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The impact of geothermal resources on the competitiveness of municipalities: evidence from Poland

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ABSTRACT

In addition to large-scale environmental benefits, geothermal resources are nowadays expected to deliver an endogenous competitive advantage. The aim of this paper is to investigate this phenomenon for Poland. Since geothermal resources are of an endogenous nature, we assume their competitive advantage character for eleven selected municipalities in Poland. A municipality competitiveness model is built using an expert method. Panel data analysis is used to estimate four models of geothermal competitiveness. A sensitive analysis examines if the results are dependent on the model we developed. All four model scenarios are robust. The results show that the geothermal estimators significantly impact the created municipality competitiveness indicator. The geothermal energy production and geothermal bathing centres are both significant elements of municipality competitiveness in Poland. Therefore, this paper provides an argument for further expansion of the extraction of the available geothermal resources in Poland.

1. Local competitiveness drivers

The endogenous growth theory that emerged in the 1980's shifts attentions to the endogenous factors and forces of economic growth (Stöhr and Taylor [1], Boltho and Holtham [2]). Opposite to neoclassical theories, the endogenous growth model omits the role of technology emphasising determinants approached as endogenous, such as human or natural capital. Endogenous growth theory scholars seek a sustainable long-run growth through the deployment of human and natural resources into innovation and R&D (Romer [3], Grossman and Helpman [4], Aghion and Howitt [5]). Moreover, this theory emphasizes the role of natural resources in generating innovations and increasing macroeconomic returns to scale (Helpman [6], Barbier [7], England [8]). References for concepts of local and regional competitiveness in the endogenous growth model are found in the works of Cheshire and Magrini [9], Acs and Armington [10], Harrison [11], Button [12], Stimson et al. [13] and Taylor and Plummer [14], where endogenous local attributes and processes are recognized as drivers of growth. Kitson et al. [15], for example, underlines the endogenous local drivers' crucial role in stimulating economic development, whereas Pike et al. [16] determines the economic potential of naturally occurring resources in localities, among other endogenous factors, as a source of local development. Based on the perspective of Audretsch et al. [17], natural energy resources are local assets and therefore are considered as critical drivers of local competitiveness.

From the perspective of regional studies, definitions of local competitiveness vary among scholars. However, general findings refer to two concepts: economic welfare and sustainability. Regarding economic welfare, Stroper [18] and Meyer-Stamer [19] define local competitiveness as an ability to attract capital for similar localities, which results in an increasing local standard of living. Studies of Hunt [20] find it profitable that a locality is able to compete against others on forms of using local resources. Plummer et al. [21] underline the role of local commodities supply in building the competitive advantage. For Camagni [22] local competitiveness is a phenomenon of local policymaking that emphasizes local resources and needs. According to Iopollo et al. [23], a locality is competitive by integrating resources into its local sustainable system and as a result by improving the local quality of life. Competition analysis of Porter [24–26] finds a competitive advantage in

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the application of local resources and knowledge. The concepts of local clusters emergence and regional economic spillovers are seen as optimizations of endogenous resources. In Porter's studies, the measure of competitive advantage is how an endogenous innovation transforms into local know-how, i.e. a specialization. Environmental sustainability also creates opportunities for inter-regional and inter-local competitiveness. The transition of a locality according to the sustainability principles becomes a competitive advantage and an attractive argument for potential investors (O'Riordan and Voisey [27], Sykora [28], Krueger and Gibbs [29]). Jonas et al. [30] argue that low carbon initiatives become new competitive strategies and result in the reconstruction of the local economy.

The endogenous character of geothermal energy (Chakravorty et al. [31]) opens a discussion about the scale of the resource competitiveness in the local dimension. The competitive characteristics of geothermal energy compared with other renewables are seen in its resource energy efficiency (Seyboth [32], Aydin [33]) and non-intermitted potential and storage capability (Fridleifsson [34], Matek and Gawell [35]). Social characteristics add to the competitive advantage of this resource, such as environmental attributes and sustainable exploitation (Mock et al. [36]). Geothermal energy is considered a local capital in Porter's [37] studies, which are dedicated to the concept of geothermal competitive advantage. Porter's main findings discuss the establishment of geothermal clusters where the potential of the resource is optimally and locally used. Interactions between various actors of geothermal energy utilization generate local knowledge and market opportunities. However, Porter underlines the fact that geothermal resources become a competitive advantage at the scale of deployment. In other words, an increase of geothermal capacity utilization is the key to the competitiveness.

One of the ways to study the geothermal resource is to link it with the concept of endogenous growth theory. This approach is not yet sufficiently illustrated in the literature. The substantiation of the proposed study is the relative difficulty of mining and profitability of investment in the geothermal energy. Therefore this resource is expected to deliver more than energy production benefit to the local economy. Despite the high capital investment in geothermal exploration and the related risks for local authorities, we assume the resource is a local competitive advantage. However, regardless the arguments of geothermal advantage, it is not obvious that geothermal resource drives the local economy. It is not conditioned to exploration only, other activities have to take place. We base our concept on the endogenous nature of the resource and the variety of its direct exploitation according to the Lindal diagram (Gudmundsson et al. [38]). In order to verify this assumption, we propose a research question about the relationship between the development of geothermal energy and the competitiveness of the municipalities in Poland. Due to the complexity of the topic and the definitions of local competitiveness, we operationalize the research problem with the help of experts.

This paper is divided into the following sections: Competitiveness of the geothermal energy, Local competitiveness model, Competitiveness model data, Municipality competitiveness concept, Panel model robustness check and lastly Conclusions and discussion.

