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Determinants of Geothermal Power Sustainability Development: Do Global Competitiveness Markets Matter?

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Abstract: As a substantially capital-intensive venture, the distribution network of the geothermal business is disproportionately clustered around the project designing phase. The profound geothermal industry is broad, and consequently the geothermal economy differs substantially from one place to another. The primary goal of this study is to analyze the effect of factors relating to global competitiveness along with economic growth on the sustainability of geothermal energy among European 27 countries. Employing auto regressive distributing lag (ARDL), the major findings suggest that a significant rise in the geothermal power production sustainable development can occur in the 14 European Union emerged economies applying global competitiveness criteria than in EU13 developing economies. Among additional criteria, a conducive environment, intellectual capital, market shares, as well as an innovation ecosystem contributes more significantly to the sustainability of geothermal energy among the 14 classed as established in this research than the 13 emerging economies. The results suggest that geothermal power sustainability among the European countries regions could attain a sustainable increased level of geothermal energy generation by putting in place the necessary global competitiveness determinants for the EU 2030 Energy Union goals to be achieved. The attainment of these Energy Union goals will assist in combating climate change and fighting environmental pollution. Three estimators were adopted to confirm that all calculated projections made in the study are said to be valid. The global competitiveness measures should be made better effective by the EU nations and this will help in achieving a pollution-free society and environment. Authorities in charge of policy and law-making in the EU regions should participate more in global competitiveness for geothermal energy production to become sustainable. Cointegrated strategies that will promote sustainability should be stressed by policymakers in the EU. This will go a long way in reducing the level of carbon dioxide emissions and also in promoting sustainability in the area of geothermal power generation.

Keywords: geothermal power; global competitiveness; sustainable development; EU economies

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1. Introduction

1.1. Geothermal Background

Fossil fuel remains the key source of heat and more than half of Europe's energy needs are met through heat [1]. Heating and cooling could be made free of carbon dioxide through the aid of geothermal energy, which is an unpolluted energy source and a technological breakthrough that could be put into operation anywhere across Europe [1]. Geothermal energy is now being considered globally as a technology that has carved a niche for itself and it is becoming a mainstay of the economies of most European countries. In countries such as Sweden and Finland, it is estimated that over 2 million geothermal heat pumps have been installed [1].

Industries in geothermal power generation are minimizing the rate of carbon emissions in the EU region by providing services that brew comforts, such as conditioned air and space heating to individual homes, industrial settings, commercial hubs, and other public facilities [2]. This unpolluted form of energy is also a good source of cooling, heat

production, and electricity, and it allows for storage of thermal underground, which also stabilizes consumers' prices of fossil fuels, which are sometimes volatile [2]. Similarly, it was confirmed by the French agency ADEME, that geothermal energy is applied to heating and cooling in district (DHC) networks in France. This will have the capacity to reduce energy bills to as low as EUR 15 per megawatt-hour (MWh) among households in comparison to the cost of fossil fuels, and the least cost is estimated at EUR 61 per MWh [2].

It was further estimated that Europe is the leading global market hub for geothermal energy production with an estimated 5.5 Gigawatt thermal (GWth); this was said to be the installed capacity as of 2019 [3]. This estimation was according to the European Geothermal Energy Council in Europe. This estimation signals the increased installations of geothermal production in Europe. As of the year 2020, there were new commissions of 11 geothermal systems in 2019, this creates a megawatt add up of 130 megawatts (MWth) [3]. A good case study of this is seen in the Netherlands, which moved from zero geothermal capacity level to being among the top five European countries with the biggest geothermal production capacity in 12 years [3].

Unfortunately, no matter its reputation of being a renewable and sustainable energy source, geothermal energy also has some challenges and concerns regarding its competitiveness and sustainability. One of the largest disadvantages of geothermal energy is that it is high cost. The production of geothermal energy is capital intensive, it comes with huge production costs, which range from USD 2–5 million to have a 1-megawatt (MW) capacity plant [4]. Although the cost might be huge, returns on investment will make this -up in the long run. The exploration and drilling of new reservoirs play a big role in driving up costs and typically accounts for half of the total costs [4]. The current high price level of technologies, prices of energy, and new technological breakthroughs, might not make the geothermal installations cost effective [5]. Geothermal installations in homes and commercial hubs for heating and cooling purposes also come with a huge cost of production. The average cost of installing ground source heat pumps is around USD 15,000–40,000 and it could take an average of 10–20 years to make returns on investments [5].

Direct heating in all its forms is far more efficient than electricity generation and places less demanding temperature requirements on the heat resource [1]. Heat may come from co-generation with a geothermal electrical plant or from smaller wells or heat exchangers buried in shallow ground. As a result, geothermal heating is economical over a much greater geographical range than geothermal electricity [5]. Where temperature and pressure allow, combined heat and power should be adopted in all future geothermal developments. This will enhance efficient utilization of geothermal resources. This calls for research to explore potential direct uses especially among the communities living in geothermal resource areas [3].

With the increasing concerns on the energy shortage and carbon emission issues worldwide, sustainable energy recovery from thermal processes is consistently attracting extensive attention [2]. Nowadays, a significant amount of usable thermal energy is wasted and not recovered worldwide every year. Meanwhile, discharging the wasted thermal energy often causes environmental hazards [2]. Significant social and ecological impacts will be achieved if waste thermal energy can be effectively harnessed and reused. Novel heat utilization materials and advanced heat recovery cycles are the key factors for the development of waste high-temperature energy utilization [3]. Integrated systems with multiple products show significant application potential in waste thermal energy recovery. In addition, thermal energy storage and transportation are essential for the utilization of harnessed waste heat energy [4]. In contrast, the low recovery rate, low utilization efficiency, and inadequate assessment are the main obstacles for the waste cold energy recovery systems.

Research made it known that there are industrial settings that have been operating in the geothermal operation for the last 40 years; the huge cost of putting in place installations has made it an area where just a few manufacturers could operate solely [6]. Much of the equipment needed for the underground fittings is produced by companies that depend

on oil and gas or the mining sector [6]. Geothermal energy production sustainability has created a lucrative market for the equipment and fittings needed for geothermal productions, which are mostly produced for operations in the oil and gas sector. The interwoven relationship between the price of oil and the cost of drilling is a result of a high level of dependence on hydrocarbon production in the course of drilling and the fact that the geothermal energy sector is still limited in terms of market share [6]. This situation is likely to persist as long as the geothermal energy sector does not build up a strong market share of its own [6]. For instance, over 2160 rigs are used globally in 2018, 84 of which were in Europe. The O&G drillings account are what 70% of those rigs are being used for [6].

The market conditions for geothermal production sustainability are different across Europe, this is due to non-uniformity in the national regulations of each of the European countries, and this has made it difficult to achieve a common geothermal energy market which is European based [7]. In many of these European countries, the cost of running geothermal business operations has made just a few companies go into the business. The small number of companies in the business has not created enough room for competition. Most of these companies are not competitive in the market. Another factor that limits the number of companies that could go into geothermal production sustainability, is that geothermal energy generation requires meeting up with legal frameworks that might be a bit cumbersome [7]. The essence of this is to ensure a high level of compliance with environmental regulations. There are still several challenges that are inhibiting sustainability in the geothermal energy sector, some of these challenges are market barriers which span from financing and regulatory hiccups to challenges that come with lots of technicalities [7].

How efficient resources are put into good use is also an important issue in the geothermal industry sustainability [8]. Raw materials should be judiciously used. The need for an increased level of recyclability in value chains is prioritized for two main purposes. Firstly, manufacturers need to be faced with a minimal level of risk factors in their supply chain; therefore, the level of competition at the international level is increasing. It is, therefore, very important for resources to be efficiently maximized and supply should be tailored to the market demands to reduce the high level of exposure to risks [8]. Secondly, an increased level of resource efficiency is being promoted through the regulatory framework put in place by the European regulatory framework, this is to serve as a reward for the negative consequences of geothermal sustainability on the ecosystem and to also protect European geothermal companies from disruptions in their raw material chains [8].

