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Environmental Evaluation of Geothermal Heating Plant in Poland

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ABSTRACT

Sustainable development, environment, social and governance management, and digital transformation using artificial intelligence are areas with an increasingly strong impact on modern society. Behind them is the need for optimisation, including energy processes. Greater efficiency is understood not only through the prism of using energy resources but also, and perhaps above all, by reducing the negative impact that energy conversion processes have on the natural environment. Geothermal energy is a natural response to the need to use renewable, ecological and energy-stable resources. The complementarity of these three aspects is desirable and should be possible to measure and express numerically to assess the investment and achieve the desired social effects properly. The example of geothermal heating plants in Poland, in terms of their impact on the natural environment, is a quantification of benefits in the form of reduced emissions of pollutants into the natural environment. Energy generation was analysed in all geothermal heating plants in Poland, and calculations were made of the avoided emissions of conventional fuel combustion products, the equivalent of which would have to be used if the investment in geothermal heating plants were not implemented. The results were presented in the context of PM10 and PM2.5 particulate matter, SO_x sulphur oxides, NO_x nitrogen oxides, CO carbon monoxide and CO_2 carbon dioxide. Calculations of $ZrSO_x$ equivalent emissions were also performed, thus formulating a comprehensive conclusion regarding the impact of geothermal energy use on the natural environment at the local level.

1. INTRODUCTION

Geothermal energy is an increasingly important element of the global energy system, playing a key role in the transition to a low-emission economy and reducing greenhouse gas emissions. These changes are occurring locally in the first step, which results from the nature of renewable energy sources, including geothermal energy, as an energy source with the potential to decentralise energy systems, both in the context of electricity production and the production of heat (Bayer et al., 2013; Rahman, 2022). However, each energy technology, including geothermal energy, may be associated with environmental costs and pose specific threats, regardless of whether it is based on conventional or renewable energy sources, which should be remembered (Sakellariou, 2018; Kaczmarczyk et al., 2024).

Impact categories commonly used in environmental impact assessments include various factors such as climate change, ozone depletion, photooxidation, acidification, eutrophication, human toxicity and ecotoxicity (Kaczmarczyk et al., 2024). These categories can be classified as global, regional and local. The research presented in this article is focused quite precisely and refers firstly to the local scale, and secondly to the emission of pollutants into the air. The reason for such a focus of research is that air pollution still significantly impacts the health of the human population, especially in urban areas. It is one of the greatest environmental threats to human health on a global scale (Lelieveld et al., 2015; Cohen et al., 2017; Landrigan et al., 2018; Manisalidis et al., 2020; Gruszecka-Kosowska et al., 2021; Kaczmarczyk and Sowiżdżał, 2024). At the same time, these are areas that have the potential to implement centralised heating systems based on the use of geothermal resources, which results directly from the existence of a heat recipient market, provided, of course, that this fact is correlated with the identification technical and economic possibility of using geothermal resources for energy purposes. The method of providing households with heat is, in this sense, utilitarian and also applies to the example of geothermal heating systems in Poland considered in this article.

Using geothermal energy and water in Poland primarily focuses on district heating systems, balneotherapy, and recreation. As of 2022, Poland had seven operational geothermal district heating systems, located in Podhale, Mszczonów, Pyrzyce, Uniejów, Stargard, Poddębice and Toruń. By the end of 2022, these systems' total installed thermal capacity was approximately 129 MW, with geothermal heat production reaching about 1,122 TJ. The share of geothermal heat in the total production and sale of heat in these systems varied between 30% and 100% (Kępińska and Hajto, 2023). The share of geothermal energy in Poland's final energy consumption – within the renewable energy mix and overall energy usage – remains below 1%. However, the sector's growth, particularly in shallow geothermal systems, signals increasing integration into Poland's energy landscape.

