UNIVERSITY OF PIRAEUS

SCHOOL OF ECONOMICS, BUSINESS AND INTERNATIONAL STUDIES

DEPARTMENT OF INTERNATIONAL AND EUROPEAN STUDIES

M.S. IN ENERGY: STRATEGY, LAW AND ECONOMICS

MASTER THESIS

A geopolitical analysis of geothermal energy

Author: Kalliopi Lennax

Supervisor: Dr. John Paravantis

Piraeus

2023

I declare that this master thesis has been composed solely by myself and that it has not been submitted, in whole or in part, for any other degree. I also declare that the work contained herein is my own except where explicitly stated otherwise, and that all the material deriving from other sources has been appropriately mentioned and cited.

Abstract

The current global energy crisis demonstrates that energy is a fundamental aspect of international relations and politics, as well as the driving force behind social progress. This thesis aimed to highlight the relationship between geothermal energy and geopolitics, which has received little academic attention. In the literature review, the technical characteristics, technologies, and applications of geothermal energy, along with its competitive technological and economic advantages are elucidated. Subsequently, the geopolitical value that geothermal energy possesses is presented and discussed, with a special focus on the concept of geopolitics, its prominent theoreticians, and the elements that synthesize the contemporary geopolitical landscape. Highlights on the geopolitical significance of geothermal energy were compiled and presented, sourced from leading international institutions and research studies. This thesis contributed to the state of the art by demonstrating how this renewable energy source, which is expected to become an essential component of the global green energy future, is capable of mitigating climate change, altering the dependance relations between countries, enhancing energy security, and thus influencing global politics, despite its current marginal role.

Keywords: natural resources, renewable energy sources, geothermal energy, fossil fuels, energy security, transition, climate change, diversification, geopolitics of energy, Halford Mackinder

Acknowledgements

I would like to express my deepest appreciation to my supervisor, Dr. Ioannis Paravantis, whose invaluable patience, guidance and feedback have made the composition of my dissertation an inspiring and constructive experience. Our exceptional cooperation provided me with significant methodological tools and improved my research and writing skills.

I also wish to thank Dr. Spyridon Roukanas and Dr. Nikolaos Farantouris, who, as my two-member Committee, generously provided knowledge and expertise throughout my academic years.

I would like to say a special thank you to Dr. Athanasios Dagoumas and Dr. Mary Bossis for introducing me to the fields of Energy and Energy Security during my third year of studies in the International and European Studies Department's undergraduate program, as well as to all the professors of the master's program for broadening my area of knowledge.

Lastly, I could not have undertaken this project without the support of my family.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Preamble

Energy is a “precondition of all commodities, a basic factor equal with air, water, and earth” (Schumacher, Nobel Laureate Economist, 1977). It is imperative for survival and constitutes an economic, ill-distributed and expensive good, present throughout human history and subject to price fluctuations that affect human security and economic development. [1] Energy comprises the driving force for the functioning of societies, both at individual level, facilitating movement, heating, and electricity related activities, and at state level, by being at the core of the industry and supporting shipping, aviation, the armed forces, and the conventional weapons systems. In addition, energy sources have historically been used as a negotiating tool to maximize geopolitical power and as a weapon in the hands of governments, energy companies, tribes, and even terrorist organizations, whereas scarcity can be a generative cause of armed conflicts, justifying the use of force. Therefore, energy is considered a cornerstone of international relations and politics, as it constitutes a component of grand strategy, that is, an end, a means, and a way of achieving national goals.

Humanity has exploited the two main energy sources to which it has access; on the one hand, the non-renewable energy sources, referring to the existing, finite energy reserves in the earth's crust, known as fossil fuels, and, on the other hand, the renewable energy sources, which are infinite and more equitably geographically distributed, guaranteeing greater credibility, democratization, economic development and security. [2] However, energy, and especially conventional resources, are not as available as they used to be decades ago, a reality that augments national concerns about resource depletion and scarcity. The widespread use of fossil fuels has posed a number of challenges to the international community, including growing energy demand, rising fossil fuel prices, depletion of fossil fuel reserves, high reliance on energy imports, price volatility caused by internal unrest in producing and transit countries, limited diversification of sources, the adverse effects of climate change and the deterioration of environmental conditions. Moreover, the United Nations’ Report on Energy Transition adds the following interconnected issues that put additional pressure on the energy sector: first, the need to expand infrastructure to provide energy access to the approximately 700 million people who are currently unserved; second, the need to meet the Paris Agreement targets by rapidly reducing greenhouse gas (GHG) emissions, 65% of which are produced by the energy sector; and third, transition management. [3]

---

[1] Paravantis et al. (2018).

[2] IRENA (2019).

[3] United Nations (2021).

These energy challenges that hang over us like the sword of Damocles in the complex and multidimensional international environment, along with the growing awareness of the environmental issues at stake, resulting from the current industrialized modus vivendi, reflect the urgent need for a shift toward clean energy sources, among which geothermal energy, and a transition to a more sustainable energy system to improve security. The integration of energy-related issues into the concept of security arose from the empirical realization that any disruption to the flow of energy and any impediment in the operation of the global energy market have a direct impact on the global and national economies, trade and the citizens' sense of security. In this context, the concept of energy security, which refers to the uninterrupted availability of energy sources in an affordable price [4], remains to the forefront, emphasizing the importance of diversification of energy sources in dealing with both the looming repercussions of climate change and energy crises with a global reach.

Given the prominent power of energy, any change in the current energy patterns, as well as a shift to renewable energy sources are expected to incite fundamental changes in power relations between producer and consumer countries. It is, thus, evident that, apart from being a commodity, energy is also an important geopolitical driver, since it can serve as an economic and political advantage that defines international relations, shapes geopolitics, and promotes national interests. [5] The concept of geopolitics has a dynamic nature and refers to power relations over map. It is perceived as the study of international relations from a spatial or geographical perspective, placing great emphasis on the role of geography. Modern geopolitics rely on the broad shoulders of theoreticians, strategists and academics, none broader than Sir Halford Mackinder's, whose aim was to prove that geopolitics, geography, and strategy are inextricably linked. Following his geopolitical thought that matured between 1904 and 1943, one can grasp the interaction between geopolitics and energy and detect elements of Mackinder's geopolitics that are valid to this day, an effort that has been thoroughly caried through in the dissertation's second chapter.

At present, renewable energy is still a marginal contributor to the global primary energy and electricity supply, yet it has emerged as the fastest growing energy source in the last decade.[6] Geothermal energy is a renewable energy source, currently accounting for a small portion of the world's power capacity, that has a place in the energy transition and can reappraise the relationship between human and the environment to a more viable one. Geothermal resources, whose availability far outstrips that of fossil fuels, can be harnessed for heating and cooling purposes and electricity generation, with applications in several economic sectors, such as industry and buildings. It is a mature and commercially proven technology that can provide low cost, "always-on" capacity in regions with medium to high-temperature conventional geothermal resources and it

---

[4] IEA (2019).

