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Geothermal Energy as an Alternative Source and a Countermeasure Against Low Emission in the Ecological Security Strategy

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Abstract

This paper considers the implications of geothermal energy as an alternative source for the counteracting of low emission, as part of the ecological security strategy.

The issue has received considerable critical attention for several reasons. The primary problem is fulfilling the social and living needs of households. The growing consumption of energy and problems resulting from it are the natural consequence of and the price to be paid for economic growth and the progress of civilisation. Secondly, there is the problem of the fuel poverty (or energy poverty) of Polish households, which is one of the factors contributing to low emission. The third aspect is the effect of low emission on ecological security levels expressed in high levels of atmospheric air pollution, which is directly connected with the fourth aspect – the increasing importance of air protection against pollution. The significance of environmental protection against pollution is visible on the national, European and global scale through a number of environmental safety policies, such as the Clean Air for Europe Directive (CAFE). The directive in question imposes the obligation on EU member states to develop air protection plans for areas where air pollution concentrations exceed normative values, thus affecting the quality of human life. Finally, the fifth pillar is the use of geothermal energy as an alternative source of thermal energy as a measure to reduce low emission and diminish its consequences from the viewpoint of ecological security. These activities address the national environmental security policy, as well as EU requirements that oblige its members to proliferate renewable energy, which includes geothermal resources.

The research problem in the article is theoretical and empirical. The theoretical considerations take the form of a systematic review and a critical analysis of current Polish and foreign scientific achievements in the field of low emissions, thermal energy and energy poverty, as well as their consequences for ecological security. This examination involves the implementation of methods for analysis, defining, synthesising and generalising with the aim of identifying the essence and analysing the conceptual basis of the undertaken research problem. In addition, these will serve as methods for defining and showing the dynamics of the phenomena, processes and relations indicated in the current domestic and foreign scientific literature on the subject.

The empirical part of the work employs methods of quantitative and qualitative research to determine and examine the extent of the energy poverty of Polish households, and to determine the temporal and spatial characteristics of atmospheric air pollution. The referenced studies have led to determining the distribution and intensity of the studied phenomena, as well as inferring on the cause-and-effect relationships between these phenomena.

To provide a deeper understanding of the problem, the paper presents the results and the statistical analysis of the survey questionnaires and interview sheets carried out on over 300 respondents.

Keywords: low emission, environmental pollution, geothermal energy, thermal energy, ecological security

1. Introduction

The problem of low emission is one of the key, if not the top-priority, issues in Polish ecological security policy and strategy, similarly as it is in other countries of the European Union and around the world. There are several premises for ecological security fast becoming a critical issue in the policies of countries world-wide. All of them stem from the fact that emerging ecological risks are the consequence of improper management of our planet's most valuable assets: air, water, soil, ecosystems, biological resources, ecological diversity *etc* – labelled under the common term the *natural environment*. The source of ecological risk analysed in this paper is low emission from domestic heating, agriculture, industry and fuel combustion for vehicles. The thermal energy supply systems are predominantly fuelled by conventional fossil fuels, such as hard and

brown coal, oil and natural gas. However, it is coal that remains the most popular fuel in Polish household conditions; unfortunately, due to fuel poverty, this entails significant consumption of low-quality coal derivatives, and coal waste products such as: culm, coal mud or coal flotation concentrate, which contain large amounts of ash and sulphur, and simultaneously are of low calorific value. Because of the overuse of low-quality heat sources the emission standards are permanently exceeded in the daily and annual perspective. The problem predominantly pertains to the inner city areas of large cities and conurbations. In the summer season the main issue is the excessive concentration of tropospheric ozone, whereas in the winter (throughout the heating season, lasting from October to March) – excessive concentrations of PM_{10} (lead, arsenic, cadmium, nickel), $PM_{2.5}$ and benzo(a)pyrene.

