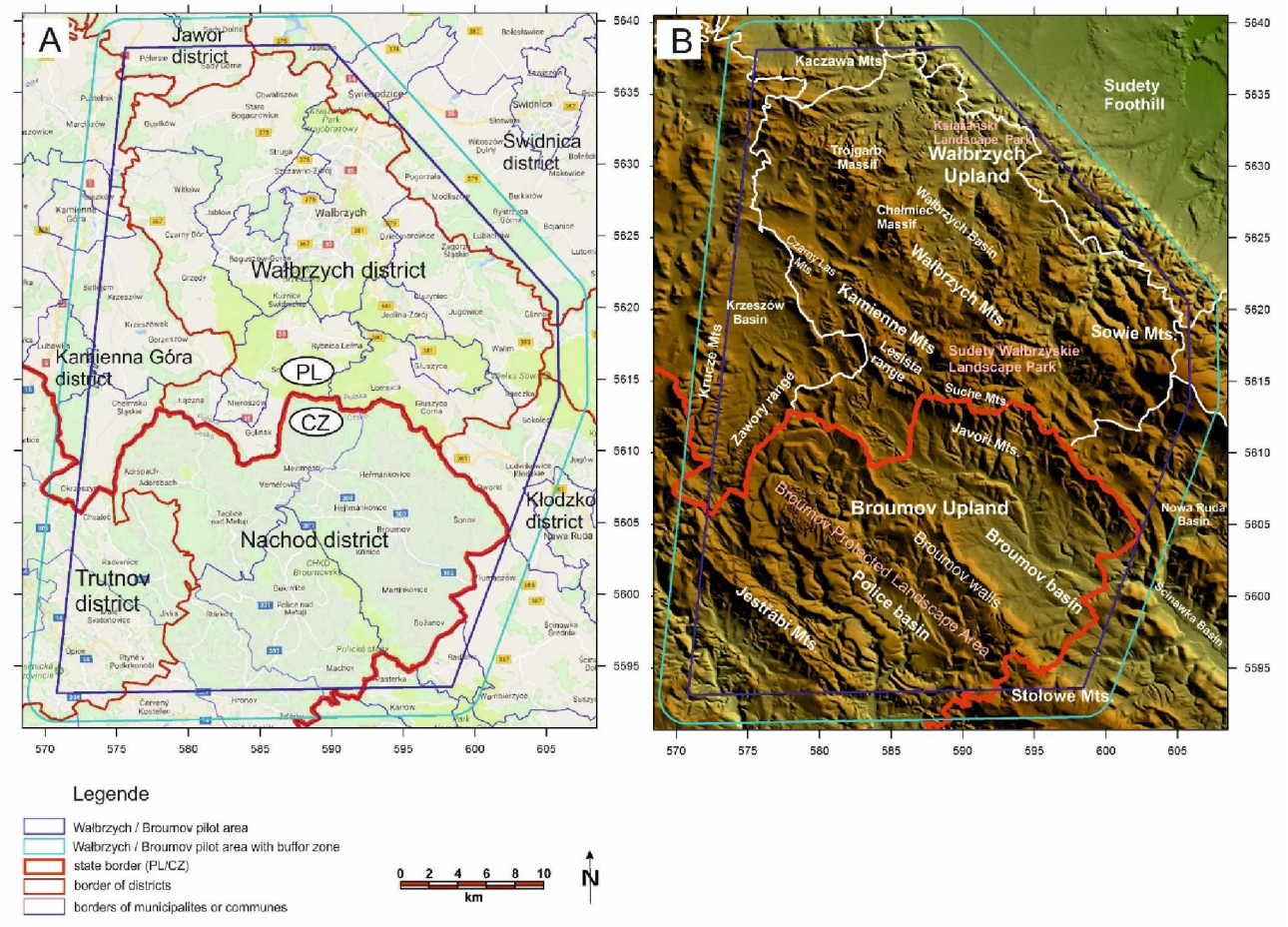

Figure 1. A. Location of the Wałbrzych / Broumov pilot area on topographic map. B. Morphological map of the investigated area shown on Digital Elevation Model (DEM).