[5] Bitsa (2019).

[6] Franza, Bianchi, Bergamaschi (2020).

presents huge potential for growth. Despite having the highest installed cost and levelized cost of electricity in 2020, geothermal technologies present the highest capacity factors, as they are typically designed to run as often as possible and provide firm power around the clock. Moreover, the cost of electricity production using geothermal technologies is becoming increasingly competitive and is expected to keep declining until 2050.

Its geopolitical significance stems from its reliability, as geothermal energy is resistant to fluctuations of fossil fuel prices, presents lower variability and intermittency than solar and wind energy, offsets reliance on energy imports, and is unaffected by global depletion of resources. Equally important is its contribution in mitigating the alarming effects of climate change, since geothermal power plants do not depend on burning fuels and, therefore, produce negligible greenhouse gas emissions during their operation. Currently, overall development has been slow, which is unsurprising given that fossil fuels are a major competitor. Nonetheless, thanks to the global focus on decarbonizing economies by 2050, geothermal is destined to play a significant role in our world's clean energy future, as an essential component of the future energy mix.

Scientific research efforts to associate the two worlds of geopolitics and renewables have emerged during the last decades, due to the urgent need to reduce dependence on fossil fuels and mitigate climate change. The literature is extensive on the significant geopolitical value of renewable energy sources in general, nevertheless the distinct geopolitical contribution of geothermal energy has barely been scratched and reviewed. Thus, the aim of this master thesis, which, to our knowledge, is among the first to investigate this topic as of 2022, is to conduct a literature review on the geopolitical value of geothermal energy, in order to extract highlights and key points that are brought out to the Conclusions.

1.2 Structure of thesis

The structure of this thesis is organized as follows:

Chapter 1 consists of a brief outline of the current energy system and its challenges that call for a greater integration of renewable energy. Chapter 2 begins with a literature review on the two facets of geothermal energy: the technical and the geopolitical. More precisely, the second chapter accommodates a review of the basic technical characteristics of geothermal energy, concerning its distribution, installed capacity, applications, technologies and costs, as well as an extensive analysis on the concept of geopolitics, with an effort to define it, present the thoughts of prominent theoreticians, and reveal the correlation between geopolitics and energy. Furthermore, the second chapter proceeds with a review of geothermal energy's geopolitical value, followed by a segment devoted to a discussion of our research's results and final remarks. Finally, Chapter 3 ends with the thesis' conclusions, limitations and recommendations for further research.

Chapter 2: Literature review

2.1 Introduction

The world is in the grip of a global energy crisis that induces extremely high and volatile prices, particularly for fossil fuels. The last two years have been marked by unprecedented turmoil in energy markets, that emerged during the pandemic, when supply chains were disrupted and demand was restricted before outpacing supplies, and was later exacerbated by the Russian-Ukraine war, given Russia's leading position in global energy markets. During this time that countries struggle to decarbonize their economies by 2050, the energy sector is requested to comply with the processes of energy transition, energy efficiency and energy saving. These latest developments have accelerated the shift to renewable energy sources, among which geothermal energy, in order to improve overall energy security.

Chapter 2 provides an overview of the relevant literature on both technical and theoretical aspects of geothermal energy. Firstly, the distribution, capacity, uses, technologies and costs of geothermal energy are evaluated up to 2021, and secondly, a detailed examination of the concept of geopolitics and the geopolitical value of geothermal energy has been undertaken through specific cases. The aim of this Chapter is to support the point that geothermal energy can play a decisive role in global politics.

2.2 Global geothermal distribution, technologies and utilization

Per definition, geothermal energy is a type of renewable energy stored in the form of heat within the accessible portions of the earth's crust and carried to the surface through water or steam. Depending on its characteristics, it can be harnessed for electricity production or for heating and cooling purposes. [7,8] This domestic source of sustainable energy, used for over 2,000 years by many countries for industrial or domestic applications, is available year-long, whereas wind and solar energy present higher variability and intermittency. As a resource that is naturally replenished on a human timescale, geothermal energy is not affected by global resources depletion and remains resistant to fluctuations in fossil fuel prices. Countries can thereby reduce their reliance on energy imports, eliminate pollutants such as carbon particles and greenhouse gases, and mitigate the negative consequences of climate change by harnessing their geothermal resources.

Geothermal power has considerable potential for growth. Existing technologies permit drilling up to around 5000 meters, where the temperature level ranges from

---

[7] IRENA (2021).

[8] Beardsmore, et al. (2016).

0 ^{o}C- 200 ^{o}C. [9] The suitability of geothermal sites for plant installations and energy production is determined by a complex combination of geophysical characteristics, including carbon dioxide emissions, earthquake density, altitude, heat flow, sediment thickness and surface air temperature. [10]

2.2.1 Global distribution of geothermal energy

The most active geothermal resources are usually located near volcanoes, along the boundaries of major tectonic plates. One of the world's most active geothermal areas that hosts a large percentage of the global geothermal energy production encircles the Pacific Ocean and is known as "the Ring of Fire" (ROF). The chain around the Pacific Ocean Basin runs up along the western coast of South and North America, crosses over the Aleutian Islands in Alaska, runs down the eastern coast of Asia and ends on the northern coast of Antarctica. [11] More precisely, the Pacific ROF, bounded by Chile, Peru, Guatemala, the United States, Canada, Russia, Japan, the Philippines, Indonesia, New Guinea and New Zealand, is highly volcanic with seismic activity, since there are more than 450 active and dormant volcanoes located within its borders. [12]

Apart from the Pacific Ring of Fire, other conventional geothermal resources for power generation can be found in Iceland, the Great Rift Valley countries of Africa, Turkey, Italy, Germany, Portugal, and France. Out of the 1159 wells drilled for power projects during the five-year period of 2015-2020, 58% was in Asia by 9 countries (1537 wells), 15% in Africa by 4 countries (396 wells), 12.2% in Europe by 18 countries (322 wells), 10.5% in America by 9 countries (278 wells), and 4.3% in Oceania by 2 countries (114 wells). [13] Although these natural resources have been harnessed for direct heat for millennia and for electrical power since 1904, the global geothermal community has only recently started to compile "best practice" guides on their exploration. [14]

---

[9] Goetzl (2020).

[10] Coro, Trumpy (2020).

[11] Masum, Ali Akbar (2020).

[12] Masum, Ali Akbar (2020).

[13] Hutter (2021).

[14] Beardsmore, et al. (2016).

