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Potential of existing and newly designed geothermal heating plants in limiting of low emissions in Poland

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Abstract. Geothermal energy as one of renewable energy sources is an alternative to conventional methods of heat production, and thus contributes to reducing the emission of pollutants into the environment, especially the so-called low emission. Poland is facing the problem of pollutant emissions from combustion processes, in the context to individual households using mainly solid fuels to ensure heat demand for central heating and hot water production. The paper presents the results of calculations of avoided emissions in the context of replacement of conventional individual heating for geothermal heating systems, taking into consideration not only the problem of air pollution in Poland, but also issues of fuel quality (calorific value) and efficiency of used heating devices.

1 Introduction

Pollution of the environment, that the modern society is struggling with, is mainly related to the energy sector. The right approach to this issue requires taking into account the problem of occurrence so-called low emission. This concept has no authority in Polish legislation, but it has been precisely formulated in the monograph "Low emission. From the reasons for occurrence to the methods of elimination." [1], where it was indicated that it is emission from emitters with a height not exceeding 40 m, and its main source are the processes of heat production for central heating and hot water production in households [2]. Therefore, it is natural to look for solutions in the modernization of heat sources, including the development of local heating networks using renewable energy sources. The answer to the need to produce heat in a less invasive way for the environment is geothermal energy, which due to the nature of thermal energy conversion accumulated in geothermal waters for usable energy, can be considered not only as an ecological but also a stable source.

2 Low emission problem in Poland

Air quality standards in Poland are permanently exceeded, which is evidenced by data published, among others by the Chief Inspectorate for Environmental Protection in Poland

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(2017), as well as the European Environment Agency (2017). The problem of exceeded standards concerns mainly particulates PM_{10}, $PM_{2.5}$ and benzo(a)pyrene, and to a lesser extent SO_x and NO_x. Figure 1 presents the data on concentration of PM_{10} and $PM_{2.5}$ in 2015 (annual limit value), in combination with number of days in the Polish agglomerations (EEA, 2017; GIOŚ, 2017). Poland is characterized by one of the highest exceedances of permissible PM_{10} standards, locally above 50 μg/m^3. The situation is similar with $PM_{2.5}$, locally exceeding 30 μg/m^3. The data presented in the bar graph, which concern PM_{10} measurements, indicate that by far the worst air quality in Poland is in Krakow, Upper Silesian and Rybnik-Jastrzębie agglomerations. Each agglomeration is characterized by three bars, the first one (dark blue) is responsible for the number of days with exceedances of the permissible level of PM_{10} recorded at the measuring station, on which the highest number of such days occurred. The second one (blue) means the average number of days with exceedances of the permissible level of PM_{10} for all measurement stations in the agglomeration. The third (light blue) applies to the number of days with exceeding the permissible level of PM_{10}, recorded at the measuring station where the least number of such days occurred. In addition, the value in brackets indicates the number of measurement stations from which data was acquired. Despite the clearly exceeded standards in almost all of Poland, it should be noted that the positive exception are Szczecin, Tricity and Białystok agglomerations.