2. Competitiveness of the geothermal energy

Geothermal energy is considered an optimal source of clean energy and becomes substantially cheaper than fossil fuels fired energy if supported by the state (Armstead [39], Duffield and Sass [40], Energy Roadmap 2050 [41]). According to sustainability criteria for heating and cooling, the geothermal renewable reveals the highest CO_2 capture potential (Randolph and Saar [42]), and it leads in sustainable performance over biomass and solar energy (Dincer and Acar [43]). Moreover, International Energy Agency [44] and IRENA [45] predictions point to an upcoming tenfold increase in the geothermal heat and power capacity in Europe.

References to the geothermal resources as a competitive feature of local economy and a sustainably factor are found in the works of Murphy and Niitsuma [46], Cataldi [47], Chandrasekharam and Bundschuh [48], Niitsuma and Nakata [49], Rybach [50], Green and Nix [51], Carley et al. [52], Goldstein et al. [53], Dumas and Angelino [54], Michaelides [55] and Kurek [56] among others. The main observation points to the role of the geothermal resource in the economic development, especially the low-grade resources, e.g. the geothermal waters application in geothermal bathing centres.

In the case of Poland, the geothermal resource is competitive on the supply side. It is found under 80% of the country beneath the earth's crust, one of the highest percentages in Europe. 40% of this potential is technically ready to deliver economically attractive geothermal heat and energy, argue Kępińska [57] and Górecki et al. [58]. Moreover, Poland can produce 625.000 PJ of geothermal energy, whereas the annual energy consumption is circa 5500 PJ (Ney [59], Huclak et al. [60]). According to Skjærseth [61] and Szulecki et al. [62], increased geothermal production creates a degree of energy independence from conventional resources and imports. Jarczewski et al. [63] discusses that optimal conditions for geothermal exploitation are found in relatively small to mid-size municipalities in Poland with dense housing and an infrastructure network that are at the source of or in close vicinity to the renewable geothermal energy. It provides them with geothermal related opportunities, such as local energy source, job creation, local budget alleviation and increased entrepreneurship. Despite the resource potential in Poland, the geothermal renewable is used for the local district heating and the recreational or bathing centres (Halaj [64], Sowizdżał [65]). Since geothermal investment and operations in Poland are mostly carried out locally in the area of a municipality, the potential competitiveness is therefore assumed to reveal itself there. Hence, we set the following hypothesis: The exploitation of the geothermal resource has a positive impact on the competitiveness of a municipality. In practice it is presumed that an increase of local competitiveness is explained by the scale of the geothermal resource utilization.

To test the hypothesis, we employ a statistical model of municipality competitiveness and introduce geothermal parameters in order to observe the assumed relation. We aim to measure how the two forms of geothermal exploitation, i.e. heat energy and recreational/spa centres, determine the level of municipality competitiveness. Municipality competitiveness is represented by a synthetic indicator, a measure that is comprised of the elaborated socioeconomic indicators. A similar approach to creating a synthetic index for measuring regional competitiveness in Poland is found in studies by Bronisz et al. [66], Heijman et al. [67], Michalek and Zarnekow [68], Grzebyk and Stec [69], Kusz et al. [70] and Strojny et al. [71]. In order to examine the competitiveness of a municipality in relation to geothermal utilization , a comparison is required. A comparative analysis of the local competitiveness model is to be carried out for municipalities with geothermal exploitation and for municipalities that do not deploy the geothermal resources. A benchmark methodology allows us to analyse the local competitiveness model where geothermal parameters are the competitiveness determinants.

3. Local competitiveness model

The model that tests the relation of geothermal exploitation to local competitiveness requires adequate variables. The data is primarily built since this research is a quite pioneering one. Therefore, the variables result from the authors approach to the research problem and availability of sources. The model is relation testing oriented hence we had to build variables that can illustrate an assumed relation. Since the research problem is limited by data availability we attempt to conceptualize the model with data that best describe the phenomenon studied. Therefore, competitiveness on the municipality level is represented by relevant indicators that illustrate economic welfare and sustainability as per the local competitiveness interpretation. For this purpose, a local competitiveness index is built by coupling the indicators, and it constitutes the model's dependent variables. Its construction is explained in Section 5 of this paper. Model testing implies a valid statistical relation between the model components. As model determinants, we appoint variables that reflect the size of the geothermal resource exploitation in Poland. The technical data on the exploitation of the resource is not meeting the model assumptions, thus other data illustrating the use of the resource but not its extraction has to be found. Since the other purposes of geothermal resources in Poland are still in the initial stage of development, there are two descriptive variables that refer to the local geothermal operations, i.e. the establishment of a geothermal spa/recreational centre and a volume of the gigajoules (GJ) of geothermal energy produced at the local geothermal plants. If the geothermal energy production has a competitiveness potential for a municipality, we use the geothermal energy production variable measured in GJ, not the processed geothermal heat power in megawatts (MW). Due to its structure, the geothermal spa parameter is converted into a dummy variable, whereas the geothermal GJ output is a numeric value.

In order to be able to determine the geothermal variables' contribution to the municipalities' competitiveness indicators, control variables are required. The selection of control variables aims to reduce the bias of the geothermal variables in the local competitiveness model. This selection is to control for other factors that are relevant in the research assumption. We introduce these variables to validate the model results. Without the control variables the growth of the municipality competitiveness cannot be identified related to the geothermal resources exploitation, but attributed to other factors. Therefore, one control variable is a competitiveness indicator for municipalities that do not exploit geothermal resources appointed throughout the benchmark concept. Two other control variables refer to the administrative area of a county where a geothermal municipality is located. County (poviat) is the second degree of local government and administrative area of Poland, equal to the NUTS-4 geographical nomenclature. The county level measured income per capita and the heat energy provision helps to identify clearly the relationship geothermal variables have with the model. A lagged variable is introduced to measure the dynamics of geothermal developments in the municipalities. A time lagged variable tackles the issue of values from the previous period affecting the one being tested. The application of a lagged variable is used since the effects of geothermal operations and investment have a delayed impact on the economy (Lovekin [72], Ngugi [73], Daniilidis et al. [74]). Table 1 introduces the model variables and their reasoning. These variables seem to possibly describe the phenomenon of geothermal energy in a municipality and its potential impact on local competitiveness.