Due to generally mountaineous character, average heights of the Wałbrzych area vary from 300-400 m a.s.l. in the N and up to 800-940 m a.s.l. in the S (Kamienne Mts.). The main rivers flowing through the area are the Lesk, the Pełcznica, the Ścinawka, the Bystrzyca and the Zadrna.

In terms of administrative division, the Wałbrzych area is located in the southern part of the Lower Silesian Voivodship and comprises territory of the Wałbrzych City (town with district rights) and a whole Wałbrzych district.

The Wałbrzych area is moderately to strongly urbanized, especially in the central part near towns Wałbrzych, Świebodzice, Boguszów-Gorce and Szczawno Zdrój. Population of the sole Wałbrzych city is ca. 120,000 inhabitants (1,400 inh./km^2) and of the Wałbrzych district 57,000 (113 inh./km^2). The main factor for the economic development of the Wałbrzych region during the 19th and 20th centuries was black coal mining, making driving force for the creation of the Wałbrzych Industrial District. Nowadays, the region is essentially an agro-industrial with strong service sector (over 40% of employees) and highly developed tourist function (recreation centers in Walim, Rzeczka, Zagórze Slaskie) and spa-cities (Szczawno Zdrój, Jedlina Zdrój). There are also located, among others, clothing factories, porcelain factory, producers and wholesalers of the building materials and several units of agri-food industry. Of big importance is the Wałbrzych Special Economic Zone, where the Toyota carmaker factory was established. Still important for the region is the mining industry for road and construction stones (a large quarry of melaphyre in Rybnica Leśna). Through in the whole Wałbrzych area there are many active and abandoned railway lines and a dense network of roads. The railway line of national importance runs from Wałbrzych by Boguszów-Gorce and Marciszów to Jelenia Góra.

More than 90% of area of Czech part is protected as Protected Landscape Area of Broumovsko. This fact is a strong impulse for tourist industry and makes the region a frequent destination for Czech domestic holidays. This region is famous for its Cretaceous sandstone rock towns – “Adršpach-Teplice rocks” and “Broumov walls”, but many smaller and less known tourist places are situated in the area. Geomorphology of Broumov area can be seen on Figure 1. A. Location of the Wałbrzych / Broumov pilot area on topographic map. B. Morphological map of the investigated area shown on Digital Elevation Model (DEM).Figure 1 B. The highest altitude (ca 800 m a. s. l.) is reached by “Broumov Walls” and “Adršpach-Teplice Rocks”, and the lowest altitude 390 m a. s. l. is recorded North of Hronov.

Only two cities over 5,000 inhabitants – Broumov (7,604 inh.) and Úpice (5,683 inh.) are located in the region. The other important towns are Police nad Metují (4,172 inh.), Rtyně v Podkrkonoší (2,978 inh.) and Teplice nad Metují (1,696 inh.) The area is covered quite uniformly by 31 small villages with less than 1,000 inhabitants. The population of the region is approximately about 40,000 (Český statistický úřad, 2016).

In the past Broumov region industry was represented mainly by textile and engineering factories. Mining industry (black coal, copper ore, building stones) was also present. In the 90’s of 20th century the industry came through the decline. Recently one of the biggest employers in region are Veba a.s. textile company in Broumov (>1,700 employees) and Siemens VDO in Adršpach (automotive industry). Agriculture and wood industry are also important in the Broumov region. They are characterized by several hundreds of small companies or individual economic subjects. No heavy or large scale industry is situated in this region (Podnikatelský klub Broumovska, 2017).

Despite Broumov region is close to the state border and it is less populated the road infrastructure is quite dense, but mainly second and third class roads are present. Railway transport is represented by two non-electrified rail tracks.