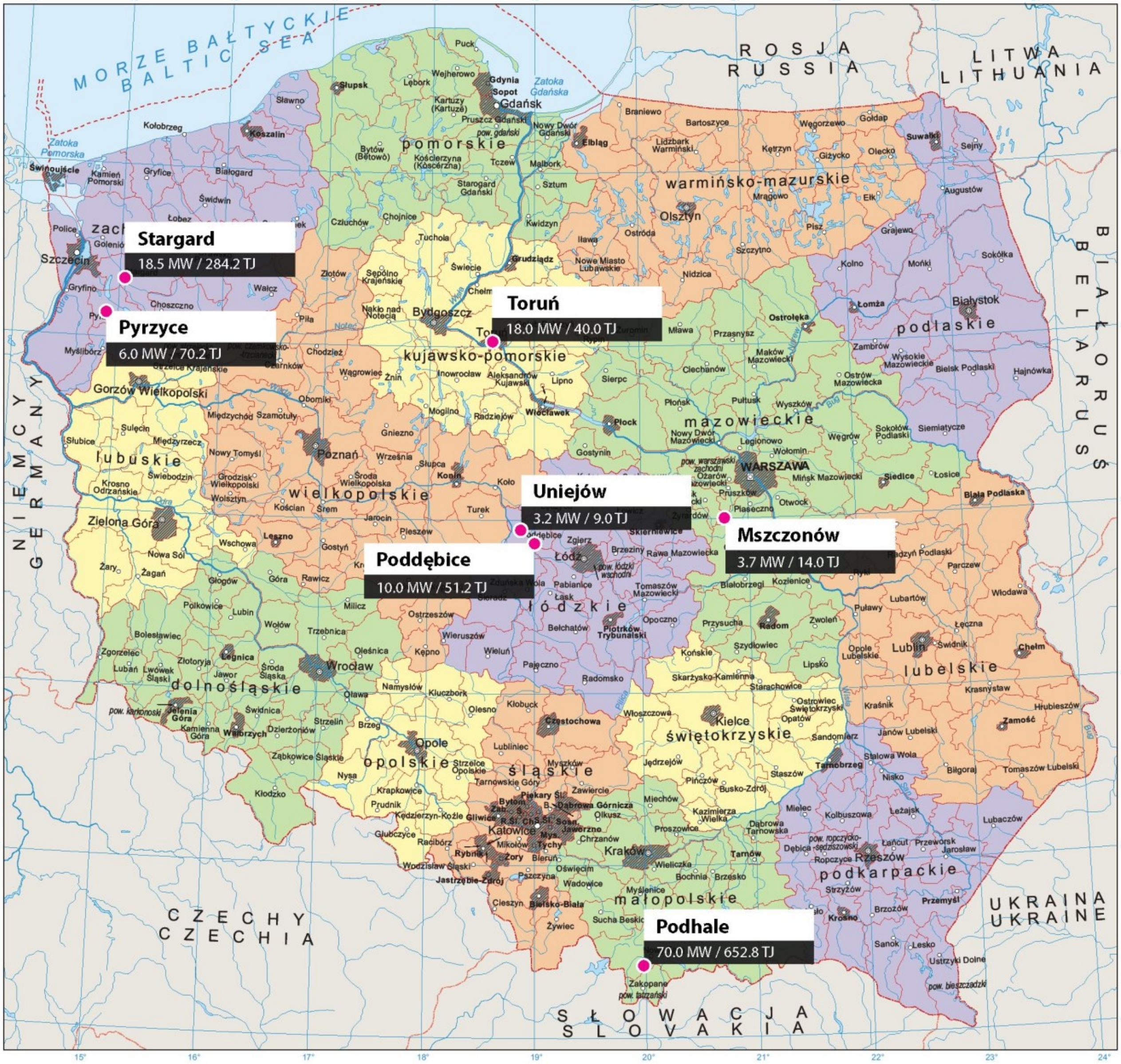

Figure 1: Localisation of a geothermal heating plant in Poland with the value of installed capacity and energy produced (administrative map of Poland: www.gov.pl; installed capacity and energy produced based on Kępińska and Hajto, 2023).

At the same time, it is evident that there is a strong correlation between air quality and energy resources used in the heat production processes for central heating and hot water preparation. A key issue for many economies worldwide is increasing energy efficiency and reducing emissions (Ju et al., 2016; Höltl et al., 2017; Liu et al., 2019). Increasing the use of decentralised renewable energy sources, especially at the local level, is an important factor in improving air quality (Xing et al., 2019; Kaczmarczyk et al., 2020; Thunis et al., 2021, Kaczmarczyk, 2024).