The data on the geothermal municipalities and their benchmark municipalities offers a time series observations. A methodological approach is to test the assumption that forms of geothermal resource exploitation increase the indicators of municipality competitiveness. As a time series analysis, panel analysis serves to verify the hypothesis. Panel research is used in economics to conduct the longitudinal analysis of development, change and related socio-economic phenomena. It endows regression with both spatial (cross units) and temporal (time series) observations and applies in situations of data heterogeneity, assuming unchanging phenomenon in time data. In the panel econometric models that are estimated on the basis of the panel data it is generally assumed that the evolution of an explanatory variable is influenced by unmeasurable, constant in time factors that are specific to a given object (Baltagi [75]). Panel analysis is used in studies that seek links and long-term determinants of data relationships. Studies that use panel modelling in local competitiveness analysis (Naudé and Saayman [76], Zhang and Jensen [77], Nevima and Melecký [78]) underline the accuracy of this methodology in tackling the unobservable individual effects of a country, an area or subject such as natural environments, unique attractions or the climate constant over time. A panel data regression model (or a panel data model) is an econometric model specifically designed for panel data. This methodology addresses the traditional statistical problems in regression, incorporating the unobserved effects and model uncertainty (Greene [79]). A major advantage of the panel data analysis is its ability to control for omitted (unobserved or mismeasured) variables, argues Hsiao [80]. However, in general a threat to time series data models is the variables' non-stationarity characteristics, which often lead to the identification of apparent intercorrelations (Phillips [81]).

In general, we adopt the regression panel model structure that is based on the Least Square Dummy Variable model. Due to the variable structure, it is a multivariate panel model. We estimate this model to be static or dynamic, depending on the lagged variable employment. When static, it is a fixed effects regression panel model. It assumes the correlation between an entity's error term and its predictor variable isn't related to any other model characteristic. In this case, the competitiveness index is assumed related to the geothermal variables. When dynamic, it takes the form of a dynamic panel model. A dynamic panel model is based on the general fixed panel model, but with a difference of containing error components with a lagged dependent variable. The Hausman test will be applied to justify the fixed effect model determination.

We introduce the panel model in the following formula:

$$y_{it} = \delta\gamma y_{i,t\text{-}1} + \beta_{\text{i}}\, x_{it} + (\alpha_i + \varepsilon_{it}),\ i = 1, \dots N,\ t = 1, \dots \text{T}, \tag{1}$$

Where

$i = 1, \dots, N$ (objects)
$t = 1, \dots,$ (time units)
y_{it} - dependent variable
x_{it} - independent variable vector
β - vector with the N dimension of the structural parameters of the model
δ - panel parameter [0,1], where $\delta = 0$ in the static panel model and $\delta = 1$ in the dynamic panel model
γ - structural parameter
α_i - group effect for observation i
ε_{it} - pure random error (Baltagi, 2003)[1]

Panel data methodology allows for observations of the interdependency between the geothermal exploitation variables and the competitiveness index of a municipality where the geothermal resource is exploited. The specifics of the dynamic panel model include a lagged variable. The verification of the hypothesis boils down to the application of the geothermal municipality competitiveness index and the independent model variables forming a

[1] B.H. Baltagi, 2003, *Econometric Analysis of Panel Data*, John Wiley & Sons, LTD, England 2003, ch.8.

Table 1
Description of the model variables.

Variable	Value	Description	Reference
dependent variable y_t: *geothermal municipality competitiveness index (CI)*	Synthetic indicator of geothermal municipality competitiveness $0 \le y_t \le 1$	Geothermal municipality competitiveness level.	Explains the appointed measures of local competitiveness in the form of a synthetic indicator.
independent variable *x1*: *geothermal spa/ recreational centre*	Binary value [0, 1]	Exploitation of the resource for a geothermal spa/recreational bathing centre.	Indicates if a geothermal waters spa is present in a given year; 0 denotes that within a given year a geothermal spa is not present; 1 denotes that within a given year a geothermal spa is present.
independent variable *x2*: *geothermal GJ*	Numerical variable [0 … N]	Geothermal energy (in GJ) produced for heating purposes.	Output of geothermal production in GJ. Depicts the intensity of geothermal use and implies the occurrences of geothermal activities in a municipality.
control variable *x3*: *benchmark municipality competitiveness index*	Synthetic indicator of benchmarked municipalities competitiveness $0 \le x3 \le 1$	Benchmarks competitiveness level.	Built of the same measures as the geothermal CI. Applied to observe the local competitiveness measures in benchmark municipalities with similar socioeconomic structures and no geothermal operations.
control variable *x4*: *county heat* per capita	[0 … N] numerical variable	Heat dam^3 produced per county inhabitant, (where 1 $dam^3 = 10m^3$).	Units of heat from all sources delivered to a country's infrastructure. Helps to identify if a municipality's competitiveness is related to the increased heat energy provision from all sources (or only the local geothermal heat energy).
control variable *x5*: *county income* per capita	[0 … N] numerical variable	Own income in Polish zlotys per capita of a county where a geothermal municipality is located.	Indicates the general level of wealth of an administrative area where the geothermal municipality belongs. It functions in the model as a verification if a municipality's competitiveness is related to its county wealth.
control variable *x6*: *time lag*	y_{t-1}	Delayed variable (lagged).	Assumes the lagged effect of the geothermal energy exploitation on the local economy.

Source: own elaboration

Table 2
Selection of the geothermal municipalities in Poland.