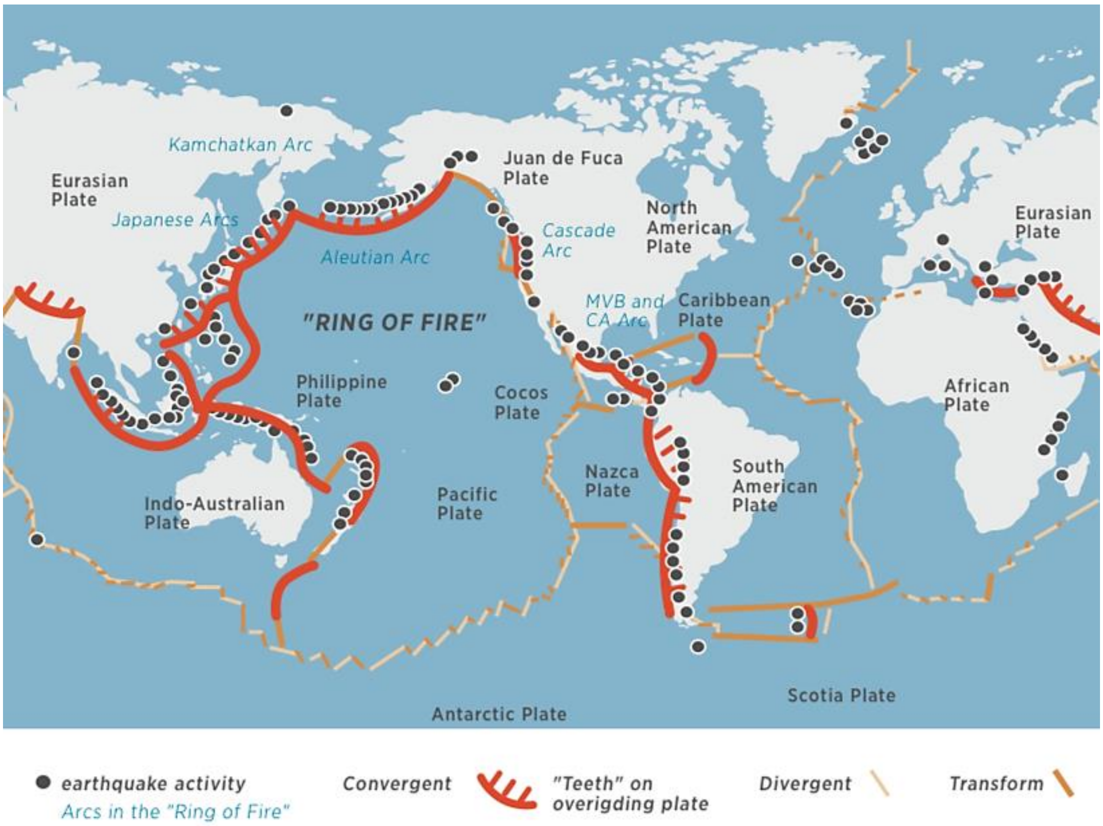

Figure 2.1: The Pacific Ring of Fire [15]

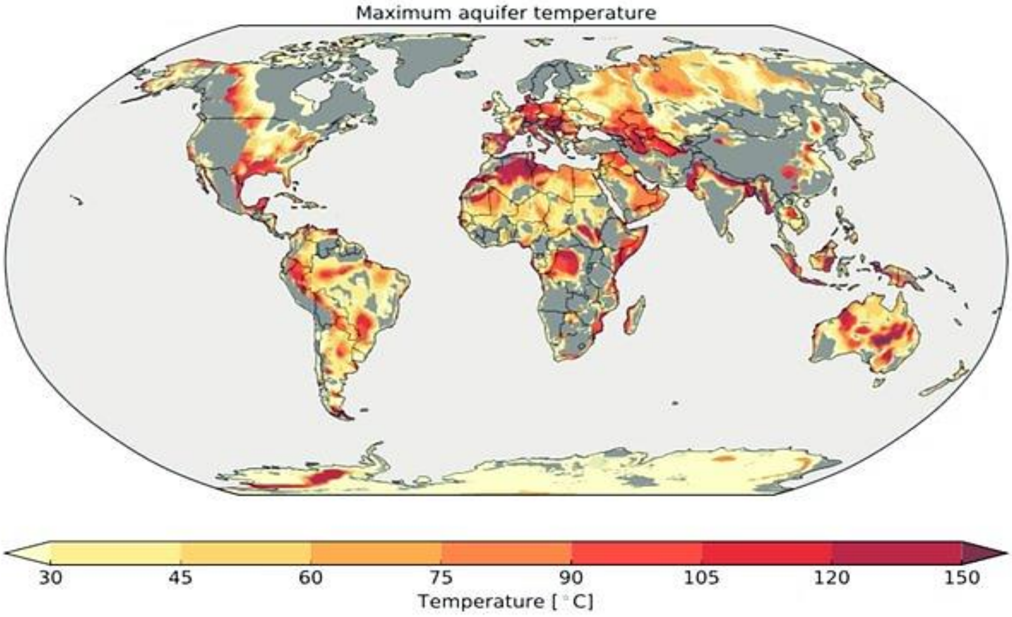

Figure 2.2: Worldwide distribution of geothermal energy, according to the temperature scale [16]

---

[15] IRENA (2017).

[16] Kurek (2021).

2.2.2 Global installed capacity of geothermal energy

The steady increase in the use of geothermal energy globally crystallizes the emerging trend toward renewable energy, as well as the need to counterbalance the negative effects of climate change and replace imported fuels with environmentally friendly technologies. In 1985, only 11 countries reported an installed capacity over 100 MWt, while, by 2020, this number increased to 38 countries [17], with geothermal power generation stations accounting for 0.5% of the global installed renewable power generation capacity. [18] As projected in Figure 2.3, the global geothermal installed capacity has gradually increased over the last decade, reaching approximately 15.6 GW in 2021, which was more than 55% higher than in 2010 and was largely found in active geothermal zones. Furthermore, geothermal capacity is expected to increase 28% by 2024, reaching 18 GW, with Asia accounting for one-third of the global expansion, mainly through projects currently under development in Indonesia and the Philippines. [19]