It should be noted that in light of the research conducted so far on the impact of geothermal energy on the natural environment, there is a need for a comprehensive understanding of the extraction and use of geothermal resources in the life cycle (Kaczmarczyk et al., 2024). This enables a holistic assessment of the impact of geothermal energy on the environment, society and economy (Pehnt, 2006). Accurate environmental impact assessments conducted before operations can help identify and mitigate potential negative effects. The use of low-emission technologies helps to reduce pollutant emissions during the operation of energy installations, as discussed in this article, but, e.g. routine monitoring of water quality, gas emissions, seismic activity and risk management enables a quick response to potential problems not directly related to heating, but to the specificity of the energy source used. In this context, in-depth knowledge of the impact of geothermal energy on the environment is crucial to understanding its potential in creating sustainable energy production systems.

Geothermal energy offers several advantages, including the mentioned minimal greenhouse gas emissions, which contribute to reducing environmental impact and carbon dioxide emissions. In addition, it provides independence from external factors by using the Earth's natural heat resources, making it less susceptible to fluctuations in raw material prices or international political tensions and providing greater energy security. In addition, geothermal energy is known for its constant availability, regardless of weather conditions, ensuring stable energy production.

In the context of future research, it is worth paying attention to conducting a life cycle analysis and water footprint for the geothermal sector, which will be crucial for a comprehensive understanding and assessment of all aspects of geothermal energy production, from resource extraction to use. This assessment can confirm the low impact of geothermal energy on the environment and consider other factors, such as water consumption, gas emissions and the impact on local communities. By conducting a life cycle analysis, better insight into the overall impact of geothermal energy on the environment and society can be made, facilitating more objective decision-making regarding its development (Kaczmarczyk, 2019; Kaczmarczyk et al., 2024). Geothermal energy also has limitations, including its availability mainly in specific geographical areas, which reduces its potential use in some regions. On the other hand, the high initial costs of building geothermal installations can be a barrier to entry for some entities. However, the development of geothermal technologies creates opportunities for the expansion of the sector, and technological progress can potentially reduce the costs and increase the efficiency of extracting and using geothermal energy, which can be carefully analysed in terms of the life cycle and water footprint. Government initiatives and policies promoting the development of renewable energy sources while taking into account LCA analysis can create a favourable environment for the geothermal sector. Moreover, the growing interest in environmental protection and reduction of greenhouse gas emissions can drive the demand for geothermal energy as a clean energy source, which was one of the goals of the research presented in the article.

2. METHODOLOGY

The starting point for the analysis was data on thermal energy production in existing geothermal heating plants in Poland. For this purpose, data collected and published by Kępińska and Hajto (2023) were used. In the next steps, available methodologies for calculating ecological effects, including omitted and equivalent emissions commonly used in Poland, were analysed. Energy generation was analysed in all geothermal heating plants in Poland, and calculations were made of the avoided emissions of conventional fuel combustion products, the equivalent of which would have to be used if the investment in geothermal heating plants were not implemented. The results were presented in the context of TSP, PM10 and PM2.5 particulate matter, SO_x sulphur oxides, NO_x nitrogen oxides, CO carbon monoxide and CO_2 carbon dioxide. Calculations of $ZrSO_x$ equivalent emissions were also performed, thus formulating a comprehensive conclusion regarding the impact of geothermal energy use on the natural environment at the local level. The results were compared to hard coal, the dominant fuel used in households to produce heat for heating and domestic hot water, which is confirmed by the data of the Central Statistical Office (GUS, 2024). The latest available data on energy consumption and energy carriers in households in Poland indicate that the share of hard coal in 2021 was 20.1%, second only to district heating (54.5%). The indicator for brown coal was 0.4% and for coke, 0.1%. This information is supplemented by using piece wood at 18.9% and other types of biomass at 3%. So, further analyses focused on comparing the results only to conventional fuels. The structure of energy consumption in households in Poland and the directions of use supplement this information. It shows that energy was used primarily for space heating (65.1%), followed by the preparation of hot water (17%), food preparation (8.5%), lighting and other electrical devices (9%) (GUS, 2024).