	Geothermal enterprise	Municipality	Installation year	Recreational centre
1	Geotermia Mazowiecka S.A.	Mszczonów	1999	2008
2	Geotermia Uniejów LLC	Uniejów	2001	2008
3	Geotermia Poddębice LLC	Poddębice	2013	2011
4	Geotermia Podhalańska S.A.	Zakopane	2001	2006
5	Geotermia Podhalańska S.A.	Szaflary	1993	2007 (1st) and 2015 (2nd)
6	Geotermia Podhalańska S.A.	Biały Dunajec	1996	*n.a.*
7	Geotermia Podhalańska S.A.	Poronin	2001	*n.a.*
8	Bukowina Geothermal Society LLC	Bukowina Tatrzańska	2008	2008 (1st) and 2011(2nd)
9	Geotermia Grudziądz LLC	Grudziądz	2006	2006
10	Geotermia Pyrzyce LLC	Pyrzyce	1999	*n.a.*
11	Geotermia Stargard LLC	Stargard	2005	*n.a.*

Sources: www.pgi.gov.pl; www.termalni.pl

panel data set based on the developed formula 1. The results of the model testing are expected to reveal a significant relationship only between the dependent variable and the geothermal parameters. Control variables are expected to have low or no relationship to the determined one. Outcomes of the panel analysis are displayed in the Table 6.

4. Competitiveness model data

The panel data observes selected indicators of local competitiveness in years 1999–2017. This time period is determined by the administrative reform in Poland that took place in 1999, which introduced the administrative county units. Counties data constitutes the two models' control variables. The model's variables data (shown in Table 1) comes from two sources: the geothermal enterprises and the Central Statistical Office in Poland.

Table 2 presents a selection of eleven municipalities in Poland that have geothermal operations limited to a minimum of 5 years of resource exploitation. Otherwise no competitiveness observations are statistically valid. They are actually the majority of municipalities in Poland where geothermal installations are present except few installations for the recreational purposes in other locations. Geothermal enterprises of various ownership, including local authorities, produce the geothermal heat and water that are further distributed to the communal network or power the geothermal recreational centres. Geotermia Podhalańska S.A. powers four municipalities due to their proximity. Geothermal recreational centres are established in seven out of the eleven municipalities. In the case of Poddębice, the geothermal recreational centre was built before the geothermal municipal heating plant. Information about the geothermal energy production in GJ is collected directly from the geothermal enterprises, and it constitutes the primary data. We inquired about the access to the data either in person or via correspondence. The data of years 1999–2017 forms a panel data, which has a different size for each of the municipalities depending on the start time of their geothermal operations (see Table 2).

The model determined variable and the control variables are sourced from the Local Data Bank[2] of the Central Statistical Office at the level of NUTS 4 and 5[3] for the years 1999–2017. A benchmarking approach is used to determine the control variable of the municipalities with no geothermal operations. Following the benchmarking concept taken from regional studies in Poland

[2] https://bdl.stat.gov.pl/BDLS.

[3] NUTS is the Eurostat's Nomenclature of Territorial Units for Statistics. In Poland, NUTS levels 4 and 5 correspond with counties and municipalities administrative units respectively.

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Table 3
The expert model of indicators determining municipality competitiveness in Poland.

Model of the synthetic competitiveness indicator (CI)					
categories					
Population (C_p)	Local Economy (C_e)	Local government (C_g)	Tourism (C_t)	Infrastructure (C_i)	Level of life (C_l)
subcategories					
Internal migration (C_p1)	% of employed inhabitants (C_e1)	Own municipality income per inhabitant (C_g1)	Polish tourists accommodated per 1000 inhabitants (C_t1)	Water consumption for industrial and domestic purpose per inhabitant (C_i1)	Out-Patient health care facilities per 10.000 inhabitants (C_l1)
Natural increase (C_p2)	No. of private economic activities (C_e2)	Municipality investment expenses per inhabitant (C_g2)	Foreign tourists accommodated per 1000 inhabitants (C_t2)	Dwellings delivered per 100 inhabitants (C_i2)	Environmental protection investment per inhabitant (C_l2)
% of the population with a productive age (C_p3)	No. of national commercial companies (C_e3)	PIT income per employed inhabitant (C_g3)	Tourism accommodation establishments per 1000 inhabitants (C_t3)	km of water network and canalization per inhabitant (C_i3)	Primary and lower secondary education expenses per pupil (C_l3)
Live births (C_p4)	No. of commercial companies with foreign capital (C_e4)	Budget deficit (C_g4)	Overnights spent (C_t4)	Water system connections leading to residential buildings and residences for communities per inhabitants (C_i4)	Population connected to wastewater treatment plants (C_l4)

Legend.
1 – Both criteria have the same impact on the choice.
3 – One criterion is slightly more important than the other.
5 – One criterion is more important than the other, but the advantage is at an average level.
7 – One criterion is clearly more important than the other.
9 – One criterion is much more important than the other.
Source: own elaboration

(Kobylinska and Glinska [82], Gędek et al. [83], Strojny [84]), the eleven geothermal municipalities receive a matching benchmark group composed of five municipalities with corresponding size (population and territory in km^2), administrative profile and geographical location. The control variable aims to represent a similar socioeconomic structure as the geothermal municipality but without any exploitation of the geothermal resources. The composition of the municipality competitiveness indicator for the geothermal municipalities and for the benchmarked municipalities is explained in the next section.

5. Municipality competitiveness concept

As discussed in Section 1, the concept of local competitiveness has a wide definition. For such a methodological issue, an expert method may serve as a solution. In our case, an expert opinion supports the specification of the local competitiveness model. The Analytical Hierarchy Process (AHP) expert method is used to determine the local competitiveness index construction. Since our research discusses the aspects of regional economics and a renewable energy resource exploitation the expert group is built in relation to these two research problems.