Considering the notoriously high levels of air pollution in Poland and the obligation to comply with European pollutant emission standards (limits established by the Directive of the European Parliament and of the Council and defined by the Clean Air For Europe <CAFÉ> programme and <European Climate Change Programme ECCP>), it becomes apparent that Poland is still facing considerable challenges and tasks whose primary objective is to improve air quality. This obligation furthermore arises from the fact that Poland as a member of the European community – is bound by the "Climate and Energy Package," to implement the activities labelled under 3*20, which embrace: “a reduction of GHG emissions by 20% by 2020 below 1990 levels; an increase in the share of renewables to 20% of primary energy consumption; and a 20% improvement in energy efficiency (energy savings) compared to 2007 projections of 2020 consumption.” The abovementioned obligations follow from the referenced documents, as well as many other EU documents, such as: Europe 2020 - A strategy for smart, sustainable and inclusive growth and Directives of the European Parliament and of the Council on low-emission economy targets, Action Plan for the Improvement of Energy Efficiency in the European Community, European Climate Change Programme, Green Paper - Towards a European Strategy for the Security of Energy Supply; and national acts such as: Establishment of the National Programme for the Development of a Low-carbon Economy, Long-term National Development Strategy - Poland 2030, National Development Strategy 2020, Strategy Energy Security and Environment – Perspective by 2020, Energy Policy of Poland until 2030; National Energy Efficiency Action Plan (NEEAP), National Renewable Energy Action Plan; Operational Programme Infrastructure and Environment 2014-2020; Act on the Promotion of Thermomodernisation and Renovation; Act on Energy Efficiency). It appears that one of the sources that fully meets these challenges is geothermal energy. Therefore, the authors of this article aim to show how and to what extent geothermal energy may provide an alternative source for counteracting low emissions within the ecological security strategy. The proposed solutions are expected to spur other countries for which the phenomenon of low emission may also constitute a serious ecological problem, threat and challenge.

2. Low emission: definition and sources

The term "*low emission*" is generally understood to mean the emission of hazardous dusts and gases by low emitters: typically chimneys located up to 40 m above the ground level. The pollutants released into air at this level tend to accumulate at the source of their origin – particularly if the houses are located in valleys – exerting a harmful effect on our health and environment, both animate and inanimate, including the infrastructure. These substances include: particulate matter, PM_{10} and $PM_{2.5}$; sulphur dioxide (SO_2); nitrogen oxides (NO_x); heavy metals (including mercury, cadmium, lead, manganese, chromium); polycyclic aromatic hydrocarbons (PAHs); dioxins and benzo(a)pyrene (Apte, et al., 2017; Dong, et al., 2018).

Low emission should not be confused with small emission, of quantitative character, or *low-emission economy*, which strives to reduce pollutant emission and is currently a priority direction of activities of environmental security strategies worldwide.

In order to fully comprehend the gravity of the low emission problem and to determine suitable remedial measures, one should also consider what the sources of low emission are, and what the priority of actions should be, according to health hazards. Studies show that low emission originates in three main sources: household and agricultural activities, local boiler houses and transport (Kumar Verma and Sangle, 2015).

Each of these pollution sources has its particular character and the associated environmental impact; for instance, individual households and single- and multi-family farms (approx. 9 million of which there are in Poland) consume large amounts of thermal energy to satisfy their basic existential and living needs. The thermal energy distribution shows dominant consumption for domestic heating (approx. 69% of total energy), for heating water (approx. 15% of all energy) and for meal preparation (approx. 9% of all energy). To provide the necessary energy, these households utilise a basic energy carrier *i.e.* solid heating fuels, 49% of which is poor or very poor quality (especially coal, wood, briquette, biomass), and even waste, incinerated in the amount of approx. 2 million tonnes per year.