It is worth noting that the method of calculating ecological effects has evolved in Poland over the last decade. In 2015, emission indicators of pollutants based on methodology allowed for adopting sulphur and dust content values in the fuel in the calculations, which significantly differentiated the results, were still in force (KOBIZE, 2015). The amount of emissions was also calculated in relation to emission indicators expressed in g/Mg for solid and liquid fuels, except propane and propane-butane liquid gases expressed in g/GJ and natural gas expressed in g/m^3. In the methodology from 2021, the emission is related to the unit g/GJ for each fuel group.

The methodology for calculating the omitted emissions for individual pollutants was simplified based on the KOBIZE methodology (2023a) for boilers with a capacity not exceeding 5 MW (Table 1). In the first step, the amount of heat energy produced was multiplied by the average emission factor, which was determined for a specific group of piles and devices as a representative set.

Table 1: Average emission factors for various types of fuels (based on KOBZIE, 2023a).

	TSP	PM10	PM2.5	B(a)P	SO_x	NO_x	CO	CO_2	Unit
Solid fuels – hard coal	155.67	138.83	108.33	0.08764	473	185	2,113	96,434	[g/GJ]
Solid fuels – anthracite, coke/semi-coke from hard/ brown coal	39.60	35.60	28.60	0.04297	402	148	2,183	102,957	[g/GJ]

Calculations for the first variant were performed according to the formula:

$$\text{Emission [kg]} = \text{Amount of energy produced [TJ]} * \text{Emission factor [g/GJ]} \qquad (1)$$

In the second step, the calculations were made considering the energy efficiency of heating devices and averaged calorific values concerning analogous fuel groups, as in the first step. Therefore, two additional criteria were implemented, linking the unit amount of fuel per unit of generated heat energy and the calorific value, which finally allowed for the inclusion of the amount of energy contained in the fuel, but with the aforementioned consideration of efficiency (Table 2). The efficiency of heating devices, in particular, deserves attention because the KOBIZE methodology (2023a) does not explain how it differentiates emission indicators and whether it does so at all or whether groups of devices differ in indicators not due to energy efficiency but rather the emission resulting from technical solutions for conducting the combustion process of conventional fuels, which results from technological progress and grouping devices by production date. Referring to the fuel quantity indicator based on calorific value and efficiency, it was decided to make such a comparison to simulate the equivalent of the same amount of energy produced in a geothermal heating plant in individual heat sources. Of course, it should be noted that constructing geothermal heating plants does not eliminate one fuel type. However, the presented studies did not analyse the region's energy mix, and the results, as explained above, were related to the dominant conventional fuel used in Poland, hard coal. The values were unified to the starting point of the fuel calorific value, which was assumed to be 10 MJ/kg or 10 MJ/m^3. This is a continuation of the research method proposed by Kaczmarczyk and Sowiżdżał (2024), as well as an extension of earlier studies conducted by Kaczmarczyk (2018) and Kaczmarczyk et al. (2020), but taking into account the new KOBIZE methodology (2023a) and current emission indicators.

Table 2: Type of fuels, nominal efficiency and calorific value used in calculations (based on Kaczmarczyk, 2018 – updated).

Type of fuel		Assumed efficiency [-]	Assumed calorific value [MJ/unit]
Hard coal	anthracite	0.75	26.70
	coking coal	0.75	28.20
	energy hard coal	0.75	25.80
	sub-bituminous coal	0.75	21.00
	coal briquettes	0.75	20.70
Solid fuels	coke and semi-coke	0.75	28.20
	peat	0.75	9.76

Calculations for the second variant were performed according to the formula:

$$\text{Emission [kg]} = \text{Energy [MJ]} * \text{Emission factor [g/GJ]} * 10\ \text{[MJ/unit]} / \text{calorific value [MJ/unit]} * \text{efficiency [-]} \quad (2)$$

In the third step, CO$_2$ emissions were calculated exclusively for heating systems based on conventional fuel use by KOBIZE indicators (2023b) (Table 3). This supplemented the idea of replacing individual heat sources with an aspect resulting from the modernisation of conventional heating plants towards the use of geothermal resources.

Table 3: CO$_2$ emission indicators for professional and industrial energy (based on KOBIZE, 2023b).