2. Regional, geological and hydrogeological characteristics

From the geological point of view, the Wałbrzych / Broumov area belongs to the Central Sudety Mts. block and includes several sub-units (Figure 2). About two thirds of its territory is built by transboundary

geological unit - the Intra-Sudetic Basin (or Synclinorium) - filled with sedimentary and volcanic rocks. Along the northern edge of the Wałbrzych / Broumov area there is a small belt of the Kaczawa Mts. metamorphic complex and the Świebodzice Basin in its NE corner. The eastern part of the area is made by a fragment of the Sowie Mts. gneiss complex. The listed geological units are characterized by complicated tectonic structure and by high diversity of the lithostratigraphic rock formations, ranging in age from Lower Paleozoic reported in the basement, metamorphic complexes and Świebodzice Basin to Upper Paleozoic and Mesozoic in the Inta-Sudetic Basin. All the pre-Tertiary rock units of the Wałbrzych / Broumov area are presented on the published transboundary, regional map of the Lausitz – Izera – Karkonosze block (Krentz et al. 2000) and briefly described in the associated explanatory notes (Kozdrój et al. 2001). Late cover of Neogene (Tertiary) and Quaternary sediments is of minor significance and spatial distribution.

A small fragment of the Kaczawa Mts. Metamorphic Complex occurring in the Wałbrzych area is built of the Lower Paleozoic (Cambrian to Silurian) greenstones, greenschists, and locally distributed metamorphic slates and phyllites of sedimentary and volcanic origin.

The Sowie Mts. Gneiss Complex currently recognized as Ordovician (in earlier literature described as Precambrian) is built of monotonous gneisses and migmatites, with subordinate inserts of granulites and calc-silicate rocks. Locally outcrop amphibolites and ultrabasic rocks, which possibly represent little intrusions emplaced in Silurian or Devonian time. Locally the older gneisses and migmatites are covered by the Lower Carboniferous conglomerates or Pleistocene boulder clays.The Świebodzice Basin is built of sedimentary rocks: sandstones, siltstones, conglomerates, occasionally limestones, all of the Upper Devonian to Lower Carboniferous age. Within this geological unit the following lithostratigraphic formations are distinguished: Pogorzała Fm., Pełcznica Fm., Książ Fm. and Chwaliszów Fm.

The Intra-Sudetic Basin is filled with a prominent, up to 6 km thick association (packet) of the Lower Carboniferous to Upper Cretaceous sedimentary and volcanic rocks. The deposits are folded and make a set of synclines and anticlines with NW-SE directed axes. The thickness of the Upper Cretaceous sediments reaches ca. 300 m, the Triassic deposits ca. 100 m, the Permian up to 1,500 m, the Upper Carboniferous up to 2,200 m and the Lower Carboniferous sediments about 3,000 m. The basin sequence can be divided into three main groups. The first group is composed of terrestrial, mostly fluvial formations of Carboniferous (with the exception of marine sediments forming the Upper Visean Szczawno formation), Permian and Triassic age. The second group represent Carboniferous and Permian volcanic formations and the third - and the youngest - Upper Cretaceous marine deposits.

The Carboniferous and Permian deposits are mainly composed of sandstones, conglomerates, siltstones and claystones. Within the Lower Carboniferous continental deposits of 8 lithostratigraphic formations were distinguished. Solely within the Upper Carboniferous formations there are numerous hard coal seams interlayers. Upper Carboniferous and Permian volcanic rocks outcropping in the Intra-Sudetic Basin are mainly rhyolites, trachybasalts and volcanic tuffs. They form synsedimentary, conformable interlayers within host sediments or bigger intrusive bodies making today the prominent heights (Chełmiec and Trójgarb hills).

The Mesozoic rocks of the area are represented by the Lower Triassic (Buntsandstein) sandstones and the Upper Cretaceous (Cenomanian and Turonian) sandstones and marls.

Police basin as a part of the Intra-Sudetic basin and makes dominant geological unit in Czech part of pilot area. This unit is almost entirely separated from the main part of the Bohemian Cretaceous basin by outcrops of stratigraphically older rocks. The basin forms a syncline, elongated in the NW-SE direction, approximately 10 km wide and max. 24 km long (between the northern and southern Czech-Polish frontiers), total area of the Czech part of the basin is approximately 230 km^2. The maximum thickness of Cretaceous deposits reaches 450–500 m. The Cretaceous deposits of the Police basin are sandstones, sandy marlstones and marlstones. The bedrock of the Police basin is formed by Permian and Carboniferous deposits and volcanic rocks and Triassic sandstones, outcropping in the vicinity of the Police basin.