The reasons for such behaviour are twofold and correlated, *i.e.* high price of thermal energy and low financial income of households. A significant problem of households, which dramatically affects the low emission

levels in Poland, is the poor technical condition of houses, which contributes to low energy efficiency of buildings. There are several major factors contributing to the poor energy efficiency rating of Polish homes: quality of thermal insulation, degree of window tightness, tightness of balcony doors, tightness of roofs, condition of technical equipment and installations, degree of ventilation efficiency, *etc*. Studies have shown that a large proportion of buildings (detached houses, tenement houses, blocks) is completely uninsulated or insufficiently insulated (over 70% of approx. 5 million single-family houses – which amounts to 3.6 million); however, the condition of the remaining 30% still exhibits the need for thorough thermomodernisation, replacement of heating equipment and the system for production, regulation, storage, and distribution of thermal energy. The condition of these buildings adds to the large loss of thermal energy, determining that they do not maintain the rational level of thermal consumption. By way of illustration, in an energy-inefficient single-family house, thermal losses are distributed accordingly: windows - 36.3%, inefficient ventilation - 30.5%, external walls - 13.3%, roof - 13.3%, ground floor – 4.9%, front doors - 1.8%. This particularly applies to buildings constructed in the 1990s and earlier (Świerszcz and Grenda, 2018). Another important factor is the size of the dwelling. In basic terms, the lower the efficiency of the building components listed in the preceding lines, the higher the expenses concerning ensuring comfortable living conditions through heating in winter or air-conditioning in summer. Furthermore, the costs grow with the increase in the size of flat/house: *e.g.* a 10% larger flat increases heating expenses by 4%. This difference can also be seen between the city and the countryside: dwellings larger by 10% generate an increase in heating expenses by 3.2% in the city and 1.2% in the rural areas. The degree of energy efficiency of buildings and the associated heating costs show a distinct correlation with the age of buildings. More recently erected buildings, understandably, show greater energy efficiency, hence the heating costs are reduced. Statistics show, for instance, that households in buildings constructed after 2006 tend to pay less by as much as 17% compared to buildings built earlier (Świerszcz, 2017a).

Another household-related factor affecting the rate or concentration of low emission is inefficient or faulty heating installation (Świerszcz, 2016) and dated, inefficient heating stoves, the number of which, according to the Institute of Environmental Economics, revolves around 3.5 million pieces, installed at over 49% of households. Recent studies show that households obtain heat energy from: boilers and fireplaces for wood and biomass - 13.7% (687,000); coal-fired boilers of unknown parameters - 2.4% (120,000); coal-fired retort furnaces aged 10 or more - 1.5% (75,000); coal-fired retort furnaces below 10 years - 6.5% (325,000); coal-fired boilers, less than 10 years old - 30.1% (1.5 million) (Sadlok, 2014). Many Polish households use top combustion stoves, which enable burning virtually anything thrown inside (hence their Polish derogatives "*trasher*" or *"smoker"*). Their simple construction, which has basically remained unchanged for over 100 years corresponds to the most important need of domestic heating systems – the economy factor. The advantages of these ovens are low price and high versatility, while the disadvantages are high emissivity and low energy efficiency, at the rate of 50-60%, however in practice it may well prove even two times lower.

2018). The attempted presentation of low-emission sources in the context of everyday struggle of numerous Polish households are described collectively as the factors of *fuel poverty* or *energy poverty* (Świerszcz, 2017b, Poruschi and Ambrey 2018).

The data referenced in the previous considerations clearly show that low emission is not only the problem of environmental nature, but also - and perhaps above all - a social problem, whose consequences carry multiple risks both to the ecosystem and to the infrastructure.

3. The effect of low emission on the environment quality

The impact of low emission on the natural environment and its consequences are experienced in Poland throughout the year. They concern: air, water and soil, and thus refer to all living organisms that breathe and consume contaminated water and food. They are also by no means indifferent to the material environment that is their true source and where humans live.