Power plants and combined heat and power plants		Industrial CHP plants	Heating plants	
Hard coal	**Lignite**	**Hard coal**	**Hard coal**	**Lignite**
93.55 [kg/GJ]	110.72 [kg/GJ]	94.16 [kg/GJ]	94.83 [kg/GJ]	110.21 [kg/GJ]

Calculations for the first variant were performed according to the formula:

$$\text{Emission [kg]} = \text{Amount of energy produced [TJ]} * CO_2\ \text{emission factor [kg/GJ]} * 1000\ \text{[-]} \quad (3)$$

Additionally, for calculation results from steps 1 and 2, the ZrSO$_x$ equivalent emission was calculated. This indicator was introduced due to its utility in the context of the summary assessment of many energy entities using one parameter. For this purpose, the methodology proposed by Kaczmarczyk (2024) was used in the context of determining the emission equivalent for energy processes in the construction sector and previously used in determining the impact of geothermal heating plants on the natural environment in terms of concentrations of pollutants in the air, by Hajto and Kaczmarczyk (2022).

$$Z_{rSOx} = Z_{SOx} + Z_{NOx} \times e_{SOx}/e_{NOx} + Z_{B(a)P} \times e_{SOx}/e_{B(a)p} + Z_{PM10} \times e_{SOx}/e_{PM10} + Z_{PM2.5} \times e_{SOx}/e_{PM2.5} \qquad (4)$$

where Z_{rSOx} – equivalent emission per SO$_x$; Z_i – emission of i-th pollutant, where " i " denotes SO$_x$, NO$_x$, B(a)P, PM10, PM2.5; e_{SOx}/ei – toxicity coefficient of the i-th pollutant with respect per SO$_x$, where „i" means NO$_x$ (assumed value 0.8), B(a)P (20,000), PM10 (0.5), PM2,5 (0.8).

When analysing the obtained results, it should be noted that although the starting point is the amount of heat energy produced in geothermal heating plants in specific locations, they do not refer to a specific energy mix in the places where they operate. Without a doubt, such modelling, supplemented with a technical and energy inventory, can be indicated as a further research direction. Similarly, this type of research is supplemented with an analysis of data on the concentration of pollutants of individual substances in the air based on measurement data from air quality monitoring stations.

3. RESULTS

The obtained calculation results are presented as the avoided emission indicator of ZrSO$_x$ equivalent, presented in Table 4. The values of avoided emissions are also presented regarding the dominant fuel in Polish centralised heating – hard coal (Table 5). The results are presented as a range of minimum and maximum values obtained in the calculation process, the method of which is presented in the methodology.

Table 4: Results of avoided ZrSO$_x$ equivalent emissions [kg/year].

	Mszczonów	**Poddębice**	**Podhale**	**Pyrzyce**	**Stargard**	**Uniejów**	**Toruń**
Solid fuels – hard coal	19,129 – 23,181	69,959 – 84,774	891,975 – 1,080,874	95,920 – 116,234	388,326 – 470,564	12,297 – 14,902	54,655 – 66,230
Solid fuels – anthracite, coke/semi-coke from hard/ brown coal	18,280 – 18,779	66,853 – 68,676	852,372 – 875,623	91,661 – 94,162	371,085 – 381,207	11,751 – 12,072	52,229 – 53,653

The presented data summarise the ranges of avoided equivalent emissions of ZrSO$_x$, classified by fuel type and location, offering insights into the environmental benefits of transitioning to cleaner energy sources. The analysis highlights significant regional variability influenced by the availability and utilisation of different fuel types. Podhale consistently stands out as a leader in emission reductions, which results directly from the most immense amount of energy generated using geothermal waters.

Solid fuels, particularly hard coal and anthracite, show substantial emission reduction potential. Hard coal delivers the highest avoided emissions, with Podhale reaching an impressive 891,975–1,080,874 kg/year of ZrSO$_x$ and Pyrzyce achieving 388,326–470,564 kg/year of ZrSO$_x$. In comparison, anthracite and coke provide slightly lower reductions, with Podhale again leading at 852,372–875,623 kg/year of ZrSO$_x$. In contrast, Toruń generally reports the lowest avoided emissions, reflecting a smaller energy consumption profile in fuel use. Of course, one should be aware of the direct dependence of the result determined directly by the amount of energy produced from geothermal energy. The comparison between coal types suggests that while both are impactful in terms of emissions, the slight differences reflect variations in combustion efficiency and carbon content.