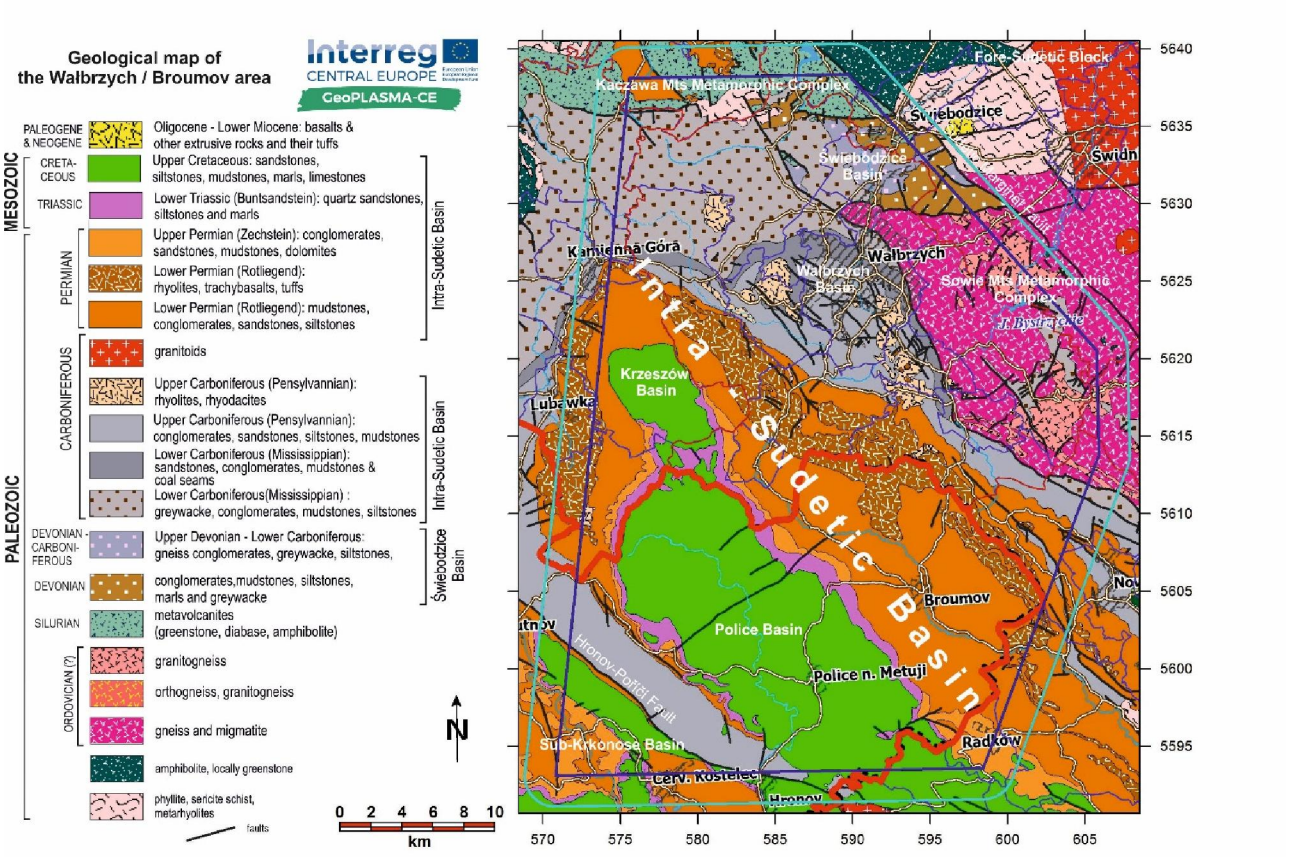

Figure 2. Geological map of the Wałbrzych / Broumov area.