The most noticeable consequence of low emission is its direct impact on the condition of human health and wellbeing. Its effects are typically present in diseases of the respiratory system (*e.g.* oral mucositis, pharyngitis, chronic bronchitis, lung cancer, chronic cough, lung failure and bronchial asthma); disorders of the central nervous system (*e.g.* insomnia, headaches, malaise, increased aggressiveness); eye diseases (*e.g.* conjunctivitis); allergies; circulatory system; weakening of fertility, weakening of the immune system, as well as cancers. As research have shown, the abovementioned factors not only effect in the weakening of the state of human health and condition, but also constitute the leading cause of human death. It is estimated that every year 40-45 thousand people die in Poland as a consequence of emission. (Ochoa-Hueso, *et al.*, 2017).

By negatively affecting the condition of humans, low emission also generates economic costs, the so-called external costs to be borne by every citizen. These costs include, in particular: health care expenses incurred directly by people who suffer from low emission exposure, as well as expenditure within the health care system itself; not to mention the costs that result from lower productivity of employees or even their absence in

the workplace owing to their or their family's illness. Estimated economic costs of poor air quality associated with the total $PM_{2.5}$ emission into air designated for Krakow, according to the methodology used in the European Union in the *Clean Air for Europe* (CAFE-CBA), amount to PLN 740 million per year (Rao, *et al*., 2017; Ćwik, 2017).

The detrimental effect of low emission may also be observed in its impact on the condition and quality of material goods, which becomes evident in the face of deterioration or even ruination of monuments (cultural heritage) and facades of residential and public buildings. Crumbling plaster falling off the building, buildings whose facades are hidden behind a layer of dark coating, discolouring of walls and roofs are some of the effects of sulphur and other chemicals spoiling the visual and investment attractiveness of not only buildings but also entire cities. These changes also significantly affect the cities' tourist value. Low emission deteriorating the condition and quality of buildings, similarly in this case increases the economic costs associated with more frequent and more extensive renovations, whose costs amount to millions of zlotys per year. Another effect of low emission is the corrosion of metals and increased wear of machinery and equipment. The reason for this is combined action of sulphur and oxygen in various compounds, as well as of carbon dioxide (one of the products of low emission), which significantly accelerate the natural process of metal corrosion. This in turn translates to higher wear rate of machines and various devices used on everyday basis, thus shortening their lifespan. Furthermore, yet another effect is the accelerated wear of leather, paper and clothing as well as prolonged drying time of paints and varnishes (Sadlok, 2014).

4. Geothermal energy as an alternative source of thermal heat in response to low emission

The answer to the problem of low emission reduction in urban and rural centres may be provided by geothermal energy. This postulate is supported by many arguments, two of which are particularly significant: a substantial reduction in the emission of pollutants (especially in the winter season) and relatively low prices of thermal energy (Świerszcz and Ćwik, 2017; Loppi and Nascimbene, 2010). The city of Zakopane provides a suitable exemplification of how to effectively harness geothermal energy. The implemented heating network connected to the geothermal thermal plant "*PEC Geotermia Podhalańska SA,"* provides thermal energy to the entire city and its residents, as a result the current level of pollutant emission has been significantly reduced throughout the Podhale region. This is confirmed by the recent records: CO_2 – reduction down to 39.6 thousand tonnes per year; SO_2 levels amounting to mere 12 μg/m^3 per year; PM_{10} - emission of only 32 μg/m^3 per year. These developments led to exciting results in the period of 1999-2016, where: the amount of coal used – dropped to 243.3 thousand tonnes and CO_2 emissions - to 488 thousand tonnes. At present, the geothermal heating plant has a heating network spreading over the length of 100 km, distributing heat to the surrounding villages and inhabitants of Zakopane. An integral part of the heating system is the 42 MW heating plant in Zakopane. The boiler room is a peak load power station incorporated in the geothermal heating system. The heating plant acquires 70.7 MWt of geothermal energy (the total power of 80.5 MWt). Each recipient has an individual heat distribution centre installed, which is adapted to the needs of a given recipient and includes two channels: central heating and municipal water heating system. There are three types of individual nodes present in the network with heat exchangers of the following capacities (respectively central heating / water heating): 15 kW/33 kW; 25 kW/43 kW and 33 kW/50 kW. Depending on the selected tariff group, specific tariffs and rates are set. In available tariff groups (M1, M2, M4) - the price of heating is PLN 19.01 /GJ, while the price of the thermal carrier is PLN 17.43 /m^3; in tariff group (G) – the price of heating is PLN 16.52 and thermal carrier price is PLN 3.35 / m^3 (Decision, 2018).