In summary, the results emphasise the considerable environmental benefits of transitioning to cleaner energy sources, with solid biomass and hard coal replacements offering the most significant potential for reducing emissions. Another issue is the assessment of the air quality in the region, which in the future should become a supplement to this type of research, in order to complement the assessment of the impact of geothermal heating plants on improving air quality.

Table 5: Results of avoided emissions compared to conventional solid fuels [kg/year].

	TSP	PM10	PM2.5	B(a)P	SO$_x$	NO$_x$	CO	CO$_2$
Mszczonów								
Hard coal	1,177 – 2,179	1,050 – 1,944	819 – 1,517	1	3,578 – 6,624	1,395 – 2,583	15,976 – 29,577	729,227 – 1,350,069
Anthracite, coke, semi-coke	510 – 554	458 – 498	368 – 400	1	5,170 – 5,622	1,905 – 2,072	28,101 – 30,562	1,325,320 – 1,542,940
Poddębice								
Hard coal	4,305 – 7,970	3,839 – 7,108	2,996 – 5,547	2 – 4	13,086 – 24,226	5,102 – 9,446	58,426 – 108,169	2,666,886 – 4,937,395
Anthracite, coke, semi-coke	1,864 – 2,028	1,676 – 1,823	1,346 – 1,464	2	18,906 – 20,562	6,967 – 7,578	102,768 – 111,770	4,846,885 – 5,642,752
Podhale								
Hard coal	54,889 – 101,619	48,953 – 90,630	38,199 – 70,720	31 – 57	166,840 – 308,883	65,055 – 120,442	744,934 – 1,379,149	34,002,791 – 62,951,789
Anthracite, coke, semi-coke	23,769 – 25,851	21,368 – 23,240	17,167 – 18,670	26 – 28	241,052 – 262,164	88,834 – 96,614	1,310,297 – 1,425,062	61,797,782 – 71,945,088
Pyrzyce								
Hard coal	5,903 – 10,928	5,264 – 9,746	4,108 – 7,605	3 – 6	17,941 – 33,216	6,996 – 12,952	80,108 – 148,309	3,656,550 – 6,769,632
Anthracite, coke, semi-coke	2,556 – 2,780	2,298 – 2,499	1,846 – 2,008	3	25,922 – 28,192	9,553 – 10,390	140,905 – 153,247	6,645,534 – 7,736,742
Stargard								
Hard coal	23,896 – 44,240	21,312 – 39,456	16,630 – 30,788	13 – 25	72,635 – 134,474	28,322 – 52,435	324,311 – 600,420	14,803,298 – 27,406,401
Anthracite, coke, semi-coke	10,348 – 11,254	9,303 – 10,118	7,474 – 8,128	11 – 12	104,943 – 114,135	38,674 – 42,062	570,445 – 620,409	26,903,998 – 31,321,682
Uniejów								
Hard coal	757 – 1,401	675 – 1,250	527 – 975	0 – 1	2,300 – 4,259	897 – 1,661	10,270 – 19,014	468,788 – 867,902
Anthracite, coke, semi-coke	328 – 356	295 – 320	237 – 257	0	3,323 – 3,614	1,225 – 1,332	18,065 – 19,647	851,991 – 991,890
Toruń								
Hard coal	3,363 – 6,227	3,000 – 5,553	2,341 – 4,333	0 – 1	10,223 – 18,927	3,986 – 7,380	45,645 – 84,507	2,083,504 – 3,857,340
Anthracite, coke, semi-coke	1,456 – 1,584	1,309 – 1,424	1,052 – 1,144	0 – 1	14,770 – 16,064	5,443 – 5,920	80,288 – 87,320	3,786,629 – 4,408,400

The presented data provide detailed insights into the ranges of avoided emissions of various pollutants when transitioning from conventional solid fuels, such as hard coal, anthracite, coke, and semi-coke, to alternative energy sources. The pollutants analysed include Total Suspended Particles (TSP), particulate matter (PM10, PM2.5), benzo(a)pyrene (B(a)PB), sulphur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), and carbon dioxide (CO_2). The results illustrate substantial regional variability and differences between fuel types, highlighting the significant environmental benefits of fuel substitution.