One contention is that geothermal remains a good source of sustainable, unpolluted, and eco-friendly energy, which gives a high level of reliability. However, the cost of production of this safe, renewable energy has been a key challenge to the growth of the geothermal industry sustainability in Europe, which is causing the full potential of geothermal not to be fully realized [7]. However, there are a lot of uncertainties surrounding the future of geothermal production sustainability in Europe, and the future success of geothermal in Europe is dependent on factors such as technological breakthroughs, stability in energy prices, and politics. These uncertainties have made it difficult to predict the future of geothermal in the few decades to come [8].

1.2. Main Challenges

Some environmental difficulties connect geothermal installation sustainability as well. Geothermal energy, in nature, is location-specific, and it must be situated in a location with a good accessibility level to the energy, which indicates that not all regions would be befitting for the constructions of sustainability of geothermal output [9]. Additionally, although geothermal energy is recognized for not adding to greenhouse gases, it must be remembered that these other gases become released in the procedure of digging the soil [10]. Communities with geothermal components are highly inclined to earthquakes or other natural disasters. This is due to modifications in the land's morphology due to digging operations [11]. Geothermal power plants can have impacts on both water quality

and consumption. Hot water pumped from underground reservoirs often contains high levels of sulfur, salt, and other minerals [11]. Most geothermal facilities have closed-loop water systems, in which extracted water is pumped directly back into the geothermal reservoir after it has been used for heat or electricity production. In such systems, the water is contained within steel well casings cemented to the surrounding rock [11]. There have been no reported cases of water contamination from geothermal sites in the United States and Europe.

Apart from this, geothermal sustainable development is a capital-intensive project that requires a huge cost to set up. This alone has limited the number of companies that could go into the sustainable production of geothermal. The average cost for a plant fitting that has a capacity of 1 megawatt is between USD 2 and USD 7 million [12]. The cost of maintenance is also very high. The sustainability of geothermal energy comes with a huge cost outlay, for example, the fluid must be constantly pumped back to the underground reservoir once it is getting depleted. The pumping back of the fluid must be faster than the rate at which it is depleting. The impact of geothermal sustainability on the quality of water and other sea life cannot be underestimated [13]. Sulfur contents, salts, and other minerals are often found in the hot water being pumped out of the underground reservoir [13]. There are also social problems related to the geothermal energy sustainability. Its installations could mean loss of livelihood to some people, and trampling on the rights of the indigenous people, such as taking possession of their land. This could brew unending land disputes. Other social problems are related to noise pollution, odors, and a poor level of consultation between the concerned stakeholders over economic returns benefits, such as employment [14,15].

The primary research topics were: (1) How can global competitiveness considerations improve the long-term viability of the geothermal energy industry in the Eurozone throughout the period from 1990 and 2021? (2) Which European states are more exposed to the consequences of geothermal energy market sustainability generated by competitiveness index factors? (3) What will be the effect of global competitiveness measures on the sustainability of the geothermal energy supply among the 28 European countries? In a bid to curb climate change, it becomes necessary for the European countries to understand in what ways global competitiveness measures could promote the sustainability of geothermal energy, which is clean and safe in the European regions and sub-regions.

The objectives of this study are to:

1. Make an elaborate finding on what effect global competitiveness will have on geothermal production sustainability among the EU regions between 1990 and 2021.
2. To give a comprehensive study on geothermal power industry sustainability implications of global competitiveness drivers between the Union emerging markets and emerged states in the period frame of 1990–2021.

This study will contribute a significant amount to the existing body of literature in the domain of the sustainability of geothermal energy. This research will attempt to establish connections among the research variables captured for this study, and how global competitiveness measures could be used to promote energy security in Europe. The findings of this study on global competitiveness and geothermal sustainability might aid these European countries in combatting climate change and minimizing environmental pollution in EU regions and sub-regions. An analytical tool that fits into the EU setting was adopted for this study. This research also examines geothermal energy sustainability with global competitiveness to ascertain whether pre-determined guidelines that ensure the sustainability of geothermal energy are being fulfilled. The measures of EU competitiveness factors in this study are grouped in the following categories: investment, innovations, skills, enterprise, and competitive market. The study further adopted four indicators adapted from the World Competitiveness Yearbook, and the four indicators are factors of four elements which are: infrastructural base, the performance of the economy, efficiency in governance, and business [7,8]. If the identified socio-economic and environmental problems are given due attention and adequately addressed, it is expected global competitiveness will make a significant positive contribution to the sustainability of geothermal energy in the 14 EU

emerged economies and 13 EU emerging economies. It is also within the context of this study to find out the connection between global competitiveness and geothermal energy sustainability. It is also expected that the measures of global competitiveness identified for this study, will better explain the influence of global competitiveness on sustainable development. Once this is identified, EU countries could leverage this to boost their level of commitment to their sustainable development goals. In this manner, policy formulation and implementation will also be reduced among the 27 EU nations.

Numerous extant literatures have sought to investigate the correlation between sustainability of geothermal power and competitiveness at a global level. The research has distinct geo-graphical country localities and the research is of distinct modellings, methodology, findings, and conclusions. The author was able to infer that little research has been able to study the link between geothermal power sustainability and worldwide competitiveness, and the findings are inconclusive. The primary goal of this research is, therefore, to explore, in pursuit of existing research, on how the global competitiveness criterion could influence the development of the sustainability of the geothermal sector in the 14 European Union emerged countries and 13 European Union emerging countries between 1999 and 2021. The author was not able to obtain any previous research that seem to have examined concurrently the influence of global competitiveness drivers on the sustainability of geothermal power sustainability utilizing the Auto Regressive Lag (ARDL). Furthermore, this study explores the linkages between social-economic variables and competitiveness utilizing the growth hypothesis.

In our latest effort, improvements were made to the models used in this study models to enable a better description of sustainability of geothermal power at the European regional and sub-regional levels. All estimates have additionally been substantially modified taking into account the emphasis on the EU. The estimations focus on the possible advantages of geothermal energy in the long term based on data generated from subsurface temperatures from a model built by [7,8,16]. This has been a key advance of our model since the prior version represented these opportunities in just a rudimentary form. In three fundamental respects, the findings reported in this study paper, consequently, constitute a fresh contribution to the existing body of literature: along the dimension of geothermal power for sustainable development possibilities, their applications at an environmental level, and their focus geographical wise. The structure of this scholarly research is laid out as follows: Section 2 presents a comprehensive review of the current literature. Section 3 describes the research approach, encompassing specifications of the model and the estimating strategy. The empirical findings and discussions are provided in Section 4. Finally, Section 5 closes the article and expounds on the ramifications.