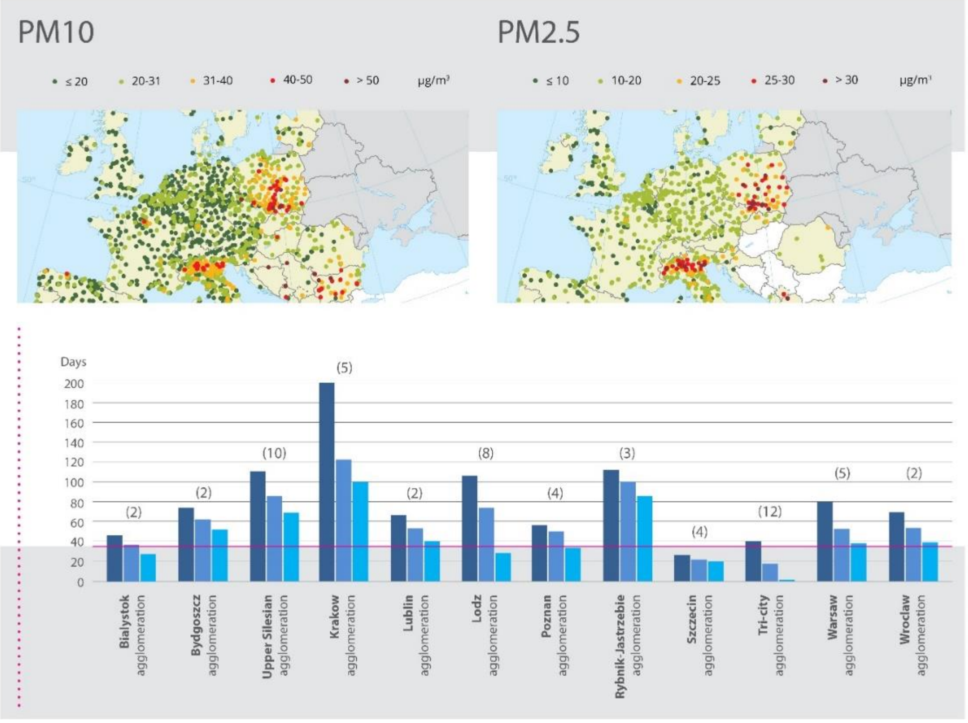

Fig. 1. Concentration of PM_{10} and $PM_{2.5}$ in 2015 – annual limit value, in combination with number of days with exceedances of the 24-hour level admissible for PM10 in 2015 in Polish agglomerations (based on [2, 3]). Dark blue bar – the number of days with exceedances of PM10 recorded at the measuring station, on which the highest number of such days occurred. Blue – the average number of days for all measurement stations in the agglomeration. Light blue – the number of days recorded at the station where the least number of such days occurred. Red line – allowed limit of 35 days in a year with exceedances of PM_{10}.

Low emission problem in Poland is primarily caused by heat production for central heating and domestic hot water in households. Evidence for this is the data presented in figure 2 regarding the percentage share of individual sectors in the emissions of PM_{10}, $PM_{2.5}$ and benzo (a) pyrene. It should be emphasized that for both PM_{10} and $PM_{2.5}$, almost 50% of emissions are covered by the so-called combustion processes outside the industry, 48.5% (PM_{10}) and 49.7% ($PM_{2.5}$) respectively. In the case of benzo(a)pyrene, this value reaches 86%, which taking into account the fact that it is a carcinogen substance, takes on special significance.

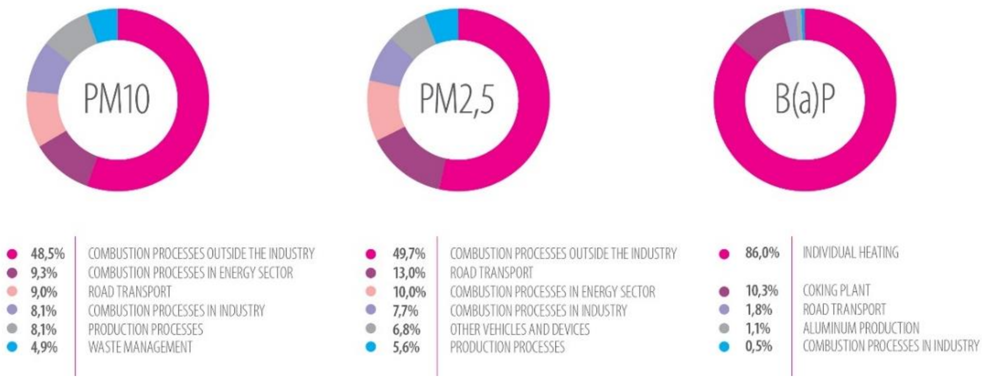

Fig. 2. Sectors responsible for PM_{10}, $PM_{2.5}$ and benzo(a)pyrene emission in Poland (based on [2]).

3 Geothermal district heating in Poland

The present state of recognition of geothermal resources in Poland allows to determine prospective areas for geothermal installations of district heating systems. In Poland, four geothermal provinces are distinguished: Polish Lowlands (about 250,000 km^2 – 80% of the country), Carpathian Province (6.5%), Carpathian Foredeep (6.5%), Sudety Region. They differ in geological conditions, petrophysical and thermal parameters of rocks, which translates into their usefulness for heating purposes. The most prospective regions from the heating point of view are the Polish Lowlands and the Inner Carpathians.