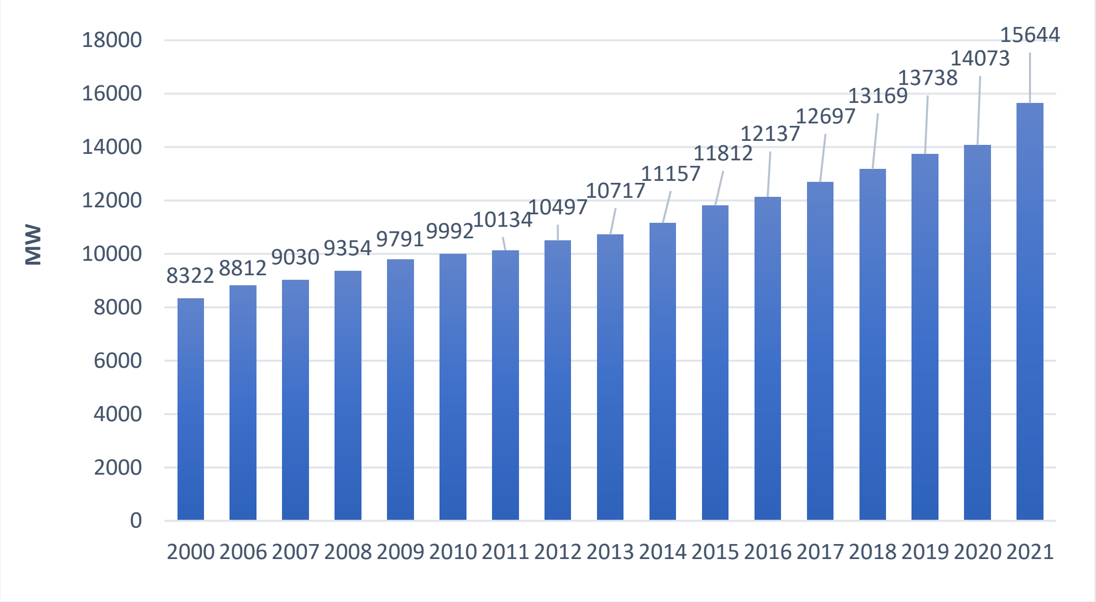

Figure 2.3: Global geothermal installed capacity, 2000-2021 [20, 21, 22]

---

[17] Lund, Toth (2020).

[18] IRENA (2021).

[19] IEA (2019).

[20] IRENA (2015).

[21] IRENA (2016).

[22] Jaganmohan (2022).

Table 2.1: Geothermal power statistics and forecast by continent, 2000-2020 [23, 24, 25, 26, 27]

Continent	Capacity (MW) 2000*	Production (GWh) 2000	Capacity (MW) 2006	Production (GWh) 2006	Capacity (MW) 2010	Production (GWh) 2010	Capacity (MW) 2015	Production (GWh) 2015	Capacity (MW) 2020	Production (GWh) 2020
Africa	67	-	139	1018	205	1401	611	4481	831	9988
Asia	3018	-	3390	20320	3597	22060	3896	23831	4540	27791
C America + Carib	360	-	474	2819	527	3277	640	3927	723	4027
Eurasia	44	-	110	557	175	1173	702	3882	1695	8609
Europe	776	-	1120	8247	1336	10068	1504	11617	1652	12710
N America	3639	-	3234	23266	3370	24195	3448	25058	3492	23741
Oceania	418	-	454	3593	782	6267	997	8409	1040	7729
S America	-	-	1	-	-	-	-	-	40	400
* Totals drive from the sum of the indexes of 32 states.										

---

[23] IRENA (2015).

[24] IRENA (2016).

[25] IRENA (2020).

[26] IRENA (2021).

[27] Hutter (2021).

Table 2.2: Geothermal power statistics and forecast for the top 20 geothermal countries, 2000-2020 [28, 29, 30, 31, 32]

Top 20 countries	Capacity (MW) 2000	Production (GWh) 2000	Capacity (MW) 2006	Production (GWh) 2006	Capacity (MW) 2010	Production (GWh) 2010	Capacity (MW) 2015	Production (GWh) 2015	Capacity (MW) 2020	Production (GWh) 2020	Forecast for 2025 (MW)
China	26	-	26	95	24	140	26	144	35	174	386
Costa Rica	-	-	166	1147	166	1176	217	1376	262	1559	262
El Salvador	161	-	151	1140	204	1525	204	1540	204	1442	284
France	-	-	-	-	-	-	16	92	16	136	25
Germany	-	-	0	0	7	28	29	133	40	165	43
Guatemala	29	-	54	143	54	259	49	252	49	237	95
Iceland	172	-	422	2631	575	4465	665	5003	756	6010	755
Indonesia	525	-	850	6658	1189	9357	1438	10048	2131	15315	4362
Italy	590	-	671	5527	728	5376	768	6185	797	6100	936

---

[28] IRENA (2015).

[29] IRENA (2016).

[30] IRENA (2020).

[31] IRENA (2021).

[32] Hutter (2021).

Top 20 countries	Capacity (MW) 2000	Production (GWh) 2000	Capacity (MW) 2006	Production (GWh) 2006	Capacity (MW) 2010	Production (GWh) 2010	Capacity (MW) 2015	Production (GWh) 2015	Capacity (MW) 2020	Production (GWh) 2020	Forecast for 2025 (MW)
Japan	535	-	535	3100	537	2632	516	2595	481	2409	554
Kenya	60	-	132	1018	198	1377	604	4481	824	9930	600
Mexico	855	-	960	6685	965	6618	906	6331	906	5375	1061
Nicaragua	21	-	88	311	88	302	155	678	153	492	159
New Zealand	418	-	433	3368	726	5867	941	8008	984	7728	-
Papua N Guinea	-	-	21	224	56	400	56	400	56	-	50
Philippines	1931	-	1978	10465	1847	9929	1916	11044	1928	9893	2009
Portugal	14	-	25	85	25	197	25	204	29	216	43
Russia	26	-	87	463	81	505	78	457	81	441	96
Turkey	18	-	23	94	94	668	624	3425	1613	8168	2600
USA	2784	-	2274	16581	2405	17577	2542	18727	2587	18366	4313

Table 2.3: Geothermal power statistics and forecast for the newcomers, 2020-2025 [33, 34, 35, 36, 37]

Newcomers	**Capacity (MW) 2020**	**Production (GWh) 2020**	**Forecast for 2025 (MW)**
Chile	40	400	81
Croatia	10	76	24
Honduras	39	297	35
Hungary	3	5	3

---

[33] IRENA (2015).

[34] IRENA (2016).

[35] IRENA (2020).

[36] IRENA (2021).

[37] Hutter (2021).

As illustrated in Tables 2.1, 2.2, and 2.3, that lay out the changes in terms of capacity (MW) and energy production (GWh) taking place between 2000-2020, the leading countries are, in descending order, the USA, Indonesia, the Philippines, Turkey, New Zealand, Mexico, Kenya, Italy, Iceland, Japan, and Costa Rica. [38] These countries accounted altogether for 90.453 GWh in 2020 [39,40], representing almost 95% of total geothermal electricity production, and they are expected to continue to lead in power generation from geothermal sources thanks to their abundant and untapped resource availability. Moreover, as demonstrated in Figures 2.4 and 2.5, the United States, Indonesia, and the Philippines not only have some of the world's largest geothermal plants, but they also have a number of geothermal projects under development. Given that Indonesia has four of the world's largest power plants and plans to further develop its geothermal resources, it might conceivably overtake the USA by about 2027 and, therefore, become the global market leader. [41] Nonetheless, the modest decline in the predicted capacity increase forecast for 2025 in certain countries, as shown in the above Tables, is attributed to price-related competition from solar, wind, and natural gas, along with hesitancy from many national governments to encourage new geothermal development. [42]