2. Review of the Literature

Competitiveness is a must if the European region is to accomplish the aims of a wise, inclusive, and sustainable geothermal energy industry growth, producing a high level of employment, social cohesion, and productivity as stated, including its Europe 2020 policy. For example, Qi et al. (2021) [17] examined how to advance competitiveness at an international level, and of China's renewable power sustainability, implying that within the renewable power product trade networking, the United States, Germany, and China are in a straightforward strong position, a few European economies are semi-marginal, and a few developing economies and emerging markets are steadily emerging. Likewise, ref. [4] examined the impact of geothermal renewable sources on how competitive towns are in Poland, revealing that geothermal energy generation and geothermal bathing sites are both key parts of municipal competitiveness in Poland. In a comparable manner, ref. [5] studied the association between the sustainability of geothermal power and competition at the municipal level in Poland. The study showed that geothermal energy was claimed to be of local competitive edge in the municipalities wherein renewable power sustainability is being utilized. Under the governance regulation, numerous studies, such as [18–20], produced inclusive national power and climate frameworks to cover the elements of the Energy

Union relating to the internal energy market, decarburization, energy efficiency, energy sustainability, research, innovation, and competitiveness. For instance, ref. [14] evaluated how the inhabitants of Korea conceive geothermal structural facilities after the Pohang earthquake in 2017 by utilizing the theory of social representation, recommending that Pohang inhabitants had a considerably bad view of geothermal plants irrespective of climate change mitigation, sustainable development, safety, and economic factors. Conversely, ref. [14] inspected the policy and resource driven appraisal of the sustainability of geothermal energy possibilities across the island nations of Grenadines and St. Vincent, suggesting that several frameworks, such as public–private partnership promotion, reliability of sources of information, augmented institutions, and regulator mechanisms are instances through which geothermal power demands could be sustained. In the same fashion, refs. [20–22] investigated the architecture of institutions, and the impact of socio-material types of energy-on-energy administration, and its infrastructural basis. The study delineated, furthermore, that the cultural background of the territories underneath the scope do influence national regulatory mechanisms on the sustainability of geothermal energy in Italy. Trained human elements and skills can play an essential part in conceptual frameworks in the sphere of sustainability of the geothermal power industry [23–25]. In this sense, ref. [26] examined the effect of human performance levels on the growth of geothermal energy sources and sustainable development, with the claim that the efficacy and effectiveness of geothermal power systems is connected to both the natural structural properties and human-controlled elements. In exactly the same way, ref. [27] looked into the possibilities of hybrid geothermal energy integrating with a desalination system, showing that relatively low capital costs can cut the cost of power generation and provide a substantial increase in this way toward sustainable development. Correspondingly, ref. [28] discussed the geothermal efficiency of multiple nodes in steamy sedimentary groundwater resources, suggesting that human input variables in a multiple-doublet system significantly impacts the fluid flow and heat transmission techniques to achieve effectual geothermal energy production sustainability. Several studies explained the correlation between geothermal and sustainability developmental issues, such as those in [29–39].

The technology sustainability could be leveraged to cut down the production cost of geothermal energy, and it is expected that technology will speed up the rate of drilling and cut down the estimated time on tripping with a high level of efficiency of all drilling parts [40–42]. In this sense, ref. [43] investigated the closed-loop geothermal energy recovery technology from deep high-enthalpy systems, suggesting that the commercial application of closed-loop geothermal technology to deep high-enthalpy systems is now feasible given advances in drilling technology. In the same manner, ref. [44] explored the pairing of geothermal energy technology and solar photovoltaic for net-zero energy in the residential sector, indicating that the massive savings potential in electricity production can be achieved along with a short payback period in cold climates. Similarly, ref. [45] searched the critical success factors for geothermal energy industry investments in Turkey, pointing out that the most important success factor is innovation and technology, which can ensure geothermal power project success.

Geothermal markets in the EU are under the regulation of strict governments, to put a check on the issue of climate change in the developed and developing countries of the world [3,46,47]. While the global geothermal power market was valued at USD 4.6 billion in 2018 and is projected to reach USD 6.8 billion by 2026, growing 5.0% from 2019 to 2026. In this sense, ref. [48] investigated the geothermal power market for energy sustainability in Europe, suggesting that the geothermal power sustainable supply is connected with the recognition of the crucial role that geothermal energy could play in the European market, as well as the future energy scenarios based on the replacement of fossil fuels with renewable sources. Furthermore, ref. [49] searched renewable energy market development on islands, referring to the idea that, although geothermal use is still in a juvenile market stage compared to other renewable energy, it has a significant role in developing the renewable energy market rapidly. On the other hand, previous research, such as [50–52],

examines the connection between renewable power and the growth of the economy of some South Asian Countries. The study showed that geothermal sustainability contributes more to the spate of economic growth than other sources of renewable energy sources [53,54].

It could be inferred from the literature reviewed that the connection between geothermal energy sustainability, global competitiveness, and economic growth was briefly discussed, but findings from most of these studies are still inconclusive. The criticisms leveled against most of these studies is that their estimated coefficients and elasticity could not be validated because the studies were not structured on a quantitative framework. Two tests are important in getting unbiased regression analysis and these are diagnostics and specification tests. Most of these papers evaluated do not examine this. The difference between this research and the other studies is shown in how this research carried out estimates to indicate the long-running influence of international competitiveness on geothermal power sustainability development in EU rising nations and EU emerged countries during the period of 1990–2021. Simultaneously, the growth hypothesis was employed to study the link among socio-economic variables as they impact geothermal energy sustainability. This investigation was not undertaken inside the Eurozone in the period of 1990–2021. Thirdly, this present analysis conducts diagnostics and specification checks, which were scarcely discovered to have been employed in any earlier study, and finally, an updated panel data technique to reveal cross-sectional dependency and to evaluate unobserved factors that are heterogeneous.

3. Methodology and Data

3.1. Theoretical Framework

Production function is a mathematical description of connection between physical outputs and physical inputs of an institution [7]. There are several kinds of production functions that may be categorized according to the degree of replacement of one input by the other, including the constant elasticity of substitution (CES) production function, the Leontief production function, and the Cobb–Douglas production function, which relates to the production function wherein one input may be substituted by the other, but to a limited degree [7]. For instance, capital and labor may be utilized as a replacement for each other, albeit to a certain degree only [8]. Meanwhile, the Leontief production function uses a fixed proportion of inputs, having no substitutability between them. It is regarded as the limiting case for the constant elasticity of substitution. Nevertheless, CES stands for the constant elasticity of substitution. The CES production function shows a constant change produced in the output due to a change in input of production [8].

In economics and econometrics, the Cobb–Douglas production function is a particular functional form of the production function, widely used to represent the technological relationship between the amounts of two or more inputs (particularly physical capital and labor) and the amount of output that can be produced by those inputs. The Cobb–Douglas production function is based on the empirical study of the American manufacturing industry made by Paul H. Douglas and C.W. Cobb. It is a linear homogeneous production function of degree one, which takes into account two inputs, labor and capital, for the entire output of the manufacturing industry (see Figure 1). The Cobb–Douglas form is developed and tested against statistical evidence by Charles Cobb and Paul Douglas between 1927 and 1947 [7]. According to Douglas, the functional form itself was developed earlier by Philip Wicksteed [8].

The focus of this research is to examine the connection between geothermal energy sustainability and global competitiveness in the EU economies. The study also considered some variables that are considered external to geothermal energy. Some of these factors are: a conducive environment, human resources, the size of the market, the level of innovations in the ecosystem, and the level of growth achieved and sustained in the economy. Some

previous studies were reviewed, such as those in [7,8,55–57], which allows us to formulate the following empirical model based on the Cobb–Douglas production function:

$$Y = f(K_{it}, L_{it}) \quad (1)$$

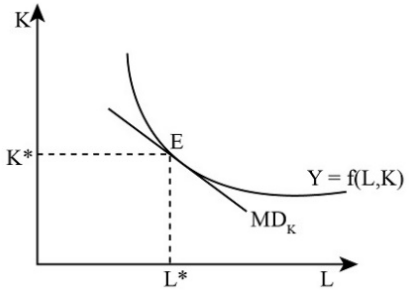


Figure 1. Cobb–Douglas Production Function.

As shown in the first equation (Equation (1) and Figure 1), Y stands for the output, K is capital, L refers to labor, I is used to represent the number of individuals, and t refers to the period considered for this study. The first equation was transformed into a log-linear form (Check Equation (2)), putting into consideration the dependent factor and connected determinants in logarithms. This will limit dynamic restrictions on the database selected for the study. Furthermore, supplemental empirical findings were derived from previous studies, such as those in [7,8,58–62], and this was reflected in the second equation model of competitiveness and outgrowth at the international level. Factors that could promote sustainable development in the long run are intervention and outgrowth, and these were also put into consideration. The logic of the model, selecting geothermal (GT) (dependent variable), enabling environment (ENV), human capital (HC), market size (MRK), innovation ecosystem (INN), and economic growth (EG) as dependent variables, is supported by common sense and relative research papers, such as those in [7,8]. Moreover, many important factors are addressed in this study, such as human capital, market size, innovation, the environment of the institution, and economic growth.