The Polish Lowlands is formed of sedimentary rocks of the Paleozoic and Mesozoic age with a maximum thickness of approx. 8 km. The geothermal gradient in this area is from 2 to over 3°C/100 m, and the heat flux is 35–105 mW/m^2. Temperatures of geothermal waters (20–130°C), mineralization (1–300 g/l) and flow rate (from a few to above 300 m /h) are also differentiated. However it should be remembered that Polish Lowlands includes 250,000 km^2 area. Geothermal waters reservoirs form sandstones, marls and limestones. The most prospective from the point of view of geothermal heating are Lower Cretaceous and Lower Jurassic reservoirs. Particularly good values of parameters such as temperatures and thickness of reservoir deposits were found in the belt of the Szczecin-Mogilno-Łódź basin [4]. Currently, geothermal heat plants in Pyrzyce (6.0 MWt), Stargard Szczeciński (12.6 MWt), Mszczonów (3.7 MWt), Uniejów (3.2 MWt) and Poddębice (10 MWt) operate in the Polish Lowlands [5].

In the case of the Carpathian Province, two areas with a different geological structure are distinguished: Outer Carpathians and Inner Carpathians, which determines large fluctuations in geological, petrophysical and thermal parameters, important from the point of view of district heating. The geothermal gradient for the Carpathian Province is in the range of 2–3.6°C/100 m, and the heat flux is 60–95 mW/m^2. The reservoirs of the outer Carpathian basin are flysch. This tank is characterized by temperatures of 20–60°C, mineralization of

10–120 g/dm^3 and flow rate with maximum values up to several tens of m^3/h. From the point of view of geothermal heating systems, these parameters are not sufficient for the independent use of waters with the given parameters, but it is worth considering the use of these resources in systems with heat pumps. The reservoirs of Inner Carpathians Basin are limestones and dolomites of the Middle Triassic, Jurassic sandstones and carbonate forms of the Middle Eocene. The deep temperature of geothermal waters ranges from 20 to even 127°C (at a depth of about 4800 m, Bańska IG-1 borehole), the total area mineralization does not exceed 3 g/l [6–9], and flow rate reaches a maximum value of 550 m^3/h. The confirmation of these very good conditions is the heating plant PEC Geotermia Podhalańska SA operating successfully since 1994 (40.7 MWt geothermal power, total 82.6 MWt).

Less-perspective areas from the point of view of district heating, although locally possible to develop, are the Sudety Region and Carpathian Foredeep (relatively poorly recognized area). In the Sudety, geothermal reservoirs form highly crystalline rocks, which results from the occurrence of deep fault zones. The heat flux in this area is in the range of 40–70 mW/m^2, the temperature is from about 20 to 86°C (at a depth of about 2000 m), and the mineralization does not exceed 1 g/dm^3. Despite good parameters, this reservoirs are not prospective for district heating applications due to the low flow rate of 10 m^3/h on average [10]

The Carpathian Foredeep deposits are sedimentary rocks of the Oligocene and Miocene age, with a thickness up to 3 km. The heat flux in this area is 60–95 mW/m^2, and the geothermal gradient is in the range of 1.8–4.5°C/100 m. The reservoirs of this area are sandstones, marls and limestones. Geothermal waters are characterized by temperatures from 20 to 100°C (at a depth of about 3 km) and mineralization in the range of 1–100 (locally 150) g/dm^3. The flow rate from geothermal well is several m^3/h [11, 12].

To sum up – geothermal reservoirs of the greatest importance for use in heating purposes occur within the Carpathian Province as well as Lower Cretaceous and Lower Jurassic reservoirs in the Polish Lowlands. Taking into account the extent of the area and parameters, the effective management of the Polish Lowlands resources is of the greatest importance for Poland. Confirmation of this are the heating plants operating in Podhale, Pyrzyce, Mszczonow, Uniejów, Stargard Szczeciński and in Poddębice. The total installed capacity from geothermal energy in these plants is 76.20 MWt [5] (tab 1).

Table 1. Geothermal district heating plants in Poland [5].

Locality	Max. flow rate [m^3/h]	Max. geothermal water temp. [°C]	Capacity [MWt]	Energy [TJ]
			Total/geothermal	
Bańska Niżna	670.00	86.00	82.60/40.70	462.92/418.98
Pyrzyce	34000	61.00	22.00/6.00	66.54/41.92
Stargard	100.10	78.00	12.60/12.60	213.61/213.61
Mszczonów	60.00	42.50	8.30/3.70	15.69/5.99
Uniejów	120.00	68.00	7.40/3.20	6.80/5.44
Poddębice	115.9	71.00	10.00/10.00	51.98/51.98
Total	1190.00	-	142.90/76.20	817.54/737.92

Table 2 presents the potential locations for geothermal heat plants in Poland, which can be considered as the most prospective, taking into account the reservoir parameters (geothermal water temperature, flow rates) and access to the so-called consumers. However, it should be emphasized that this list does not cover the whole potential of geothermal energy in Poland in the context of heating.