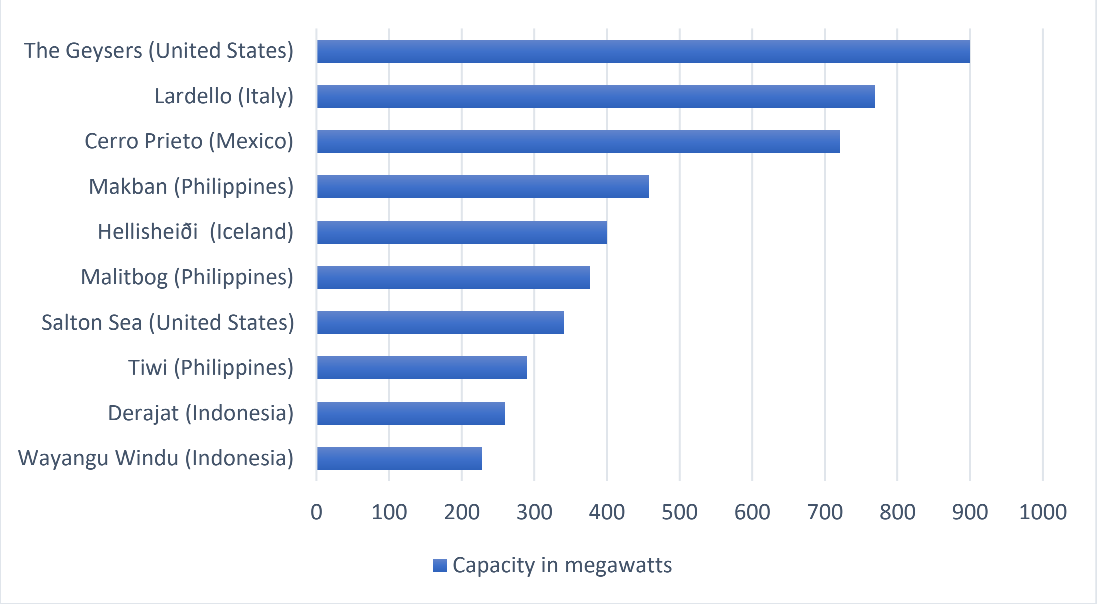

Figure 2.4: Ranking of the largest geothermal plants worldwide, as of January 2021 [43]

---

[38] IRENA (2021).

[39] IRENA (2021).

[40] Hutter (2021).

[41] Hutter (2021).

[42] Hutter (2021).

[43] Statista (2022).

Figure 2.5: Geothermal Power Plants, 2020 [44]

2.2.3 Geothermal applications

As of 2020, underground heat was used indirectly for electricity production in 26 countries, while direct use for heating, cooling, agriculture and industrial processes took place in 88 countries, an increase from 82 countries in 2015, 78 in 2010, 72 in 2005, 58 in 2000, and 28 countries in 1995 (Figure 2.6). [45] Despite the fact that the number of states using geothermal energy to generate electricity remains small in comparison to those that exploit their thermal resources for direct use, it is gratifying to see that new lands are joining the former group, with interest in developing geothermal projects. Namely, during the five-year term of 2015-2020, five countries generated geothermal power for the first time (Table 2.3). These were Belgium (0.8 MW installed capacity and 2 GWh of energy produced), Chile (40 MW – 400 GWh), Croatia, (10 MW – 76 GWh), Honduras (35 MW – 297 GWh), and Hungary (3 MW – 5 GWh). [46, 47]

---

[44] Hutter (2021).

[45] Lund, Toth (2020).

[46] Hutter (2021).

[47] IRENA (2021).

Figure 2.6: Global geothermal use, 2015 [48]

Regarding electricity production from geothermal resources, the 2020 levels reached 94 TWh after steadily rising during the last two decades (Figure 2.7). An estimated 2% year-on-year increase was noted between 2019 and 2020, which is lower than the average growth rate of the previous five years, due to a number of challenges posed by the pandemic. [49]

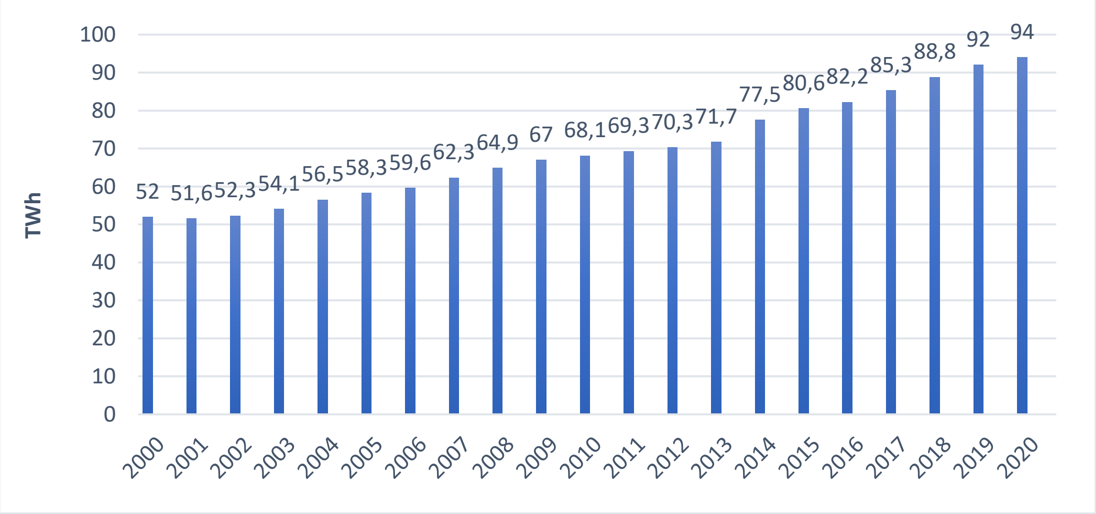

Figure 2.7: Global geothermal electricity production, 2000-2020 [50, 51]

Accordingly, the thermal energy consumed in direct geothermal applications in 2020 reached 1.020.887 TJ/yr (283.580 GWh/yr), reporting a 72.3% increase over 2015 and

---

[48] International Geothermal Association (n.d.)

[49] IEA (2021).

[50] IEA (2021).