History from Adam Smith's global business hypothesis was adopted to explain global competitiveness. Although, during this time, other determinants were impacting the competitiveness of industries at the national and regional levels. A good measure of international competitiveness was given by the Organization for Economic Co-operation and Development (OECD). The measure was put as the production capability of firms and the nation at large to produce, which keeps them competitive in the global market and gives them a high-income comparative advantage and employment rating on a benchmark that could be sustained. The first equation forms equation two log-linear.

$$\ln GT_{it} = \beta_{0+} \beta_1 \ln ENV_{it} + \beta_2 \ln HC_{it} + \beta_3 \ln MRK_{it} + \beta_4 \ln INN_{it} + \beta_5 \ln EG_{it} + \varepsilon_{it} \quad (2)$$

T in the equation is used to represent the study time consideration, which could range from 1 to 27 (T = 1 . . . N = 27). GT refers to the oil equivalent (TOE) of geothermal energy outputs. lnENV represents the environment of institutions on focus, lnHC is referring to inputs from human capital, and lnEG is the level of economic growth measures. The gross domestic product is used as the measuring yardstick. lnINN relates to the level of innovation in the ecosystem and activities revolving around intellectual properties. lnMRK refers to the market share index rated by the gross domestic product on the purchase power parity in the current international USD standard. (α) is the value taken to be constant. The World Bank Databases (WBD) and Eurostat, as shown in Table 1, were the major sources of data extracted. β1, β2, and β3 are significant signs and interests in this study. Signs such as a conducive environment, human capital agility, economic growth, level

of innovation in the ecosystem, and size of the market are expected to make significant positive contributions to this study (see Tables A1 and A2).

Table 1. Summarization of the Variables.

Variables Considered	Abbreviations	Sources of Data	Signs and Statistical	Units of Measurements
Geothermal Power	GT	Eurostat	Dependent variable	Terajoule (TJ)
Enabling Environment	ENV	WBD	Positive/significant	Confidence interval for the governance (%)
Human Capital	HC	WBD	Positive/significant	Workforce input (number)
Market Size	MRK	WBD	Positive/significant	GDP per PPP (current international USD)
Innovation Ecosystem	INN	WBD	Positive/significant	Trademark applications, direct nonresident
Economic Growth	EG	Eurostat	Positive/significant	GDP per capita growth (annual %)

3.2. Testing through Panel Unit Roots

This testing technique was utilized to assess all variables recorded for this investigation. The essence of the testing is to guarantee that no opportunity for spurious regression occurs while panel data is still being used. The major purpose for carrying out the panel unit root is to solve the issue of the low power problem in a condition where an augmented Dickey–Fuller (ADF) is implemented. In a remark ascribed to [63,64], it was pointed out that the estimate may be disputed when the overall observations in a time series is estimated to be fewer than 50. Because the panel root analysis does have a greater power level, it may, thus, be employed to suggest answers to this problem [14,65]. These strategies have been frequently employed in earlier research on the consumption of energy [66].

3.3. Panel Estimations Technique

The selected pooled mean group, and this estimator, gives estimates as well as intercepts in the long run. It also displays the pace of adaptation and the heterogeneity error variance. The value of the gradient, in the long term, is constrained to being homogeneous. This estimating approach has the benefit of being reliable and effective in describing what connection exists in the long term. However, so that it can be properly employed, we still require the values of the corrective term to be smaller than two and also be negative. In utilizing this approach, there is another extremely crucial assumption that specifies that there has to be consistency in the estimates so the residual adjustment model will indeed be free of collinearity, which will lead to non-uniformity in the recorded variables.

All these requirements will be satisfied once the time delays (p,q) are included in both the independent (p) and also the dependent (q) parameters of the research. This approach also requires a larger size of T and N, but also T must have higher levels than N. With the study of [67], N is predicted to be about 20–30 nations. Another major estimator explored for this research is the mean group, which serves as the second estimator examined in this research [68]. An advantage that may be acquired from employing this estimator is because it yields coefficients of independent regression for every one of the studied nations [69,70]. In both the long and short term, the estimator might create a heterogeneous eco-efficiency that will be distinct for each of the studied nations. The dynamic fixed effect was the third estimator investigated in this research. In terms of features, this estimator is identical to the pooled mean group, and thus the ratio of cointegration is confined to being consistent throughout all panels in the long run. This estimator also causes the coefficients to be identical in the short term with a restricted pace of modification. The estimator additionally permits the coefficients of a certain panel. Correlation models in the long term of the mean group were mathematically expressed in Equation (3) below:

$$\ln GT_{it} = \theta_i + \delta_{0i}\ln GT_{t-1} + \delta_{1i}\ln ENV_{it} + \delta_{2i}\ln HC_{it} + \delta_{3i}\ln MRK_{it} + \delta_{4i}\ln INN_{it} + \delta_{4i}\ln EG_{it} + \varepsilon_{it} \quad (3)$$

Relationships of the pooled mean group and the dynamic fixed effect are statistically expressed in Equation (4) below:

$$\ln GT_{it} = \omega_i + \sum_{j=1}^{p}\Omega_{ij}\ln GT_{i,t-j} + \sum_{j=1}^{p}\delta_{ij}\ln ENV_{i,t-j} + \sum_{j=1}^{q}\delta_{ij}\ln HC_{i,t-j} + \sum_{j=1}^{q}\delta_{ij}\ln MRK_{i,t-j} + \sum_{j=1}^{q}\delta_{ij}\ln INN_{i,t-j} + \sum_{j=1}^{q}\delta_{ij}\ln EG_{i,t-j}\ \varepsilon_{it} \quad (4)$$

In the equation, i is representing countries which number from 1 to 27, t is the considered year time frame in the study, which is 1990 to 2021, j represents time lag in the optimum, and ω_i measures the fixed effect. The relationship in the short run with error correction models is expressed below:

$$\Delta\ln GT_{it} = \omega_i + \partial_i(\ln GT_{i,t-1} - \Omega_1\ln ENV_{it} - \Omega_2\ln HC_{it} - \Omega_3\ln MRK_{it} - \Omega_4\ln INN_{it} - \Omega_5\ln EG_{it}) + \sum_{j=1}^{p}\Omega_{ij}\ln GT_{i,t-j} + \sum_{j=1}^{q}\delta_{ij}\ln ENV_{i,t-j} + \sum_{j=1}^{q}\delta_{ij}\ln HC_{i,t-j} + \sum_{j=1}^{q}\delta_{ij}\ln MRK_{i,t-j} + \sum_{j=1}^{q}\delta_{ij}\ln INN_{i,t-j} + \sum_{j=1}^{q}\delta_{ij}\ln EG_{i,t-j} + \varepsilon_{it} \quad (5)$$

3.4. Durbin–Wu–Hausman Testing

This test is deemed highly crucial in making a decision amongst three estimators examined for this investigation. That includes the mean group, the pooled mean group, and the dynamic fixed effects [71]. In selecting between the mean group and the pooled mean group, when we have the null hypothesis stated as being accepted, then the pooled mean group is selected above the mean group. This suggests the pooled mean group is more efficient. Furthermore, between both the pooled mean group as well as the dynamic fixed effects, if the hypothesis is acceptable, it signifies the pooled mean group estimator will be of greater proficiency than just the dynamic fixed effect model, and finally, if somehow the null hypothesis will have to be rejected, then perhaps the dynamic fixed effect ends up taking preference over the pooled mean group [72].