According to the AHP expert selection criteria [86] eleven professors and doctors from the Economic Department of Rzeszów Technical University and nine mayors of the examined geothermal municipalities involved in the local geothermal development are considered as experts in this study. In total, the experts batch accounts for 20 mixed experiences professionals. Since the evaluation of method results is made by the type of experts, what counts is the appropriate selection of experts, not their number.

First, experts are asked to assess the best measuring indicators of municipality competitiveness from the data available at the Local Data Bank for years 1999–2017. Data for each municipality is collected on the NUTS-5 level. Table 3 presents the selection of indicators that best refer, according to the experts, to economic welfare and sustainability dimensions (see Section 1). Consequently, the competitiveness model of a municipality is organized into 6 main categories and 4 subcategories, which yields in total a matrix of 24 indicators determining municipality competitiveness in Poland. Due to the various data structures, the 24 indicators are normalized by the Zero Unitarization Method (Kukula [85]) with the normalization range [0 … 1].

The Analytical Hierarchy Process (AHP) method created in the 70s by Saaty is popular among the multicriteria analysis methods with particular applications in assessing socioeconomic and management problems (Saaty [86,87], Herath and Prato [88], Lee and Chan [89], Sipahi and Timor [90], Linkov and Moberg [91], Subramanian and Ramanathan [92]). The benefits of engaging experts from the examined scientific subject is addressed in the works of Cox et al. [93], Boulanger and Bréchet [94], Rezaei-Moghaddam and Karami [95], Singh and Nachtnebel [96] and Strojny and Heijman [97], among others. The AHP procedure is based on a hierarchical modelling of the criteria and their subcriteria. Experts evaluate their relationship in pairs using the Saaty's 1–9 scale (see Table 3 legend). On the basis of the significance analysis in a given pair made by experts, the weight of a particular indicator is assigned. The AHP is a mixed quantitative and qualitative method. The essence of the method is also the consistency of the comparison in the matrix determined by the Consistency Ratio coefficient (CR). Expert preferences are examined, while the remainder is a mathematical procedure during which the consistency of each expert's response ratio is calculated. The function of the CR is to ensure the internal validity of responses. Therefore, there is no need for additional verification of results, the method itself takes over this task and itself examines the internal consistency of expert responses (Ho [98]). We use the dedicated AHP software *Super Decisions* (version 3.2) to accept or reject the weighting of given indicators while considering the CR score. The AHP tool that was distributed to the experts, i.e. the questionnaire of municipality competitiveness with the elaborated Saaty's scale is presented in the data article (Kurek [99]).

Resulting from the pairwise comparisons, each model element receives a weight, specifically the weight of the model category, w_i, and the subcategory indicator weight, $w_i i$. The experts' judgements decompose the problem to a reciprocal matrix (KxK) of *P* criterions where numbers in each criterion pair p_i and p_j to represent a ratio $(p_i/p_j)/1$ (Saty and Kearns [100], Oddershede et al. [101]). According to the AHP methodology, weights in each category sum up to 1 (or 100%) since the elements from the same level are compared and weighted relative to each other. Therefore, a weight is interpreted

Table 4
The AHP computed municipality competitiveness indicators weights.

Model of the synthetic competitiveness indicator (CI)					
weights of categories					
$wC_p = 0,14$	$wC_e = 0,24$	$wC_g = 0,12$	$wC_t = 0,17$	$wC_i = 0,19$	$wC_l = 0,14$
weights of subcategories					
$wC_p1 = 0,26$	$wC_e1 = 0,25$	$wC_g1 = 0,19$	$wC_t1 = 0,23$	$wC_i1 = 0,16$	$wC_l1 = 0,18$
$wC_p2 = 0,29$	$wC_e2 = 0,23$	$wC_g2 = 0,39$	$wC_t2 = 0,29$	$wC_i2 = 0,38$	$wC_l2 = 0,28$
$wC_p3 = 0,28$	$wC_e3 = 0,28$	$wC_g3 = 0,26$	$wC_t3 = 0,21$	$wC_i3 = 0,25$	$wC_l3 = 0,38$
$wC_p4 = 0,17$	$wC_e4 = 0,24$	$wC_g4 = 0,17$	$wC_t4 = 0,27$	$wC_i4 = 0,22$	$wC_l4 = 0,16$

Source: own elaboration

Table 5
The synthetic competitiveness index (CI) for the geothermal municipalities and the established benchmark municipalities.