The most south-western corner of the pilot area is located in Sub-Krkonoše basin. The basin is limited on the SW side by Lužice fault and it is separated from Police basin by Hronov-Poříčí fault. The rocks of Sub-Krkonoše basin consists of continental sediments, mainly reddish, brown colored sandstones with interlayers of grey or dark bitumenous siltstones, claystones or carbonate sediments. One, localy two layers of black coal are present in Carboniferous sediments. The overall age of Sub-Krkonoše basin sediments is from Carboniferous throught Permian to Triassic. Basic and intermediate (lavas and melaphyres), rarely acidic (andesites) volcanic rocks are also present present in Sub-Krkonoše basin. All formations of the Intra-Sudetic Basin are locally covered by the Quaternary sediments, which occur mainly along present river valleys.

The geological units of the Wałbrzych – Broumov area are dissected by many faults showing different dipping angles and length. The densest and complicated tectonic pattern of the faults with predominant NW-SE direction is observed in the Intra-Sudetic Basin within ca 5-10 km wide border zone along SW edge of the Sowie Mts. Gneiss Complex. Other main faults (fault zones) tlocated in the Police basin indicate about hundred metres of vertical displacement.

2.1. Hydrogeological characteristics.

The degree of recognition of hydrogeological conditions within the studied terrain is very uneven. The areas which are best recognized are represented by individual groundwater intakes and abandoned coal mining sites. The remaining areas are not sufficiently characterized in terms of hydrogeology. The natural hydrogeological conditions were significantly affected in the sites of coal mining. Dewatering of mines in the area around Wałbrzych, Žacléř, Radvanice Malé and Svatoňovice caused decrease of groundwater

levels up to hundreds of meters. After the end of the mining in recent years there has been a gradual restoration of the former hydrogeological conditions.

In the project area the groundwaters mostly occur in the near-surface layer of strongly weathered and fissured rocks. These groundwaters are recharged directly by precipitation percolating through the ground surface and thereafter drained towards the mountain streams and springs. This aquifer is often exploited for drinking water supply for local purposes with support of a numbers of drainage and infiltration intakes. Other aquifers, related to the sub-Cenozoic sedimentary (fissured-porous) and crystalline (fissured) rocks, are exploited by the single wells and well fields.

In the North nearly no major useful aquifers occur, except for the north-western part where the minor Carboniferous and Quaternary multi-layered aquifer systems are present. In the West, centre and South-East the Permian and Permo-Carboniferous multi-layered aquifer systems constitute the major aquifers. In the West, within the Krzeszów basin, the aquifers associated with the Triassic and Cretaceous sedimentary deposits, overlay the Permian deposits which in turn show rather poor hydrogeological properties. In accordance with binding law, the area is listed as major groundwater reservoir - GZWP 342 named as the "niecka wewnątrzsudecka Krzeszów". The groundwater vulnerability to contamination is very low (Krawczyk at. al 2015). Therefore, the protection area of the basin has not been set, and its waters are under standard protection.

In the South, within the area of the Stołowe Mts., the most important is the Cretaceous multi-layered aquifer system. The eastern part of the project area (Sowie Mts. and part of the Wałbrzych Upland), is the domain of the multi-layered aquifer system built up by the Proterozoic crystalline rocks. Spatial distribution of the aquifers and the multi-layered aquifer systems as well as hydrogeological properties of the particular rock complexes are, to the great extent, determined by geology of the area.

Hydrogeological conditions in the Czech part of the Intra-Sudetic Basin are characterized by interstitial-fissure porosity, the overall decrease in permeability with depth. In the upper part of the basin to depths of several dozen meters dominates fissure porosity. The depth causes a relative decline in the proportion of fracture porosity in favour of intrinsic porosity, probably faster than in other limnic Permo-Carboniferous basins.

As in other Late Palaeozoic basins is significant, relatively fast local groundwater flow that is restricted primarily to the subsurface collector. In deeper parts flow is slow with regional character. The infiltration occurs fairly evenly on the Permo-Carboniferous outcrops of rocks. Groundwater discharge occurs partly by concentrated springs, but mainly by underground drainage to the surface water streams.