[51] IRENA (n.d.).

a compound annual growth rate of 11.5%. [52] Asia and Europe are the leaders in direct geothermal use, since 57 countries located in the Eurasian continent accounted for 77.5% of the world's installed capacity (MWt) and 80.8% of the direct-uses (TJ/year) (Table 2.4). In specific, the group of countries that stand out as major producers and consumers of geothermal fluids for direct applications includes China, the USA, Sweden, Turkey, Japan, Germany, Iceland, Finland, France, and Canada, while other countries have been preparing the necessary groundwork, conducting inventories, and quantifying their resources, in view of an improvement in their economic situation, or a resurgence of governmental and private interest in developing this domestic renewable energy source. [53] This is the case for many east African countries, that hold geothermal resources associated with the African Rift Valley. [54]

Table 2.4: Distribution of direct-use geothermal energy utilization by continent, 2020 [55]

Continent	Countries	%MWt	%TJ/year
Africa	11	0.2	0.4
Americas	17	21.7	17.7
Asia	19	45.6	53.4
Europe*	38	31.9	27.4
Oceania	3	0.6	1.1
Total	88	100%	100%
***Includes CIS countries (Georgia, Russia, and Ukraine)**			

Table 2.5: Contribution of direct-use geothermal energy to a country's economy [56]

Country	Contribution to the national economy
Iceland	90% of buildings' space heating
Japan	2000 hot springs, 5000 public baths, 1500 hotels serving 15 million guest/year
Sweden	40% of buildings heated using geothermal heat pumps

---

[52] Lund, Toth (2020).

[53] Lund, Toth (2020).

[54] Lund, Toth (2020).

[55] Lund, Toth (2020).

[56] Lund, Toth (2020).

Turkey	116000 apartments/residences heated in 17 cities, approaching 40% of units
USA	Approximately 1.685 million geothermal heat pumps (4.0% growth/year)

2.2.4 Geothermal technologies

The development of sustainable technologies is vital for fostering economic and social development and addressing the alarming effects of climate change. Geothermal energy has showed significant potential, since only 1% of the total estimated available geothermal resources could hypothetically provide 2800 years of power at a constant rate. [57] The exploitation of a geothermal reservoir requires the prior recognition of the geothermal resource's type, given by the ratio of porosity to permeability. [58] The reservoir's features determine the depths of production wells, that range from 300 meters to more than 3000 meters, where thermo-fluids are contained in porous hot rocks. [59] The best geothermal resources are located in active geothermal areas or near the surface of the Earth's crust and can be accessed at a relatively low cost, by drilling into the earth's surface and tapping into the naturally occurring steam or hot water for electricity generation in steam turbines. [60] In greater depths, geothermal energy can be extracted to harness the heat found in what would otherwise be dry rocks, by injecting water into the hot area through wells after drilling. [61] Given that each geothermal resource has distinct characteristics in terms of temperature, location, and well depth, there is no single technology that can be applied in all geothermal sources as a general trend.

Apart from the location, the heat content of a geothermal field also defines the technology to be used. Direct application technologies use heat energy directly from the geofluid at temperatures ranging from 10°C to 150°C. On the contrary, medium to high temperature resources are essential for electricity generation, with the vast majority of them located near areas of volcanic activity, plate boundaries, such as the "Ring of Fire," mid-oceanic ridges, such as Iceland and the Azores, rift valleys, such as the East African Rift, or hot spots, such as Hawaii. [62]

A review of the literature indicates that there are 7 main technologies that use the Earth's heat, either for heating and cooling purposes, or for electricity generation,

---

[57] Anderson, Rezaie (2019).

[58] Anderson, Rezaie (2019).

[59] Moyaa, Aldásd, Kaparaju (2018).

[60] IRENA (2021).

[61] IRENA (2021).

[62] Ito, Ruiz (2017).

taking into account the geographical distribution, availability and quality of the exploitable hydrothermal resources. For heating and cooling applications, (1) ground source heat pumps and (2) direct use geothermal systems are used, whereas the pioneer geothermal technologies for electricity production are (3) deep and enhanced geothermal systems (EGS), (4) direct dry steam plants, (5) flash steam plants, (6) binary plants, and (7) hybrid plants. [63, 64] Moreover, promising opportunities for power production from geothermal energy are also given by coupling plants with heating applications, retrofitting flash plants, and exploiting co-produced resources, by taking advantage of what otherwise would be wasted heat. [65]

First, ground source heat pumps consist of a heat pump connected to a series of buried pipes that take advantage of the naturally occurring difference between the temperature of the above-ground air and the temperature of the subsurface soil, in order to move heat from the ground to a building and vice versa, for space heating and space cooling (air conditioning) respectively. The above-ground heat pumps, that can also be used for water heating purposes, are a relatively inexpensive technology, in which underground installation pipes account for most of the system's cost. This technology requires a small amount of electricity during the heating and cooling process, since for every unit of electricity consumed, the heat pump can provide as much as five times the energy from the ground, creating a net energy benefit. [66] However, in the absence of renewable electricity, geothermal heat pump systems may not be entirely renewable and fossil-fuel free.

Second, direct use geothermal systems require groundwater that has been heated underground by natural geological processes and can be found just a few feet below the surface, less than a mile deep, in areas with volcanic or tectonic activity. Water from direct geothermal systems is utilized in a wide range of applications, including space heating, cooling, large-scale pool heating, water heating, industrial and agricultural activities, as well as district heating, which serves a variety of home and non-domestic structures. Thanks to the shallow depths, capital costs are relatively lower than in deeper geothermal systems; however direct use systems are confined to regions with hot groundwater located at or near the surface. [67]

Of all direct-use technologies, ground-source heat pumps typically have the largest use, representing 71.6% of the installed capacity and 59.2% of the annual energy use in 2020. [68] China, the USA, Sweden, Germany and Finland were the worldwide leaders in

---

[63] U.S. Environmental Protection Agency (n.d.).

[64] Ito, Ruiz (2017).

[65] Ito, Ruiz (2017).

[66] U.S. Environmental Protection Agency (n.d.).

[67] U.S. Environmental Protection Agency (n.d.).

[68] Lund, Toth (2020).

terms of both installed capacity (MWt), accounting for 77.4% of these units, and annual energy use (TJ/yr), accounting for 83.5% of the output. [69] The number of countries with installations has expanded from 26 in 2000 to 54 in 2020, with most of them located in North America, Europe, and China. [70]

In contrast to direct-use applications, power production requires heat stored at depths greater than commonly drilled, where the ground becomes less porous, the water flow is restricted, and the rocks are dry and impermeable. To overcome this limitation, artificial fractures are created to connect production and injection wells by hydraulic or chemical stimulation. In these systems, known as enhanced geothermal system (EGS), water is injected into the ground through one well, while water or steam are brought to the surface through another well. Although EGS projects have low operational costs and involved no fuels, the initial capital costs, particularly during the drilling of test and production wells, can pose financial barriers. Additionally, the locations with economically viable steam resources are limited; therefore, research is underway to develop EGS with deeper wells that are not location-constrained and can take advantage of the Earth's heat in larger areas.