4. Results and Discussion

4.1. Results

This research utilized three estimators, and the three estimators are the mean group, the pooled mean group, as well as the dynamic fixed effect, to assess the role of competitiveness at a global scale on the sustainability of geothermal energy sustainability in the EU area states utilizing their degree of economic development. The discussed European countries considered for this research are are classified into two groups: EU14 emerged economies (Spain, Sweden, Germany, Greece, Luxembourg, the Netherlands, Ireland, Italy, Finland, France, Austria, Belgium, Denmark, and Portugal) and EU13 emerging markets (Lithuania, Latvia, Estonia, Croatia, Czech, Bulgaria, Cyprus, Slovenia, Hungry, Slovakia, Romania, Poland, and Malta). To examine the existence of stationarity of the dataset in all the measures (lnINN, lnGT, lnMRK, lnENV, lnHC, and lnEG) evaluated for this work, unit root tests were performed, relying on Levin, Lin, as well as Chu (LLC), and Im, Pesaran, and Shin (IPS). It, therefore, becomes vital to identify the sequence of integration for all the parameters investigated in this research. Statistical findings on specification and diagnostic testing were reported in Table 2 in this research and it could, therefore, be determined that all the variables remain stationary at such a level and a first difference for both IPS and LLC. This illustrates that the parameters are in a mixed integration order (I (I) and I (0)). Based on these results, the panel ARDL may be implemented.

Preliminary tests have been carried out to commence the estimating procedure. A summary of the data in Table A1 demonstrates that all the parameters investigated have a normal distribution. Results from relationships are presented in the Table A2 inside the Appendix B section. In a quest to determine whether a link existed from among variables, the variance inflation factor is investigated [73,74]. The aim of these tests is to verify that no spurious regression occurs that might result in non-objectivity in conclusion. Linear

regression was undertaken well before the variance inflation factor (VIF) was conducted. This was documented in Table 3. Analysis indicates there is no association among the studied variables. The basic rule is that whenever the variance inflation factor is smaller, below five [70], there is no correlation. Consequently, all variables are considered to associate with each other.

Table 2. The Panel Unit Root Testing Findings for the Eurozone in 1990–2021.

Variables	Level		First Level	
	LLC	IPS	LLC	IPS
GT	53.330 *** (0.000)	57.267 *** (0.000)	66.766 *** (0.000)	87.880 *** (0.000)
GDP	9.209 *** (0.000)	21.204 *** (0.000)	29.711 *** (0.000)	36.329 *** (0.000)
ENV	2.189 ** (0.014)	5.018 *** (0.000)	11.917 *** (0.000)	14.911 *** (0.000)
HC	7.818 *** (0.000)	11.923 *** (0.000)	16.282 *** (0.000)	26.896 *** (0.000)
MRK	3.904 *** (0.000)	2.371 *** (0.000)	10.737 *** (0.000)	12.966 *** (0.000)
INN	3.775 *** (0.000)	4.456 *** (0.006)	6.894 *** (0.000)	10.492 *** (0.000)

Remark: ** and *** refers importance at the 5% and 1%, scale. The Levin, Lin, and Chu test (LLC), and Im, Pesaran, and Shin W-stat test (IPS).

Table 3. Regression Model Analysis.

Variables	Coefficients	The Prob.	The VIF
GDP	0.143	0.353	2.03
ENV	1.325 ***	0.000	1.52
HC	1.786 ***	0.000	1.50
MRK	0.063 *	0.075	1.07
INN	1.191 ***	0.000	1.04
C	0.483 ***	0.000	

Note: *** and * imply significance at the 1% and 10% levels, correspondingly.

To assess the impacts of global competitiveness variables on geothermal power sustainable growth, this study utilized the mean group, the pooled mean group, and the dynamic fixed effect. The examination of these three estimation techniques is provided in Table 4, by using Hausman testing; the choice was conducted among the three estimators. The analytical testing tool was utilized to create a selection between the mean group and the pooled mean group and, after which, to additionally make a choice between the pooled mean group (PMG)/mean group (MG) as well as the dynamic fixed effect. On the assessment between the mean group and the pooled mean group, the null hypothesis is accepted, and therefore the pooled mean group is picked above the mean group. On the examination between the estimator pooled mean group and the estimator dynamic fixed effect, the null hypothesis was likewise accepted, which suggests that the pooled mean group (PMG) is, however, favored above the dynamic fixed effect. All these evaluations on the three estimators were shown in Table 4. The panel models in the three considered estimators were also computed, which yield full findings outputs.

In Model 1 (as shown in Table 4), the coefficients on economic growth output is found to be positive, but showed statistical significance at a one percent statistical level, in the long term, demonstrating a positive association among economic growth output and geothermal power sector sustainability in the EU area. This means that a rise in economic growth outputs promotes the sustainability of geothermal power in the EU region.

Precisely, a 1% improvement in economic expansion will result in a 0.058% inclination in the sustainability of geothermal energy. This finding shows consistency with [29,50–54]. The conclusion implies that EU area members have the prospect of attaining their renewables and sustainability in geothermal energy objective by increasing the volume of economic output (see Figure A1, as shown in Appendix G).

Table 4. Panel Regression Summary for the EU from 1990 to 2021.

Model 1. 1990–2021 Estimation in the Long Run for the EU Regions						
Long-Run Coefficients	**The Pooled Mean Group (PMG)**		**The Mean Group (MG)**		**The Dynamic Fixed Effect (DFE)**	
	Coefficient	**Prob.**	**Coefficient**	**Prob.**	**Coefficient**	**Prob.**
GDP	**0.058** ***	**0.003**	0.114	0.740	0.880	0.124
ENV	**0.361** ***	**0.000**	0.161	0.298	0.330 *	0.078
HC	**4.440** ***	**0.000**	1.054	0.734	0.152 *	0.091
MRK	**0.102** ***	**0.007**	0.192	0.228	0.325 *	0.095
INN	**0.051** ***	**0.000**	0.051	0.555	0.905	0.325
Hausman Test	0.50	0.779			0.15	0.951

Note: *** and * imply significance at the 1% and 10% levels, correspondingly.

Furthermore, an enabling environment emerges with a significantly positive coefficient at a one percentage level in the long term, suggesting that an increment in an enabling environment by one percent leads to an increase in sustainable geothermal power supply by 0.361%. This result substantiates [14,18–22]. It shows that geothermal energy might expand fast in the European Union when a conducive environment is provided for its expansion. That is, the sustainability of geothermal energy in the European Union might be attained when three elements connected to developing a suitable environment are expanded on. The three components that need to be elaborated on are the emotional, interior, and outdoor sides of the environment.

Moreover, human capital input enters with a positive and significant coefficient at a 1% level in the long run. Specifically, a 1% increase in human capital will lead to a 4.440% increase in the geothermal energy industry sustainability. The geothermal power sector sustainability needed by the European Union can be attained by investing massively in the knowledge and human skills needed in the geothermal energy sector sustainability. This finding conforms to [23–28]. By implication, when there is a general improvement in the well-being of the community where geothermal is located, geothermal power sector sustainability could be attained at the micro-level. It, therefore, means that investment in human capital could be used to accelerate the growth of geothermal energy in the EU region.

A coefficient of 1% was obtained on the market, which was futuristically significant. The coefficient was important, and specifically, a 1% growth in the market will lead to a 0.102% inclination in geothermal sustainable production.

This finding conforms to findings in studies such as [3,46–49]. The general conclusion on these studies is that geothermal energy is the potent way to attain a sustainable energy market. The implication is that an increased level of market activities could be leveraged to increase the level of geothermal sustainability in the EU. Establishing a competitive market, in terms of size of the market, level of activities in the labor, and financial market, will help in accomplishing sustainability in the geothermal industry.

Furthermore, innovation in the ecosystem was seen as having a significant influence on geothermal production sustainability at a 1% level. The result was optimistic and it, therefore, means that when innovation is geared up by 1%, geothermal production will increase by 0.051%. This finding shows consistency with the work of [40–45]. It, therefore, means that well-designed environmental planning that promotes the conservation of the ecosystem will help in attaining sustainability of geothermal energy in the EU region.