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Mszczonów	0,36	0,49	0,51	0,52	0,44	0,53	0,51	0,54	0,51	0,51	0,44	0,42	0,43	0,39	0,41	0,42	0,45	0,45	0,49
Benchmarks	0,42	0,37	0,36	0,34	0,39	0,35	0,39	0,41	0,37	0,37	0,42	0,42	0,42	0,38	0,41	0,40	0,39	0,40	0,36
Uniejów	0,52	0,53	0,52	0,58	0,60	0,55	0,56	0,60	0,59	0,58	0,59	0,62	0,65	0,66	0,65	0,67	0,69	0,68	0,71
Benchmarks	0,40	0,37	0,35	0,38	0,41	0,40	0,39	0,39	0,34	0,35	0,35	0,35	0,38	0,39	0,36	0,41	0,37	0,36	0,32
Poddębice	0,61	0,58	0,57	0,53	0,51	0,54	0,55	0,45	0,57	0,51	0,50	0,63	0,63	0,63	0,61	0,65	0,66	0,69	0,66
Benchmarks	0,48	0,46	0,54	0,52	0,50	0,53	0,52	0,48	0,48	0,48	0,49	0,52	0,50	0,53	0,50	0,49	0,50	0,53	0,57
Szaflary	0,52	0,45	0,49	0,48	0,41	0,47	0,41	0,49	0,47	0,55	0,66	0,57	0,58	0,63	0,57	0,59	0,46	0,54	0,61
Benchmarks	0,49	0,54	0,56	0,52	0,52	0,57	0,57	0,54	0,57	0,54	0,56	0,58	0,55	0,58	0,56	0,54	0,55	0,52	0,60
Bukowina T.	0,71	0,65	0,77	0,61	0,60	0,65	0,68	0,73	0,67	0,70	0,68	0,77	0,80	0,75	0,84	0,88	0,98	0,85	0,86
Benchmarks	0,49	0,49	0,49	0,46	0,50	0,46	0,52	0,48	0,43	0,47	0,48	0,50	0,48	0,51	0,51	0,52	0,53	0,57	0,52
Poronin	0,70	0,62	0,61	0,66	0,65	0,68	0,60	0,64	0,72	0,67	0,65	0,72	0,67	0,64	0,64	0,65	0,68	0,66	0,67
Benchmarks	0,49	0,47	0,47	0,49	0,51	0,49	0,45	0,45	0,45	0,48	0,45	0,47	0,51	0,46	0,52	0,45	0,48	0,49	0,51
Zakopane	0,94	0,97	0,98	1,00	1,00	0,98	0,98	0,96	1,00	0,96	1,00	1,00	1,00	0,98	0,99	0,96	0,85	0,76	0,86
Benchmarks	0,46	0,49	0,52	0,49	0,48	0,49	0,51	0,53	0,52	0,49	0,48	0,47	0,48	0,52	0,48	0,50	0,47	0,48	0,46
Biały D.	0,80	0,84	0,62	0,71	0,67	0,66	0,67	0,67	0,61	0,64	0,62	0,57	0,60	0,60	0,62	0,61	0,71	0,75	0,75
Benchmarks	0,42	0,46	0,50	0,51	0,44	0,45	0,46	0,50	0,50	0,50	0,47	0,47	0,50	0,50	0,47	0,50	0,55	0,54	0,56
Grudziądz	0,55	0,53	0,57	0,60	0,53	0,64	0,44	0,59	0,62	0,61	0,52	0,55	0,53	0,50	0,52	0,57	0,50	0,58	0,56
Benchmarks	0,65	0,65	0,66	0,64	0,67	0,65	0,66	0,59	0,60	0,63	0,60	0,71	0,65	0,58	0,62	0,56	0,67	0,54	0,57
Pyrzyce	0,61	0,62	0,57	0,62	0,57	0,51	0,55	0,61	0,62	0,54	0,43	0,48	0,46	0,39	0,54	0,45	0,46	0,45	0,61
Benchmarks	0,57	0,56	0,54	0,56	0,50	0,53	0,56	0,60	0,61	0,64	0,64	0,62	0,62	0,63	0,65	0,65	0,62	0,59	0,59
Stargard	0,47	0,53	0,46	0,51	0,46	0,50	0,46	0,45	0,46	0,51	0,52	0,47	0,45	0,47	0,45	0,39	0,42	0,48	0,45
Benchmarks	0,56	0,57	0,56	0,55	0,60	0,59	0,60	0,56	0,59	0,53	0,58	0,56	0,55	0,57	0,55	0,58	0,58	0,50	0,56

Source: own elaboration

from the significance of an indicator in the experts' opinion. Table 4 illustrates the obtained weights for each of the municipality competitiveness indicators (see Table 3).

The stages of the AHP experts procedure can be summarized as: step one: creating a model of variables describing competitiveness at the municipality level (Table 3), step two is the assessment of individual elements in pairs according to Saaty's scale. Then, the expert responses are processed through the AHP software, which includes only the consistent expert assessments. The last step is the calculation of the average value of all the individual experts assessments obtained, the final effect of which are the weights of each competitiveness indicator (Table 4). These steps follow the principles of the AHP method experts proceedings (Saaty [102], Al-Harbi [103]).

Next, following the aggregation procedure of normalized competitiveness indicators (Table 3) and corresponding weights (Table 4) a single score i.e. the competitiveness indicator (CI) is generated according to the following formula.

$$CI = \sum^{n} w_i C_i = w_i C_i \left(\sum^{n}_{i=1} w_i i C_i i\right) \quad (2)$$

Where

$$\sum^{n}_{i=1} w_i = 1 \quad (3)$$

and

$$\sum^{n}_{i=1} w_i i = 1 \quad (4)$$

$W_i C_i$ - weight of the category of local competitiveness.
$w_i\, C_i i$ - weight of the subcategory of local competitiveness
$i = 1, \ldots, N$ (observation)

As a result of aggregation computations, each of the geothermal municipalities and the benchmark municipalities receive the competitiveness index (*CI*), a singular indicator of competitiveness for each of the observed years. The CI places in the 0–1 range, where 1 represents the highest score of geothermal municipality competitiveness throughout the observed time period. As the model dependent variable, the CI determines the level of the municipality competitiveness. Table 5 presents the compilation of the CI scores for the geothermal and benchmark municipalities.

These CI indexes are normalized to be used in the panel analysis. The next section discusses the results of panel modelling after the application of the model variables (see Tables 1 and 5) to the model formula. The outcomes are expected to verify our hypothesis.

6. Panel model robustness check

Panel data econometrics attempts to fill the research question if the geothermal exploitation parameters are significant to the municipality competitiveness model. Due to the composition of the data set and the observation of entities across the time, a balanced (full data set) and univariate panel model is used (Greene [79]). The software *GRETL* is used to run the verification of model 1 and the model variables (Table 1), whereas the dependent variable CI scores

Table 6
Results of the estimation of the univariate parameters describing the impact of geothermal variables on the municipality competitiveness level.