Table 2. Potential locality and parameters for geothermal district heating plants in Poland [13].

Locality	Max. flow rate [m^3/h]	Geothermal water temp. in the aquifer [°C]	Capacity [MWt]	Production [TJ]
			Total/geothermal	
Chociwiel	275	90	2.57/2.56	23.58/23.55
Cieplice	45	95	3.15/1.31	18.38/17.67
Koło	200	120	45.30/16.97	369.92/305.18
Konin	150	100	8.73/5.49	77.40/77.06
Łowicz	50	107	6.27/2.51	47.78/45.55
Ślesin	150	100	3.49/3.46	41.76/41.42
Turek	150	100	7.62/5.17	62.09/61.84
Żnin	250	100	17.26/10.03	141.27/140.74
Total	1270.00	-	94.39/47.05	782.18/713.01

4 Impact of geothermal heating plants low emission reduction

The specificity of geothermal heat plant's operation means that it does not emit pollutants into the air, or does it in a negligible way. To be precise, it should be clarified that auxiliary equipment used in the construction of a geothermal heating plant, e.g. circulation pumps, security devices or production and heat distribution control centers, consume electricity. However, it is obvious that in the geothermal heat plant's workplace we are not dealing with low emissions only, but also with air pollution taken in general.

The results presented in the paper refer to the comparison of the amount of thermal energy sold by existing geothermal heat plants and the amount of thermal energy possible to be produced in prospective locations, with the emission of combustion products for individual households. Unlike others, the environmental effect was not calculated in relation to the local conventional heating plant, but it was deliberately focused on the source of low emissions, and thus households. In order to calculate the emission of pollutants, the methodology was used in accordance with the guidelines of the National Center for Emissions Management (KOBIZE), on emission factors for fuel combustion in boilers with a nominal thermal capacity of 5 MW [14]. The methodology was supplemented with the efficiency of boilers, the minimum and maximum heating values, as well as the sulfur and dust content in particular types of fuels (presented in Tables 3–6). Calculations were made according to the equations:

$$B = \frac{Q \cdot A}{\eta \cdot W_O} \tag{1}$$

where:
B – amount of fuel [m^3] or [Mg],
Q – amount of produced energy [MJ/m^2·year], assumed 1 MJ/m^2·year
A – heated area [m^2], assumed 1 m^2,
η – boiler efficiency [-],
W_O – calorific value of fuel, [MJ/m^3] or [MJ/Mg].

$$E = B \cdot W \tag{2}$$

where:
E – emission of pollutants [g/MJ],
B – amount of fuel, [m^3] or [Mg],
W – emission factor [g/Mg].

The results obtained for particular groups of devices (biomass boilers, coal and coke boilers, oil boilers and gas boilers) per 1 MJ of heat are presented in Tables 3–6.

Table 3. Pollutants emission for biomass boilers < 1 MW.

Type of fuel	η [%]	Wo [MJ/m³]	B [m³]	SO_x	NO_x	CO	CO_2	TSP
				[g/MJ]				
Pellet	88	17.00	0.07	7	67	1738	80214	24
	88	21.00	0.05	6	54	1406	64935	19
Dry wood	80	16.00	0.08	9	78	2031	93750	445
	80	19.00	0.07	7	66	1710	78947	375
Straw briquette	88	17.10	0.07	7	66	1727	79745	140
	88	16.90	0.07	7	67	1748	80689	141
Wood briquette	88	20.40	0.06	6	55	1448	66845	117
	80	16.10	0.08	8	77	2019	93168	576
Rape straw	80	15.00	0.08	9	83	2167	100000	888
Corn straw	80	16.80	0.07	8	74	1935	89286	473

Table 4. Pollutants emission for hard coal and coke boilers < 0.5 MW.

Type of fuel	η [%]	Wo [MJ/m³]	B [T]	SO_x	NO_x	CO	CO_2	TSP	B(a)P
				[g/MJ]					
Ekogroszek	75	24.00	0.06	489	122	2500	102777	361	0.0008
	75	28.00	0.05	419	105	2143	88095	309	0.0007
Nut-type coal	75	24.00	0.06	391	122	2500	10277	278	0.0008
	75	28.00	0.05	305	105	2143	88095	238	0.0007
Culm	75	18.00	0.07	593	163	3333	137037	1481	0.0010
	75	26.00	0.05	410	113	2308	94871	1025	0.0007
Coke	75	27.00	0.05	316	25	1235	116543	395	0.0000

Table 5. Pollutants emission for heating oil boilers < 0.5 MW.