Furthermore, binary plants produce power from the hot brine, which is eventually re-injected into the reservoir to prevent air emissions and to keep both the pressure and production stable. [71] As far as hybrid systems are concerned, they refer to the pairing of multiple power generation systems. Existing structures combine geothermal energy with solar, biomass, thermoelectric generators and hydrogen production to take use of the leftover enthalpy in the geofluid after geothermal resources have been extracted and utilize it in a variety of applications. [72] For instance, hybrid multi-generation solar-geothermal systems produce five outputs: electrical power, cooling, space heating, hot water and industrial processes. They are proven to be reliable since they not only use low-cost collectors keeping electricity costs competitive, but they also benefit from additional capital cost reductions via shared equipment among the different systems. [73] In addition, hybrid geothermal-biomass configurations equally increase energy output and thermal efficiency, while also prolonging the life of the geothermal reservoir. [74] According to research, pairing geothermal resources with biomass allows for lower costs and environmental impact when compared to stand-alone systems. [75] Recently, a novel system for cooling, heating and power generation, integrating biomass, geothermal energy and natural gas, was proposed in an effort to increase the use of

---

[69] Lund, Toth (2020).

[70] Lund, Toth (2020).

[71] Ito, Ruiz (2017).

[72] Anderson, Rezaie (2019).

[73] Anderson, Rezaie (2019).

[74] Moyaa, Aldásd, Kaparaju (2018).

[75] Anderson, Rezaie (2019).

renewable energy, maximize energy efficiency, and improve reliability of energy delivery. [76] Nevertheless, despite the opportunity of multigeneration, the shortcomings of hybrid solar-geothermal power systems are reduced efficiency cycles, since operational hours are restricted by the availability of sunlight, scale formation, and corrosion.[77]

Finally, a new way of hydrogen (H_2) production through electrolysis powered by geothermal resources has recently been investigated. Certainly, hydrocarbons are the primary source of hydrogen production at present; however, the depletion of fossil fuels and increased environmental concerns have led to an increase in the integration of renewable technologies in hydrogen production systems, with geothermal energy demonstrating promising outcomes. These systems present both challenges and benefits. In the first case, renewable energy sources face storage constraints, as even batteries are a questionable option due to their restricted capacity. [78] Apart from that, shallow geothermal-based systems are subject to thermal imbalance and temperature changes, especially when the load is higher that the source's potential and the ground is unable to recover the energy being extracted. [79] Nevertheless, renewables, such as geothermal energy, and hydrogen production create an ideal combination in terms of economic, environmental, and thermodynamical basis, because a hybrid geothermal system can minimize ground fouling and thermal imbalance, maintaining stability in the system's performance. [80] Additionally, the costs of electrolysis by using geothermal resources are considerably lower compared to other sources. [81] As a result, hybridization has demonstrated not only significant potential to improve the energy efficiency of diverse systems, but also the ability to reduce the environmental impact of conventional fossil fuel-based systems through a cost-effective and clean alternative.

2.2.5 Geothermal costs

Geothermal is a mature and commercially proven technology that can provide low cost, "always-on" capacity in regions with medium to high-temperature conventional geothermal resources near the Earth's surface. However, the exploitation of unconventional geothermal resources often within hot dry rocks via enhanced geothermal systems is a much less mature technology. In that case, geothermal projects present a unique set of challenges that result in significantly higher costs, due to the

---

[76] Anderson, Rezaie (2019).

[77] Anderson, Rezaie (2019).

[78] Ghazvini, et al. (2019).

[79] Mahmoud, et al. (2021).

[80] Mahmoud, et al. (2021).

[81] Ghazvini, et al. (2019).

need for deep drilling. It is thus clear that depending on the depths, reservoir quality, power plant type, and the number of wells required, geothermal projects have very different risk profiles compared to other renewable power generation technologies, and are highly site-sensitive, capital-intensive, with significant upfront costs for project development, exploration, and resource assessment, including seismic surveys and test wells, field preparation, drilling, and power plant construction. [82] In addition, despite the absence of burning fossil fuels during their operation, the drilling, engineering, procurement and construction costs of geothermal power projects are influenced by fluctuations in the oil and gas industry's business cycle. [83]

Nonetheless, despite having constraints and the highest installed cost (Table 2.6) and levelized cost of electricity (Table 2.7) in 2020, geothermal technologies present one of the highest capacity factors, ranging between 60% to more than 90%, depending on geography and plant design, as they are typically designed to run as often as possible and provide firm power round the clock, as demonstrated in Table 2.8. In fact, the average capacity factors of geothermal plants using direct steam and flash technologies are estimated to be around 85% and 82% respectively, while binary power plants that exploit resources in lower temperatures achieve an average capacity factor of 78%. [84]

---

[82] Taylor, et al. (2021).

[83] Taylor, et al. (2021).

[84] Taylor, et al. (2021).

Table 2.6: Total installed cost trends by renewable technology, 2010-2020 [85]

Total installed cost by technology (2020 USD/kW)											
Technology	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Biomass	2619	1318	1513	3064	3018	2623	2201	2932	1714	2173	2543
Geothermal	2620	-	5317	3827	3613	3538	3716	3875	4221	3968	4468
Hydro	1269	1251	1338	1513	1732	1541	1828	1853	1462	1733	1870
Solar PV	4731	4007	3021	2647	2393	1823	1657	1432	1223	1009	883
Offshore wind	4706	5390	4770	5041	5308	5323	4191	4735	4631	3723	3185
Onshore wind	1971	1939	1995	1851	1797	1659	1652	1647	1566	1491	1349
Concentrating solar power	9095	10715	8281	6496	5576	7449	7830	7412	5316	6660	4581

Table 2.7: Levelized Cost of Electricity (LCOE) trends by renewable technology, 2010-2020 [86]

Global weighted-average LCOE by technology (2020 USD/kWh)											
Technology	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Biomass	0,076	0,056	0,061	0,082	0,083	0,074	0,073	0,073	0,057	0,066	0,076
Geothermal	0,049	-	0,085	0,065	0,067	0,061	0,071	0,075	0,072	0,074	0,071
Hydro	0,038	0,035	0,037	0,041	0,041	0,036	0,048	0,049	0,039	0,040	0,044
Solar PV	0,381	0,289	0,217	0,168	0,154	0,117	0,104	0,083	0,070	0,061	0,057
Offshore wind	0,162	0,171	0,147	0,139	0,165	0,142	0,118	0,114	0,111	0,093	0,084
Onshore wind	0,089	0,083	0,082	0,079	0,071	0,063	0,060	0,057	0,051	0,045	0,039
Concentrating solar power	0,340	0,336	0,331	0,249	0,217	0,224	0,254	0,216	0,152	0,212	0,108

---

[85] Taylor, et al. (2021).

[86] Taylor, et al. (2021).