	Stand $_\beta$	Coefficient	Std. Error	t-ratio	p-value	Sig.
Model 1: geothermal and control variables, fixed in time (γ = 0), 209 observations						
Time series length = 19						
Dependent variable: geot CI						
const		0.384258	0.101533	3.7846	0.0002	***
geot spa	0.184453455	0.068732	0.0274329	2.5055	0.0131	**
geot GJ	0.360533707	7.81262e-07	1.29084e-07	6.0524	<0.0001	***
benchmark CI	0.0363085	0.0788234	0.141606	0.5566	0.5784	
county income	0.543747745	0.00090932	0.000290393	3.1313	0.0020	***
county heat	−0.158056124	−0.861717	0.814754	−1.0069	0.2815	
Model 2: geothermal and control variables, dynamic in time (γ = 1), 198 observations						
Time series length = 18						
Dependent variable: geot CI						
const		0.237192	0.0982136	2.4151	0.0167	**
geot spa	0.195100347	0.0726993	0.0253881	2.8635	0.0047	***
geot GJ	0.435171921	9.43651e-07	1.23888e-07	7.6170	<0.0001	***
benchmark CI	0.00722578	0.0156867	0.13304	0.1179	0.9063	
county income	0.362484544	0.00060619	0.000270435	2.2415	0.0262	**
county heat	−0.131774552	−1.37994	0.767378	−1.7983	0.1038	
time lag	0.309629192	0.35017	0.0600092	5.8353	<0.0001	***
Model 3: geothermal and control variables (*no county incl.*), fixed in time (γ = 0), 209 observations						
Time series length = 19						
Dependent variable: geot CI						
const		0.586737	0.0800365	7.3309	<0.0001	***
geot spa	0.197449088	0.0735745	0.0280039	2.6273	0.0093	***
geot GJ	0.38200	8.28795e-07	1.31065e-07	6.3235	<0.0001	***
benchmark CI	−0.038635194	−0.0838745	0.134686	−0.6227	0.5342	
county heat	−0.035336501	−0.370043	0.731449	−0.5059	0.6135	
Model 4: geothermal and control variables (*no county incl.*), fixed in time (γ = 1), 198 observations						
Time series length = 18						
Dependent variable: geot CI						
const		0.358289	0.0829219	4.3208	<0.0001	***
geot spa	0.204643717	0.0762554	0.0256171	2.9767	0.0033	***
geot GJ	0.45400	9.84034e-07	1.23919e-07	7.9410	<0.0001	***
benchmark CI	−0.04247073	−0.0922012	0.125393	−0.7353	0.4631	
county heat	−0.049223659	−0.515469	0.67072	−0.7685	0.4432	
time lag	0.32847115	0.371479	0.059903	6.2013	<0.0001	***

Notes: 1) *, ** and *** denote p < 0.05, p < 0.01 and p < 0.001.2) Stand β stands for the standardized beta coefficient, according to the Goldberg equation, Kim and Ferree [105, p.189].
Source: GRETL own elaboration

are in Table 5. We examine the model using four scenarios of the composition of the independent variables. Cross validation of the selection of model variables in the four scenarios tests the sensitivity of the model and allows us to check the regression fit's robustness. Sensitive analysis is used with multivariate modelling in order to determine how independent variable values impact a particular dependent variable under a given set of assumptions (Chatterjee and Hadi [104]).

Since we assume that municipality competitiveness is dependent on the exploitation of geothermal resources in terms of a geothermal recreational centre or geothermal energy production, we introduce the four panel models. The two static and the two dynamic scenarios identify the influential independent model parameters and help to validate the hypothesis. These simulations test if the relation between the competitive index and geothermal variables changes while employing additional independent variables to the model. The two dynamic panel models test if the assumption of the time lag better explains the effect of the geothermal variables on local competitiveness, since the geothermal GJ production increases over time and geothermal bathing centres or spas are long-term investments in a municipality. With reference to the panel model Formula (1), the summary of the simulations is enclosed in the Table 6.

The four models examined reveal the significant, statistical relationship between the geothermal parameters of a geothermal spa and of geothermal GJ production, and the competitiveness index CI. Among the control variables, only the county income per capita results are significant in the proposed model. Yet, model 3 and 4 without this variable confirm the significant relation between the geothermal variables and the dependent variable CI. This variable is a considerably contributing factor to local competitiveness. However, our study shows that it is not a main determinant. The two other control variables are insignificant in the model. We can argue that local competitiveness in the case of the geothermal municipalities is not related to the amount of energy other sources deliver to a municipality. Moreover, the benchmark municipality competitive index in the model was insignificant. Among the four scenarios of municipality competitiveness, the models 2 and 4 with the lagged variable presents with a better quality. The interpretation confirm the assumption of a postponed impact of the geothermal investment on local economy. Table 7 captures the statistical quality of the four models.

Results show that the best quality models according to the statistical tests are the dynamic models 2 and 4. The instruments of the two tests are statistically valid, i.e. uncorrelated with the random component of the model. The R^2 interpretation confirms

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Table 7
Comparison of the statistical tests for the four panel models.

Stat. test	Model 1	Model 2	Model 3	Model 4
LSDV R^2	0.267963	0.388263	0.230772	0.371282
Within R^2	0.253172	0.369326	0.215230	0.351819
P-value (F)	1.07e-07	9.72e-13	2.38e-06	3.10e-12
Akaike criterion	−213.6834	−237.8399	−205.3262	−234.4184
rho	0.294794	−0.040573	0.325588	−0.041071
Durbin-Watson	1.319759	1.981371	1.261327	1.985350
Hausman test	χ^2 (5)>20.2401 p = 0.00112648	χ^2 (6)>17.3994 p = 0.00792225	χ^2 (4)>9.59967 p = 0.0477391	χ^2 (5)>13.8017 p = 0.0169194

Source: GRETL own elaboration

the better fit of the two dynamic models. Static models 1 and 3 are of a lower quality, yet statistically justified. The results of the Hausman test indicate the correct model assumption of the variables' exogeneity and the fixed effects panel model fit. Low p-values count against the GRETL determined null hypothesis that the random effects model is consistent and support the fixed effects model choice.