In recent years, the geothermal thermal energy sales levels showed the following tendencies: in 2010 - 376,195 GJ; in 2011 - 352,842 GJ; in 2012 - 383 738 GJ; in 2013 - 393 117 GJ; in 2014 - 361,634 GJ; in 2015 - 398 522 GJ; in 2016 - 421 130 GJ. These data clearly show that the sales of thermal energy obtained from geothermal sources is constantly growing, which indicates a rising and continuous interest in this type of heating among the recipients. The undisputable advantages of geothermal energy designate it as a particularly valuable element in the heating production structure, compared to other sources of thermal energy. The distribution of thermal energy acquisition in 2015 was as follows: geothermal energy - 81%; gas - 9%; oil - 0.39%, whereas in 2016: geothermal energy - 81%; gas - 8.36%; oil - 0.39%.

Main customers of geothermal heating are primarily residents, institutions and businesses, *i.e.* 1,473 recipients, distributed according to towns: from Zakopane - 1135 recipients, or 77.1%; Biały Dunajec - 164 recipients, or 11.1%; Szaflar - 146 recipients, or 9.9%, and Poronina - 28 recipients, or 1.9%. Geotermia Podhalańska provides thermal energy to 1473 objects, most of which are single-family buildings - 834, or 56.6%, and other buildings - 639 - or 43.38%. The "*Other buildings*" category includes: multi-family buildings - in the amount of 278, or 18.9%; service and commercial buildings - 122, or 8.3%; hotels, boarding houses, holiday houses - in the amount of 103, or 7.0%; schools, kindergartens, gyms - in the amount of 35, or 2.4%, and

other facilities - 101, or 6.9%. Geothermal PEC Geotermia Podhalańska sells the largest amount of geothermal thermal to multi-family buildings, service shops, public utilities, hotels, *etc* – 354,089 GJ, or 84.08%, while the remaining part of the energy is sold to single-family buildings - 67,041GJ, or 15.92% (Ignacok, 2017).

The high demand for geothermal energy among the inhabitants of Zakopane and its surroundings, led in 2016 to an unprecedented heating price reduction, for the first time in *PEC GT* history. However, according to the records of Polish Energy Regulatory Office, even in the preceding year of 2015, the cost of geothermal heating was more expensive than that of brown coal combustion, and cost PLN 32.38 per GJ and PLN 26.08 respectively for GJ. Nevertheless, the price was lower than the price of thermal energy produced from hard coal (PLN 37) and gas (which amounted to over PLN 50 per GJ). The records for 2016 show that Geotermia Podhalańska created over 90% of the thermal energy from geothermal sources, while the remaining portion was obtained from gas (<9%) and oil (<1%). As shown by household surveys, the price of heating a house with an area of approx. 150 m^2 oscillates in the region of PLN 400 per month. The analysis of heating prices obtained from other sources, such as brown coal, hard coal, other fuels, fuel oil, natural gas, show a distinct difference in favour of geothermal heating resources (Ignacok, 2017).

Encouraging results achieved in terms of heating prices generate constant interest among potential clients of households, institutions as well as businesses, especially those dealing with the hotel industry. Current estimates hold that approx. 77% of inhabitants of Zakopane and surrounding communities pertain to the last category. The interest in geothermal heating is also visible among nearby towns, an example of which is Nowy Targ, which hoping to introduce a more economical heating alternative into the city, has resolved to join the heating distribution network of Geotermia Podhalańska.