Innovation in the ecosystem could, therefore, be leveraged by the EU regions to boost energy sustainability in the ecosystem. These areas of innovation will include building talents, adequacy in the availability of financial resources, and an infrastructural base that will encourage local entrepreneurs in building more local content and services.

In assessing the effect of global competitiveness considerations on the sustainability growth of geothermal energy, this study employed three estimators, namely the pooled mean group (PMG), the mean group (MG), and the dynamic fixed effect (DFE). The results of the examination of these three estimators were reported in Table 5. Adopting the Hausman test, a choice was made between the pooled mean group (PMG)/mean Group (MG) and the pooled mean group (PMG)/mean group (MG) or dynamic fixed effect (in PMG and MG, the null hypothesis proposed was accepted, and thus causes the PMG to be picked above the mean group). Here, between PMG and the DFE, the null hypothesis had also been accepted, which causes the PMG to be given preference over the dynamic fixed effect. As disclosed in Table 5, panel model estimates were also conducted out on the three estimators, which produced the complete findings outputs.

Table 5. Summary of Panel Regression for EU14 Emerged Countries from 1990 to 2021.

Model 2. Long-Run Estimates for EU14 Emerged Members between 1990 and 2021						
Long-Run Coefficient Estimates	**The Pooled Mean Group**		**The Mean Group**		**The Dynamic Fixed Effects**	
	Coefficient	**Prob.**	**Coefficient**	**Prob.**	**Coefficient**	**Prob**
GDP	**0.065** **	**0.017**	0.230	0.424	0.451	0.137
ENV	**0.320** ***	**0.002**	0.444	0.232	0.068	0.593
HC	**6.521** ***	**0.000**	0.308	0.963	4.144 *	0.078
MRK	**0.248** ***	**0.005**	0.470	0.309	0.375 *	0.087
INN	**0.056** ***	**0.000**	0.112	0.290	0.067 ***	0.000
Hausman Test	2.59	0.762			0.16	0.955

Note: ***, **, and * shows significance at the 1 percent, 5 percent, and 10 percent levels, correspondingly.

In Model 2 (as shown in Table 5), the coefficients of outputs of economic growth is found to have a positive impact, but statistical significance at a five percent level, in the long term, demonstrating a positive association between economic expansion and geothermal energy sector sustainability in the EU14 nations. This suggests that a rise in economic growth outputs promotes geothermal power sustainability in the EU14 nations. Precisely, a 1% boost in economic growth will result in a 0.065 percentage point inclination in geothermal power development. This discovery is congruent with [52–54]. The analysis of these data is that geothermal electricity generation sustainable development in the 14 EU countries, which are developed nations in the European Union, would be increased with a rise in the degree of economic development. A rise in the gross domestic product of the EU14 developed markets, which will correspond to a rise in the collective value of products and services produced, would build capacity sustainability in the geothermal sector of the European Union 14 nations.

Furthermore, an enabling environment enters with a positive and substantial value at a 1% level in the long term, which indicates that an elevation in the enabling environment by one percentage point leads to an inclination in geothermal power supply by 0.320 percentage points in the EU14 nations. This result substantiates [14,21,22]. It implies that the geothermal power sector sustainable development in the EU area grows with an expansion in an enabling environment. Furthermore, this research indicated that, when institutional capability that might accept physical and institutional transformations is weak, this may brew dispute that would be of harm to human security. This study presents a proposal that EU nations might be ensured in respect of their energy demands if appropriate attention is paid to geothermal power production sustainability. When this is done, macroeconomics operations In the European Union will also be strengthened in the field of their institutions. Consequently, human capital supply enters with a positive

and substantial value at a one percentage point level in the long term. Particularly, a 1% increase in the human capital will translate to a 6.521% rise in geothermal power sector sustainability in EU14 states. The sustainable geothermal power sector demanded by the EU14 states, might be reached by raising the human capital level in the geothermal power sector sustainability. This finding corresponds to [23–28]. By inference, it suggests that an increased amount of financial commitment to human capital will boost geothermal power sustainability in the Eurozone. An increasing amount of money invested in education that instils competencies in human capital, would, thus, enhance geothermal energy efficiency in the EU14 nations.

Further study demonstrates that the market provides a co-efficient at a one percent level, particularly, a one percent market expansion rate, which would equate to a 0.0248% rise in the sustainability of geothermal power. It, therefore, signifies that a growth in market size will promote sustainable growth in the geothermal industry. The results were supported in the conclusions of research by [48,49]. These analyses suggest that emancipation by the Government helps the Norwegian financial sector to thrive since the country's energy is provided by a geothermal system.

The consequence is that the 14 developed EU countries will experience sustainability in their geothermal power, and will grow as the market volume rises. Hence, when the important elements of world economy are made a priority, such as technological advancement, the demographic, political and economic factors, legal-related factors, and factors that influence social and cultural backgrounds amongst many others, it will expedite the accomplishment of objectives in the European Union geothermal power industry.

In the research, innovation in the ecosystems ultimately exerts a major influence on the sustainable geothermal energy sector, which creates optimism at a one percentage level. This translates that a 1% rise in the amount of creativity in the ecosystems will have a 0.156% gain in geothermal energy production sustainability. These data reflect the notion of [42–45], which means that geothermal electricity lends emphasis to services related to the upstream environment. This will demonstrate divergences in valuations of rent, and the worth tag of an ecological system should be calculated on how distinct ecological compensations are dispersed. An improved degree of creativity in the ecosystem would consequently hasten geothermal output being desired among the fourteen EU developed nations. This will aid in building an innovation center that will enable small- and medium-scale firms to become competitive in the creation of relevant local services and localized contents.

In a quest to assess the effects of global competition on the sustainability of geothermal generation, this research chose three estimators that include the PMG, the MG, and the DFE. Hausman testing was used to choose between the PMG and the MG, and afterwards, it was further used to make a decision between PMG/MG and DFE. In the first investigation, between the pooled mean group and the mean group, the hypothesis established, which is null, was accepted, and hence the pooled mean group was picked above the mean group. Conversely, between the pooled mean group/mean group and the dynamic fixed effect, the null hypothesis proposed was likewise accepted, which causes the pooled mean group to also be picked above the dynamic fixed effect. These were presented in Table 6. Panel models' estimates for the three estimators were indeed shown in the same table. These panel model estimates serve as a thorough check.

In Model 3 (as shown in Table 6), the predictor on the outputs of economic growth is revealed to be positive, but statically relevant at a ten percent degree, in the long term, demonstrating a positive association between outputs of economic growth and geothermal energy sector sustainability in the 13 European nations. This means that a rise in the outputs of economic growth increases sustainable geothermal power generation in the 13 European Union nations. Precisely, a 1% improvement in economic development will result in a 0.022% inclination in geothermal energy efficiency. This observation is in accordance with [50–52]. This conclusion is conflicting with the conclusions of [50–52]; the findings indicate that the 13 EU states might accomplish the desired potential in geothermal generating sustainability, by growing their levels of economic productivity.

Table 6. Panel Regression Summarization for Emerging Nations between 1990 and 2021.

Model 3. Long-Run Estimates for Emerging EU Nations between 1990 and 2021						
Long-Run Coeffients	**The Pooled Mean Group**		**Mean Group**		**DFE**	
	Coefficient	**Prob.**	**Coefficient**	**Prob.**	**Coefficients**	**Prob.**
GDP	**0.022** *	**0.075**	0.272	0.362	0.016 **	0.025
ENV	**0.013** *	**0.071**	1.382	0.310	0.077	0.897
HC	**0.043**	**0.299**	0.740	0.430	0.309	0.811
MRK	**0.033** **	**0.025**	0.147 *	0.094	0.018 **	0.047
INN	**0.051**	**0.615**	0.131	0.490	0.022	0.469
Hausman Test	0.79	0.941			2.10	0.716

Note: ** and * indicate significance at the 5% and 10% levels, respectively.