Type of fuel/boiler		η [%]	Wo [MJ/m³]	B[m³]	SO_x	NO_x	CO	CO_2	TSP
					[g/MJ]				
Light oil	Condensing boiler	99	36.12	0.03	56	67	19	90426	11
	Traditional boiler	88	36.12	0.03	64	75	21	101729	13
Heavy oil	Condensing boiler	99	39.70	0.03	551	226	40	84810	57
	Traditional boiler	88	39.70	0.03	620	254	45	95411	64

Table 6. Pollutants emission generation for natural gas GZ50 boilers < 0.5 MW.

Type of boiler	η [%]	Wo [MJ/m³]	B [m³]	SO_x	NO_x	CO	CO_2	TSP
				[g/MJ]				
Condensing boiler	104	34.43	0.03	0	0.04	0.01	55	0
Traditional boiler	85	34.43	0.03	0	0.05	0.01	68	0.000017
Old type boiler	70	34.43	0.04	0	0.06	0.01	82	0.000021

Based on the above data, average emissions of individual pollutants were calculated for basic groups: biomass boilers, coal and coke boilers, oil fuel boilers, gas boilers. The obtained values have been referred to the total production of thermal energy in existing geothermal heat plants and for prospective locations (where geothermal district heating systems may be developed in the near future). The results are presented in table 7.

Table 7. Reduction in emissions of pollutants into the air for existing ones and prospective geothermal heat plants in Poland.

Pollutant	**Unit emission [g/MJ]**	**Existing plants total energy [TJ/rok]**	**Prospective plants total energy [TJ/rok]**	**Total**
		737.92	713.01	
Biomas				
		Emmision reduction [T]	Emmision reduction [T]	Emmision reduction [T]
SO_x	8	5 601	5 412	11 013
NO_x	69	50 887	49 169	100 056
CO	1 793	1 323 157	1 278 491	2 601 648
CO_2	82 758	61 068 636	59 007 139	120 075 775
TSP	320	236 045	228 078	464 123
Coal and coke				
SO_x	418	308 104	297 703	605 807
NO_x	108	79 533	76 848	156 381
CO	2 309	1 703 680	1 646 169	3 349 849
CO_2	104 314	76 975 394	74 376 932	151 352 327
TSP	584	431 019	416 469	847 488
B(a)P	0.0007	0.5	0.5	1
Oil				
SO_x	323	238 429	230 381	468 810
NO_x	156	114 916	111 037	225 953
CO	31	23 001	22 225	45 225
CO_2	93 094	68 696 087	66 377 110	135 073 197
TSP	36	26 632	25 733	52 364
Gas				
SO_x	0	0	0	0
NO_x	0.0525	0	0	0
CO	0.0104	39	37	76
CO_2	69.06	8	7	15
TSP	0.000013	50 961	49 240	100 201

5 Summary and conclusions

The results of calculations presented in the article clearly indicate a very large impact of geothermal heat plants in the context of reducing low emissions. In the case of replacing biomass boilers, the emission limit is over 11 000 SO_x tons, 100 000 tons of NO_x, 2.5 million tons of CO, 120 million tons of CO_2 and 464 000 tons of TSP. In the case of hard coal boilers and coke, these indicators look as follows: over 605 000 SO_x of tons, 156 000 tons of NO_x, 3.3 million tons of CO, 151 million tons of CO_2, 847 000 tons of TSP and 1.02 tons of benzo(a)pyrene. In the case of oil-fired boilers, the limit is: 468 000 tons of SO_x, 225 000 tons of NO_x, 45.000 tons of CO, 135 million tons of CO_2 and 52.000 TSP ton. Most preferably, the presented results are obtained for gas boilers, which is not surprising considering the chemical composition of the fuel: 76 tons of NO_x, 15 tons of CO, 100 000 tons of CO_2 and 0.02 tons of TSP. In the case of this fuel, the SO_x emission is negligible.

Regardless of which structure of heat production we adopt in a given commune or village, the ecological effect for investments in a geothermal heating plant will be beneficial. Hence, also this solution should be seen as a chance to reduce low-emission air pollution in Poland.

However, we should remember that the implementation of geothermal heat plant investment affects the natural environment more widely than it is considered in this article, as drilling works or power supply. However, this does not change the fact that among renewable energy sources, geothermal energy has the potential to act for environmental protection and, in a broader context, for the diversification of energy production sources.

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