Among the pollutants, particulate matter emissions (TSP, PM10, PM2.5) show the highest avoided values, particularly for hard coal. In Podhale, emissions reductions reach 54,889–101,619 kg/year for TSP, 48,953–90,630 kg/year for PM10, and 38,199–70,720 kg/year for PM2.5. These values reflect the high particulate output associated with coal combustion. Anthracite, coke, and semi-coke produce lower avoided emissions, with Podhale achieving reductions of 23,769–25,851 kg/year for TSP and proportionally lower reductions for PM10 and PM2.5. These data highlight the relative cleanliness of these fuels compared to hard coal.

B(a)P reductions are less significant in absolute terms but still meaningful. Hard coal replacements in Podhale lead to avoided emissions of 31–57 kg/year, with smaller savings observed for anthracite and coke. The limited scale of these reductions reflects the lower concentration of B(a)P in coal combustion byproducts compared to particulate matter. Nevertheless, B(a)P is a highly toxic pollutant, making even small reductions critical for improving air quality.

Sulphur oxides (SO_x) exhibit significant avoided emissions, particularly when transitioning to anthracite and coke. In Podhale, SO_x reductions range from 241,052–262,164 kg/year, while Pyrzyce achieves 25,922–28,192 kg/year reductions. These substantial differences underscore hard coal's higher sulphur content than cleaner alternatives. Similarly, nitrogen oxide (NO_x) emissions are considerably reduced, with Podhale achieving avoided emissions of 65,055–120,442 kg/year for hard coal. Anthracite and coke also yield notable reductions, though at a lower magnitude.

Carbon monoxide (CO) savings are particularly pronounced in regions with high historical reliance on hard coal. Podhale achieves reductions of 744,934–1,379,149 kg/year, while Pyrzyce reaches 80,108–148,309 kg/year. For anthracite and coke, CO reductions are lower but remain significant, reflecting the cleaner combustion characteristics of these fuels. In contrast, carbon dioxide (CO_2) savings dominate in magnitude, with Podhale again leading at 34,002,791–62,951,789 kg/year for hard coal. CO_2 reductions for anthracite and coke are slightly higher, peaking at 71,945,088 kg/year in Podhale.

Regional comparisons reveal that Podhale consistently achieves the highest avoided emissions across all pollutants, highlighting its reliance on highly polluting fuels and the significant potential for environmental improvement. Stargard and Pyrzyce also demonstrate considerable reductions, particularly for SO_x and CO_2, reflecting their substantial energy demands. In contrast, Uniejów and Toruń report the lowest avoided emissions, likely due to smaller-scale energy systems.

When comparing fuels, hard coal consistently leads to the highest avoided emissions across all pollutant categories, emphasising its high contribution to air pollution. Anthracite, coke, and semi-coke produce lower emissions, particularly for SO_x, NO_x, and PM2.5. The data indicate that transitioning from hard coal to cleaner fuels can substantially improve air quality and reduce greenhouse gas emissions.

The data underscore the environmental benefits of transitioning from conventional solid fuels to cleaner alternatives. Hard coal replacements yield the most significant reductions, particularly in regions like Podhale, where historical reliance on this fuel has led to high baseline emissions. These findings emphasise the need for targeted regional policies to maximise the reductions in key pollutants, such as PM2.5, SO_x, and CO_2, and prioritise areas with the most significant potential for improvement.

4. CONCLUSIONS

Geothermal energy is key in transitioning to a low-emission economy and improving air quality, especially in areas with high population concentrations. The results of research conducted in the context of Polish geothermal heating plants indicate that these technologies can significantly reduce emissions of pollutants such as particulate matter (PM10, PM2.5), sulphur dioxide (SO_x), nitrogen oxides (NO_x), and carbon dioxide (CO_2). The greatest potential for emission reduction was noted in the energy equivalent produced based on solid fuels, such as hard coal. From geothermal heating plants analysed in Poland, Podhale is the leader in achieved effects, which results directly from the amount of energy produced there.

In summary, the research results indicate the significant potential of geothermal energy in reducing pollutant emissions and supporting sustainable development. Key to the sector's further development is research that considers local conditions, LCA analysis, and implementing strategies that optimise the use of geothermal resources, considering environmental, economic, and social aspects. For the future, life cycle and water footprint assessment is essential and should be an integral part of assessing the environmental impact of geothermal energy.

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