Furthermore, an enabling environment has a ten percent level of substantial impact with geothermal power generation sustainability, which is good in the long term. What this signifies is that when there is a raise in the enabling environment, there would be a 0.013% inclination in geothermal production sustainability. This finding corroborates research such as [18–20]. It implies that the geothermal power sector development in the EU13 members grows with an increment in an enabling environment. From another perspective, developing an enabling environment would be a positive step towards boosting geothermal output sustainably in the EU13 nations.

Markets, as one of the variables captured in this study, also have positive and significant coefficients at a 5% level. Specifically, when there is a 1% growth in markets, 0.33% growth is expected in geothermal power sustainability. This suggests that market expansion will be a boost to geothermal energy production sustainability. This support results in studies such as [47–49]. These studies discussed that a good level of prospects in the market could be an additional source of revenue for geothermal power centers. It, therefore, means that when more market opportunities are open, this will serve as a boost to geothermal energy production sustainability. The 13 EU countries could, therefore, attain sustainability in their level of energy production by focusing on addressing green energy market challenges, such as legislation relating to environmental protection, dearth of natural resources, consumer behavioral patterns, and senior management attitudinal expressions towards green marketing.

4.2. Discussion

This research developed a framework, which is theoretical, used to classify the considered EU countries of the European Union countries according to the level of economic, development, economic activities, and sustainable development [7,8]. The framework was used to categorize the EU countries based on the demand and supply functions of their economic and environmental characteristics [7,8]. The categorization becomes necessary because it gives background information on interactions between producers and consumers of economic and environmental characteristics relative to each group. This will shape economic policies and policies on the environment in the EU regions [75–77]. EU countries that share similar characteristics were grouped into developed and developing countries, and the right environmental and regional policies were selected for each of them [75–78]. To ascertain the impact of global competitiveness on geothermal power sustainability, countries in the European Union based on their level of economic strength were divided into two groups based on binary categorization. The two divisions are 14 developed countries and 13 developing countries. The 14 categorized as developed are Sweden, the Netherlands, Portugal, Luxembourg, Finland, Ireland, Greece, Denmark, Austria, Belgium, Poland, Spain, United Kingdom, Italy, France, and Germany, while the 13 developing countries are Slovakia, Slovenia, Malta, Poland, Romania, Latvia, Lithuania, Estonia, Hungry, Croatia, Cyprus, Czech, and Bulgaria.

The three estimators adopted for the study showed short-run effects and the results of these three estimators are reflected in Tables A3–A5 (in Appendices C–E). A long-term relationship was confirmed in the three estimators since their error correct term was negative and significant at 1%. Model 1, as shown in Table 4, presented estimation results on the level to which global competitiveness factors could influence EU members' geothermal energy sustainability within the period 1990 to 2020. Meanwhile, Model 2 (Table 5), showed results on the influence of global competitiveness factors on geothermal energy industry sustainability in the EU14 emerged economies for the period 1990–2021. Likewise, Model 3 (see Table 6) shows the result of the estimated impact of global competitiveness factors on geothermal energy industry sustainability in the EU13 emerging economies for the period 1990–2021. The results from Tables 5 and 6 both reveal that global competitiveness factors have a significant positive effect on geothermal energy sustainability.

Results from the analysis showed a significant positive effect of economic growth, a conducive enabling environment, and market volume on geothermal energy production, which is more established in the EU14 than in the EU13 established countries. The magnitude of the impact is 0.065, 0.320, and 0.248 for the EU14 developed nations and 0.022, 0.013, and 0.03 for the EU13 underdeveloped countries. This suggests that significant growth in the geothermal power sustainability could be attained better among the established EU14 countries than among the EU13 establishing nations, utilizing the economic growth, enabling environment, and market size variables.

The findings also reveal that the human capital and innovation ecosystems will have a substantial positive influence on geothermal output sustainability among the fourteen European Union established nations than among the EU13 developing countries. The size of the effects is 6.521 and 0.056 for the 14 European Union wealthy nations and 0.043 and 0.051 for the 13 European Union developing countries. Consequently, it suggests that considerable and greater growth may be attained in the geothermal power industry among the established 14 European countries than in the 13 EU establishing nations applying the innovation ecosystem and human capital characteristics.

5. Conclusions and Policy Recommendations

This research explores the links between an enabling environment, economic development, market size, human capital, and innovation ecosystem with geothermal electricity sustainability within the framework of the EU area. The research applies the ARDL model with data ranging through 1990 to 2021 for the EU area. Geothermal energy sustainable development is discovered to be a clean energy source that can assist in decarbonizing the EU's economy. The research demonstrates a larger positive influence of economic development, market size, and enabling environment on geothermal power viability in the EU14 emerged nations than in EU13 developing economies. In the same way, the research demonstrates a larger beneficial influence of an innovation ecosystem and human capital on the geothermal power business in the EU14 established countries than in the EU13 developing economies (see Appendix F). Based on the findings of these results, the government of the 13 establishing countries should give priority to market stimulators, such as finished goods and services, market size, human capital markets, and financial operations. This will propel the sustainability of geothermal energy boost among the 13 EU developing countries. The government of these 13 developing EU countries should further focus on creating an enabling environment in terms of institutional supports, physical structures, maintaining an equilibrium exchange rate, wealth, and ICT-enhanced capacities, which, if enhanced, will increase the level of geothermal energy production sustainability in the 13 EU establishing countries. This study recommends that financial investment in human capital skills acquisition will boost the level of geothermal energy production sustainability among the EU's 13 underdeveloped countries. Investment in training will guarantee energy security and minimize energy dependence on other sources of energy that could cause pollution. Investment in expertise will assist in boosting the growth of the geothermal energy industry sustainability, and this could conveniently replace dependence

on fossil fuels. This will facilitate the attainment of European Union energy targets by 2030. The governments of the EU13 countries could, therefore, pay close attention to boosting the level of innovation in the ecosystem. This will assist in shaping the EU13's geothermal power sector strategies. This will increase the level of prosperity, which will increase the standard of living among the EU regions. In a clean energy competitive market, green businesses play a central role by utilizing renewable energy technologies and employing green labor forces to provide clean energy services and goods. The competitiveness market expansion can drive the growth and survival of green businesses in the EU members, with hypotheses proposed on the impacts from clean energy policies and tax incentives, labor market conditions, and economic and political environments. The global competitiveness market will, therefore, increase the level of geothermal sustainability among the EU13 and EU14 countries. It should, however, be noted that a conducive physical environment is needed for the geothermal sector to become competitive among the EU13 and the EU14 countries. When a healthy natural environment is enhanced, this will minimize the rate of environmental degradation, thereby preventing cases of illness, which could lower the rate of human productivity. Not only that, geothermal energy itself could be affected by environmental degradation, which could affect the operation of geothermal energy and limit production capacity. This will affect a country's ability to keep up with energy needs. Conclusively, to boost geothermal production sustainability, global competitiveness factors should be enhanced and the natural ecosystem should not be compromised. The environment should be protected, since geothermal sustainable development has to do with water resources harnessed from underground. If this is mismanaged, it could lead to serious land degradation and security challenges. This study identified the importance of an internal market with a huge volume of market transactions within the EU. Human and material goods should have unhindered access to the market. Attaining global competitiveness among the EU27 will be a great feat. The current economic and social turmoil makes it necessary for the EU to develop its internal markets and make them competitive and responsive to changes. There continue to be changes in the environment, and the market must be made to keep up with this dynamism. All goods and services that will keep the EU markets competitive, including geothermal production, should be enhanced. This research is not without limits, much like previous empirical studies. The extent to which the results of this investigation might be extrapolated is restricted. Cases of data that are missing also cause the sampling of data to be limited, which required the application of various econometric approaches to examine the hypotheses. The research also generated a solid framework for future investigations on open smart grids and its influence on geothermal energy. The financial implication of this should also be explored since it is essential to comprehend how the platform will be supported and the degree of returns on it. Furthermore, this study highlighted conditions that promote the effective deployment of the platform; future investigative research might be conducted to assess the degree of dependability and adequacy of these requirements. This research identified the company as the end-user of this network; future studies might view this from the standpoint of households and regulators to enhance the usefulness of the platform cut through. Similar research might also be launched in the domain of monitoring systems in other key industries other than the geothermal industry.