5. Results

The research into the potential impact of geothermal energy on reduction of low emission emitted to the natural environment, especially by households, clearly confirms the positive impact of this resource. This is possible due to the ecological properties and relatively low price of the energy obtained from geothermal sources compared to the conventional fossil fuel sources.

In addition, the study has pointed to the correlation between low emission and energy poverty, emphasising their most worrying outcome – the increasing atmospheric air pollution. This paper, furthermore, attempted to draw attention to the external factor (the barrier) that hinders or even prevents the achievement of the expected effects in the improvement of air quality, *i.e.* the phenomenon of the energy poverty of Polish households. Another step was to recommend systemic solutions aimed at improving the situation in both fields; the proposed resolutions are expected to provide an impulse for units of various levels (governmental, ministerial, local government), as well as residents of communes (cities) to undertake measures aimed at reducing the low emission of households, and thus improve the air quality in their area. It appears that dissemination of knowledge about the issue as well as promoting good practices could eventually lead to the development of effective and comprehensive instruments to help counteract low emission and related dangers of atmospheric air pollution.

6. Discussion

Currently, the problem of low emission is a priority issue in the policies and the environmental security strategy developed in Poland, in other European Union member states as well as worldwide. Specific actions in the field have already been undertaken, with the aim to motivate and encourage countries to intensify efforts (and effects) in the reduction of environmental pollution, the increase of energy efficiency, as well as greater use of renewable energy sources. However, as shown by researches, the environmental pollution, especially originating in low emission are constantly at worrying levels.

Even despite the proven validity and legitimacy of the developments in geothermal heating in Poland, the point hardly breaks through to the awareness of many decision-makers who might hold the decisive voice influencing the development of this branch of energy. Declarations of willingness to support that would lead to actual actions in the said direction are still sparse and ineffective in the light of growing needs and interest in a wide range of environments.

It is therefore of great importance to promote the awareness of the investments in national renewable energy sources, *e.g.* geothermal energy, as a long-term bond. It is a venture that could trigger the development of a competitive low-carbon economy, as well as open the possibility of introducing effective and intelligent geothermal energy networks, whose price is and should prove competitive against energy prices obtained from other thermal sources.

7. Conclusions

The protection of atmospheric air as one of the elements of the natural environment belongs to the priority directions of the strategy and policy of ecological security in Poland. Despite the systematic improvement of air quality in our country, the problem of low emission is still present and even disturbing. The rising demand for thermal energy driven by the increasing quality needs of social life, including the satisfaction of social

and household needs of settlements, are natural consequences and the price paid for the economic growth and civilisation progress. On the other hand, the notoriously persistent energy poverty problem causes that the main source of heating is low quality fuel, notwithstanding waste. An important problem boosting low emission levels are also local energy-ineffective coal-fired boilers and domestic heating stoves, in which the combustion of coal occurs in an ineffective manner, typically by means of cheap coal of low calorific values.

In order to meet the challenges of reducing low emission of hazardous chemicals into the atmosphere, we may turn to alternative solutions such as the prospects of geothermal energy and associated geothermal heating plants (heating distribution networks) could become one of the key fundaments of the low-carbon economy, which is a priority objective of our country's environmental security policy and strategy. This assumption appear to have been already confirmed by the examples from a number of Polish cities, such as: Pyrzyce, Uniejów, Stargard, Mszczonów, Zakopane and its surrounding towns, Konin and many others. The geothermal energy implemented and exploited there has not only led to considerable reductions in thermal energy prices, but has also improved the quality of air. This, in turn, translates into an array of health and social betterments, such as: improving the quality of life, the health status of the population, improving the natural environment, increasing the investment attractiveness of the area, improving its tourist and climate values and finally reducing the costs of disease treatment and renovation of buildings and monuments.

An important task today is to raise the awareness that by investing in national renewable energy sources, such as geothermal energy, we investment in our future. This is a significant step towards sustainable development of competitive low-emission economy, as well as an important implication for the effective and intelligent geothermal energy networks.

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