The Police basin represents a complex hydrogeology unit of three main extended aquifers with fissure or double porosity, separated by aquitards. The most important is the Basal Aquifer Complex consisting of three more or less connected aquifers: The Chert aquifer (A2), the Sandstone aquifer (A), both of Cretaceous age, and the Triassic sandstone aquifer (T). Two other regionally important aquifers are the Sandstone aquifer of proximal facies of the Jizera Formation (C) and the Aquifer of the Rocky-cities sandstones (D). These aquifers are separated by marlstone (siltstone) aquitards of different thickness. In some areas bodies of transient hydrogeology character occur. Between the main aquifers vertical interlayer leakage occurs through the aquitards. Based on characteristic features of the regional groundwater flow, two main aquifer systems - northern and southern - can be delimited in the Police basin. The boundary between them is the Skály fault. Each of the aquifer systems has its own recharge and discharge zones. From the point of view of water balance both the aquifer systems are almost entirely closed and independent. Within the main aquifer systems relatively independent aquifer subsystems can be delimited.

2.1.1. Legal background

UE Water Framework Directive (2000/60/EC) requires that the individual EU Member States develop and implement the programs of groundwater management and protection in order to achieve and maintain their good status.

In order to sustain quality of groundwater, definition of hydrogeological units and assessment of their condition is addressed in Decree no. 5/2011 Coll. of Ministry of the Environment of the Czech Republic. Law no. 254/2001 Coll. addresses protection of surface water and groundwater and deals with its sustainable management in Czech Republic.

The Polish national Water Law Act in accordance with UE Water Framework Directive creates a basis for documentation and protection of the most valuable resources in the form of the so called major groundwater reservoirs (GZWP in Polish). The aquifers selected for this kind of protection must achieve certain quantitative and quality requirements and as such are crucial for drinking water supply at the national level.

3. Market situation and existing shallow geothermal use

In Poland, at the moment, there is no central institution, which gathers basic, statistical information about the geothermal heat pumps (GHP), including their location, depth of boreholes, 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 and the Polish part of the pilot Wałbrzych area. Nevertheless, for more information and statistical estimations of GHPs market in Poland see similar report made for the Kraków area.

Preliminary information obtained from the Wałbrzych district office indicates that there have been so far installed 35 GHPs, all made in the closed system technology with boreholes heat exchangers. Draft figures show that the GHPs installed so far were mostly constructed for the needs of the single-family houses with individual energy power ranging from from 7 to 17 kW. Only two larger plants are recognized. One with capacity of 52 kW was constructed for the Centre of Sports and Recreation in Dzikowiec near Boguszów – Gorce, and the second set up in Krzeszów nearby Kamienna Góra to heat the selected buildings of the cistersian convent. It can be estimated that a total installed capacity of operating GHPs in the Wałbrzych area are about 525 kW and there are high hopes for the development of the GHPs market in coming years.

The existence and the evolution of the heat pump market in the Czech Republic are monitored by Ministry of Trade with the cooperation of Czech Heat Pump Association (**Chyba! Nenalezen zdroj odkazů.**). The collected data are based on form survey of companies covering >80% of heat pumps sales in the Czech Republic. The rest share (<20 %) of market is determined by expertise estimation of the Czech Heat Pump Association.

Because the statistics does not include territorial aspect, is it unfortunately not possible to determine the number of heat pump installations in Broumov region within the Czech Republic.

Tab. 1. Evolution of the heat pump market in the Czech Republic between years 2010-2015 (Bufka et al., 2017).

	Air/Air	Air/water (recuperation)	GHP (closed loop)	GHP (open loop)	Total
Year	**Number of sold heat pumps in CZE**				
2010	4,199	-	1,707	53	**5,959**
2011	4,908	-	1,951	50	**6,909**

2012	5,325	21	1,825	44	**7,215**
2013	5,747	15	1,694	49	**7,505**
2014	6,247	35	1,532	46	**7,860**
2015	7,193	11	1,479	107	**8,790**

The situation on EU market assesses the latest Heat pumps barometer report issued by EurObserv'ER institute (EUROBSERV'ER; 2016). According this report the market in the Czech Republic consists of 21,494 operated heat pumps with installed capacity of 255,751 kW in 2015.