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Data Availability Statement: Data are available upon request.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Descriptive Statistical Table.

Variable	Observations	Mean	Std. Dev.	Min.	Max.
GT	810	4.003	0.453	3.000	5.386
GDP	810	4.371	0.398	3.130	5.248
ENV	810	1.867	0.699	1.482	1.979
HC	810	1.888	0.193	1.837	1.921
MRK	810	4.408	0.229	3.744	5.044
INN	810	3.646	0.331	2.223	4.354

Appendix B

Table A2. Correlation Matrix.

Variables	GT	GDP	ENV	HC	MRK	INN
GT	1.000					
GDP	0.876	1.000				
ENV	0.424	0.667	1.000			
HC	0.482	0.284	0.656	1.000		
MRK	0.644	0.751	0.138	0.615	1.000	
INN	0.649	0.182	0.223	0.847	0.645	1.000

Appendix C

Table A3. Short-Run Estimate for the EUs from 1990 to 2021.

Long-Run Coefficient	Pooled Mean Group		Mean Group		Dynamic Fixed Estimator	
	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
ECT	−0.303 ***	0.000	−0.844 ***	0.000	−0.816 ***	0.000
GDP	0.249	0.130	0.019	0.962	0.045	0.748
ENV	1.012	0.242	2.356	0.322	0.026	0.679
HC	1.835	0.719	2.311	0.414	0.631 **	0.054
MRK	0.652 *	0.098	0.101	0.636	0.488 **	0.022
INN	0.043	0.103	0.051	0.263	0.010	0.371
C	0.948 ***	0.000	0.264 *	0.066	0.316 ***	0.363

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Appendix D

Table A4. Short-Run Estimation for the EU14 Emerged Countries from 1990 to 2021.

Long-Run Coefficient	PMG		MG		DFE	
	Coefficient	**Prob.**	**Coefficient**	**Prob.**	**Coefficient**	**Prob.**
ECT	−0.305 ***	0.001	−0.844 ***	0.000	−0.801 ***	0.000
GDP	0.447	0.108	0.627	0.391	0.545	0.194
ENV	0.330	0.120	0.470	0.115	0.267*	0.076
HC	0.900	0.535	0.300	0.183	0.219	0.186
MRK	0.019	0.156	0.543	0.197	0.715	0.113
INN	0.045	0.264	0.025	0.454	0.020	0.352
C	0.895 ***	0.001	0.176 **	0.038	0.894 ***	0.005

Note: ***, **, and * show significance at the 1 percent, 5 percent, and 10 percent levels, correspondingly.

Appendix E

Table A5. Showing Estimates in the Short-Run for the 13 EU Emerging Countries from 1990 to 2021.

Long-Run Coefficient	PMG		MG		DFE	
	Coefficient	**Prob.**	**Coefficient**	**Prob.**	**Coefficient**	**Prob.**
ECT	−0.583 ***	0.000	−0.852 ***	0.000	−0.956 ***	0.000
GDP	0.108	0.193	0.336	0.296	0.056	0.665
ENV	0.541	0.236	0.495	0.279	0.067	0.438
HC	0.219	0.225	0.467	0.159	0.914 ***	0.000
MRK	0.015	0.732	0.208	0.442	0.461 *	0.052
INN	0.016	0.952	0.334	0.995	0.857	0.845
C	0.169 ***	0.000	0.432 **	0.059	0.385 *	0.082

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Appendix F

Table A6. List of the EU Region Member Countries.

European Union (EU27) Region			
Developed Countries Member Countries (14)	Year	Underdeveloped Countries Member Countries (13)	Year
Austria	1995	Bulgaria	2007
Belgium	1958	Croatia	2013
Denmark	1973	Cyprus	2004
Finland	1995	Czech	2004
France	1958	Estonia	2004
Germany	1958	Hungary	2004
Greece	1981	Latvia	2004
Ireland	1973	Lithuania	2004
Italy	1958	Malta	2004
Luxembourg	1958	Poland	2004
Netherlands	1958	Romania	2007
Portugal	1986	Slovakia	2004
Spain	1986	Slovenia	2004
Sweden	1995		

Source: European Union Official Website (www.Europa.eu, accessed on 25 November 2022).

Appendix G

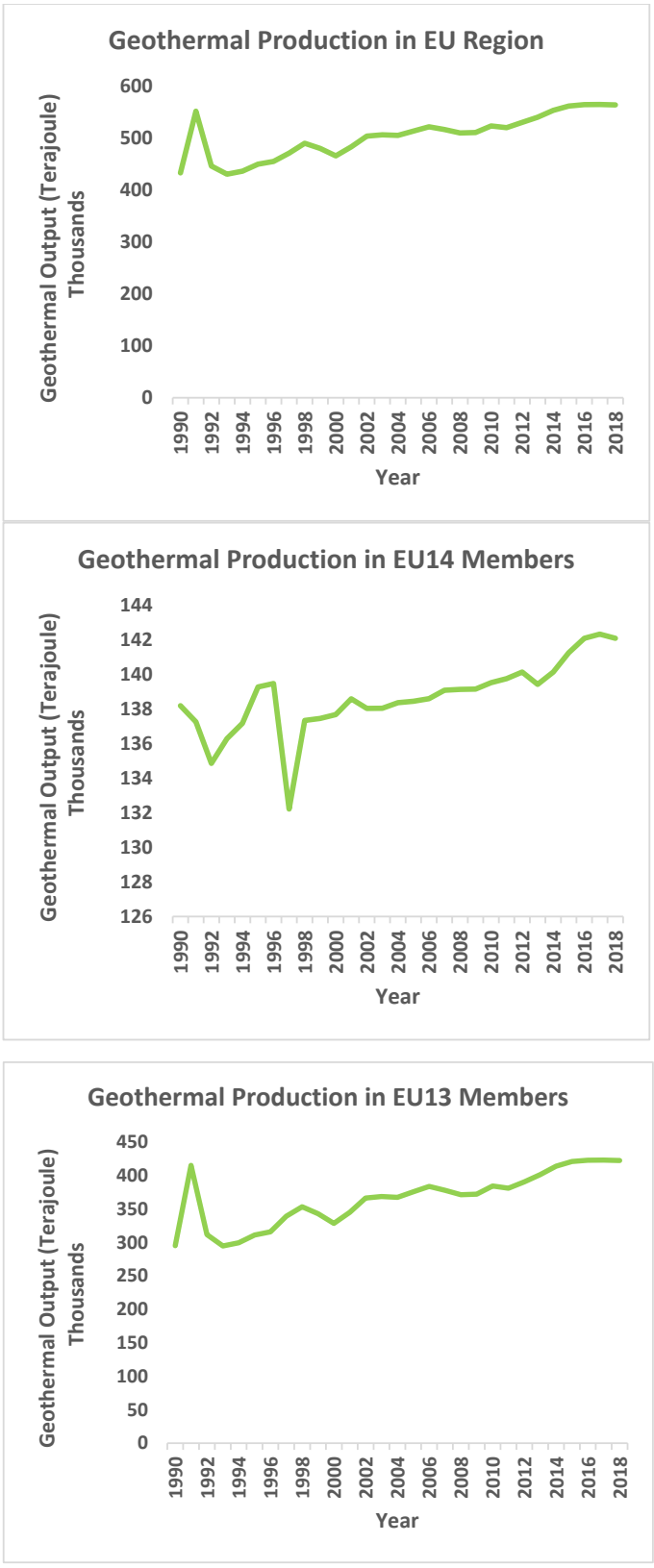


Figure A1. Geothermal Production in EU Members.

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