The geothermal GJ are produced locally in the thousands, whereas a geothermal spa is either present or not in a municipality. Therefore, the analysis of these two variables coefficients is ambiguous. In addition, the units of all the model variables are distinct and have widely varying statistical means and variances, which hinders coefficient interpretation (each of the model variables is expressed in different units). In such a case, Kim and Ferree [105], Menard [106] and Vittinghoff et al. [107] advise regression coefficient standardization. Baguley [108] argues that coefficient standardization raises statistical discussion. However, he accepts this procedure in the situation of metrics variety.

Standardization enables the comparison of the size of the impact of the model variables on the municipality competitive index. As a respective procedure, standardization does not change the statistical significance of the model variables. The standardized coefficient values estimate the strength of each predictor evaluated in identical metrics, i.e. in standard deviation units. Therefore, standardization observes how much of the CI standard deviation changes when one of the model explanatory variables changes by one of its standard deviation. In the case of geothermal GJ production, we can observe a general impact of the variable on the competitiveness index (not an impact of 1 geothermal GJ on the competitiveness index). The standardized coefficient analysis indicates in the presented four models that the scale of the geothermal GJ production has a bigger impact on the examined municipality competitiveness than a geothermal recreational centre. Although in all four scenarios, both geothermal variables are significantly related to the municipalities' competitive index.

From the comparison of the four models, we conclude that the dynamic models 2 and 4 are the best fit for the methodological concept of our study. The interpretation of the best model with the strongest coefficients value points (model 4) indicates that while the parameter of geothermal GJ production changes by one standard deviation, it results in a 0,45 change in the standard deviation of the municipality competitiveness index. In the case of the geothermal spa parameter, its increase by one standard deviation causes a 0,20 increase of the CI variable standard deviation. In addition, the standardization of coefficients confirms no statistical significance of the control variables in the models. Although a statistical relation is observed between the competitiveness index and the county income control variable, we may reject it as a core component of the geothermal municipality competitiveness. No significant change is observed among the four models if this variable appears in the model or not. Observation of the model outcomes confirms the hypothesis that geothermal energy exploitation in our model approach has a positive effect on the municipality competitiveness indicators.

7. Conclusions and discussion

This research attempts to discover if geothermal exploitation contributes to municipality competitiveness. We aim to find a statistical relation between the parameters of geothermal exploitation in Poland and municipality competitiveness that we conceptualized. Our hypothesis states that the utilization of the geothermal resource via geothermal heat production and the establishment of geothermal recreational centres positively impacts municipality competitiveness. The hypothesis is tested using panel data econometrics. In order to verify the hypothesis, we select 11 municipalities in Poland according to the criteria of statistical relevance for the panel analysis. Municipality competitiveness is represented by the competitiveness index (CI), which is determined by the expert Analytical Hierarchy Process method.

We develop a panel model where the local competitiveness index is tested in relation to the geothermal parameters and appointed control variables to exclude the biased interpretation of the geothermal predictors. The selection of the model variables is rooted in the argument of this study and aims to tackle the phenomenon of local geothermal exploitation. Using static and dynamic panel regressions, we examine whether the selection of variables is dependent on the model specification. Due to the sensitive analysis, we run four model scenarios, employing a set of control variables to support the hypothesis verification. Application of the developed model formula delivers robust results. Regardless of the higher statistical quality of the dynamic models, the analysis leads to one conclusion. In all four simulations, the geothermal variables, e.g. recreational bathing centres and GJ production, have a significant and positive impact on the developed municipality competitiveness index. Statistical significance of the appointed lagged variable stipulates that the effects of local geothermal exploitation are delayed. As such, the level of the competitiveness index for a municipality from a previous period generates the current level of the CI. Therefore, we argue that the benefits of geothermal resource usage in a municipality intensify with time.

Coefficient standardization is applied in order to observe an impact of each of the geothermal predictors on the competitiveness index. The interpretation of the standardized coefficients confirms the significant role of geothermal energy production and geothermal recreational centres in building municipality competitiveness. Whereas, the interpretation of the appointed local competitiveness control variables allows their rejection. The comparison of the county level control variables shows that the competitiveness of the examined municipalities does not follow the financial condition of the region (county). However, the county income per capita is important in two model scenarios. We can argue that a reverse effect of the local geothermal exploitation on the county where the municipality is situated occurred. Further research is needed if the geothermal municipality can increase the level of its county's own income level. As well, the county heat

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energy provision through sources that are not geothermal is insignificant in the model. Therefore, we observe a significant role of geothermal energy activities in the municipalities. The benchmark municipality competitiveness index displays no relation with our model structure. Hence, it is the geothermal resource that significantly determines the local competitiveness in case of our examination. It also corroborates the hypothesis.

Following the model outcomes, we conclude that in terms of the proposed selection of Polish geothermal municipalities, the exploitation of the endogenous geothermal resources is an essential element in their competitiveness structure. Model observations justify the conclusion that a municipality's competitiveness improves with an increased use of the available geothermal energy produced in local geothermal plants and with the establishment of geothermal recreational centres. As endorsed by Porter in his study on geothermal competitiveness (Porter [37]), local geothermal exploitation in Poland fits in the context of the endogenous growth principle. However, until now a relatively small number of Polish municipalities make use of the available geothermal resources irrespectively of the geothermal use potential. Our results deliver an argument for further local development of the geothermal resources in Poland.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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