4. Main challenges and needs for shallow geothermal use

The measurements of air pollution in the Wałbrzych area conducted in the recent years indicate significant exceeding of the normal values. The biggest problem for the Wałbrzych area remains a high level of air pollution caused by the dust suspensions of both PM10 and PM2.5 particulate matter, and benzo(a)pyrene, which are known to be harmful to human health and the environment. The main cause of this situation is burning – for heating purposes - the fossil fuels (incl. low-quality coal, coal muds). The worst conditions are noticed during the winter seasons in the city of Walbrzych and in the municipality of Nowa Ruda. Even in Szczawno Zdrój – a town holding the spa status - the days with pollution higher than the alarm levels are often recorded.

The adopted measurements in the official plans to improve the air quality in the Wałbrzych area firstly recommend to exchange of the old, coal boilers to more advanced units or gas furnaces and increase of the district heating supply network. Additional recommendations contain support for the development of renewable energy sources including geothermal heat pumps. Such solutions for use of the very clean, shallow geothermal energy are shown in action plans made for the Wałbrzych city and several municipalities of the Wałbrzych District: Czarny Bór, Głuszyca, Mieroszów, Szczawno Zdroj and Nowa Ruda.

Polish Geological Institute and the Czech Geological Survey collect many geoscientific data, which are primarily used for activities and projects not concerning the shallow geothermal energy. Both institutions use well established and state-of-the-art methodological instructions for construction geological maps and explanatory notes, however no geothermal map in the pilot area was constructed yet. Moreover, the necessary data are spread across many sources (publications, archive materials) and digital databases, which are often inconsistent. This is the reason the data suitable for evaluation of geothermal potential is planned to be gathered in a dedicated database and transposed accordingly to unified methodology.

In the context presented above, strengthening public awareness about the benefits of GHPs use and delivery of scientific and technical support aimed to enhance their wider applications in the Wałbrzych - Broumov area is the most important challenge of the GeoPLASMA-CE project. As so, the main outputs of the project include elaboration of local strategy intended to present (renewably) energy supply concepts based on sustainable management plans of shallow geothermal use. The strategy will be adjusted to existing local energy-, land use- and environmental strategies and will highlight zones of favorable geothermal utilization.

5. Project objectives

Existing geological and hydrogeological data will be used to elaborate the 3D geological model and shallow geothermal energy potential map for the Wałbrzych / Broumov area showing terrains having advantageous geothermal properties of bedrock for the installation of GHP with closed system. In the Czech part of the

pilot area the use of open system GHPs will also be evaluated. The second type of planned, geo-environmental maps will enable to determine the extent of the areas where the potential conflicts, i.e. difficulty, danger or exclusion – related to the future applications of GHPs may exists. These maps are especially important for the areas of the former hard coal mining in the region of Walbrzych, where even nowadays, cases of illegal coal extraction by the opencast method (coal pits) are reported. Another area of special attention is the area of the water protection designed for the high value Cretaceous aquifer of the Intra – Sudetic basin. The future maps of the GeoPLASMA-CE project associated with the explanatory texts will provide planning tools to develop, in cooperation with the local authorities of the Wałbrzych and Náchod counties, a reginal strategy for the development of renewable energy sources indicating favourable sites for practical use of GHPs, eg. heating and cooling of public buildings. The resulting maps and strategy will be published through a dedicated web portal of the GeoPLASMA-CE project and, if possible - via already existing- e-portals menaged by the local authorities.

With the maps developed during the GeoPLASMA-CE project it will be possible to identify the specific locations with favourable conditions for shallow geothermal use. One will be able to see the values of the heat extraction rate obtained from the 1 m depth of the borehole (given in W/m^{-1}) and values of thermal conductivity ($W/m^{-1}.K^{-1}$), and thereby determining the amount and the depth of wells needed to make GHPs with the required power parameters. The project will thus contribute to greater reliability of the data contained in preparation of future geological projects and documentation elaborated in order to use the “never ending” Earth's heat.

As part of the GeoPLASMA-CE information activities, it is planned to familiarize and convince local authorities and residents of the Wałbrzych - Broumov area with large ecological and economic benefits related to the practical use of geothermal heat pumps.

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