Table 2.8: Capacity factor trends by renewable technology, 2010-2020 [87]

Global weighted-average capacity factor by technology (%)											
Technology	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Biomass	71,7	68,1	64,5	74,3	74,7	75,5	67,2	85,8	76,4	70,0	70,3
Geothermal	87,0	-	83,3	82,4	84,1	89,0	84,9	81,0	85,4	79,4	82,6
Hydro	43,9	44,1	45,8	50,0	49,2	50,6	50,4	47,0	45,5	48,4	45,5
Solar PV	13,8	15,2	15,1	16,4	16,6	16,5	16,7	17,5	17,9	17,5	16,1
Offshore wind	37,9	38,1	39,9	45,0	35,1	41,9	39,7	44,7	43,1	42,3	40,0
Onshore wind	27,1	27,6	28,5	26,9	28,8	29,1	30,6	32,3	34,0	35,6	35,5
Concentrating solar power	30,0	35,5	27,4	31,0	28,5	40,4	36,2	38,6	45,1	36,9	41,9

---

[87] Taylor, et al. (2021).

In further detail, between 2010 and 2021, the average installed cost for geothermal energy globally ranged between USD 2700/kW to USD 5500/kW, peaking at USD 5509/kW in 2012. [88] After fluctuating for almost half a decade, installation costs have been following an increasing trend from 2015 and onwards, which has been interrupted both in 2019 and in 2020, where they slightly decreased. As presented in Figure 2.8, the average installed cost in 2021 was USD 3991/kW, almost reaching the 2016 levels. IRENA's database suggests that the cost of a geothermal power plant can be as low as USD 560/kW, without this being the norm. [89] Moreover, in contrast to direct steam and flash plants, costs for binary plants designed to harness lower temperature resources tend to be higher, as extracting electricity using this technology is more capital intensive.

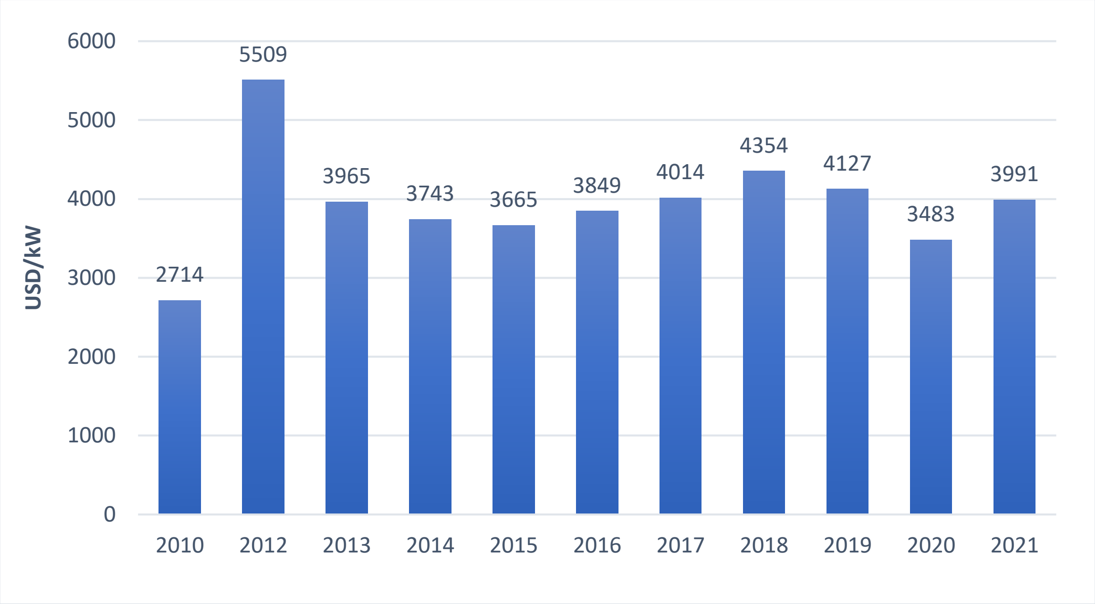

Figure 2.8: Global average installed cost of geothermal energy, 2010-2021 [90]

As far as the levelized cost of electricity (LCOE) is concerned, it is determined by the total installed costs, the weighted-average cost of capital, the economic lifetime costs of a geothermal plant, as well as the operation and maintenance expenses. As presented in Figure 2.9, the global weighted-average LCOE of geothermal power projects has ranged from USD 0.04/kWh to USD 0.17/kWh during the period 2010-2021, increasing from approximately USD 0.05/kWh in 2010 to around USD 0.07/kWh in 2020.

---

[88] Taylor, et al. (2021).

[89] Taylor, et al. (2021).

[90] Jaganmohan (2022).

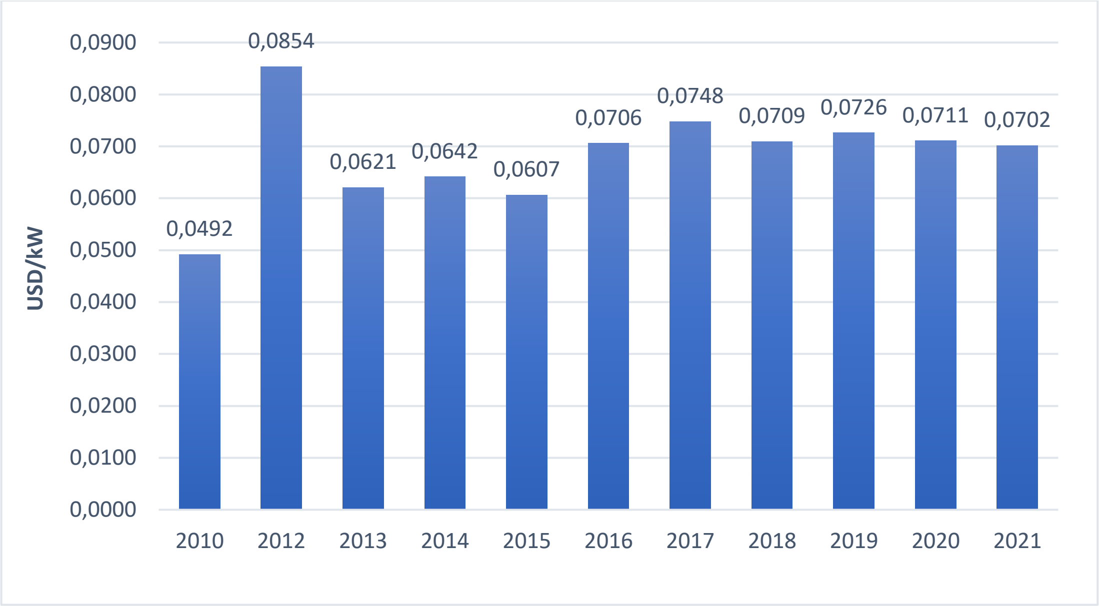

Figure 2.9: LCOE of geothermal power projects, 2010-2021 [91]

All in all, between 2010 and 2020:

1. Total installed costs for geothermal projects have reported a 71% change.
2. LCOE has increased by 45%.
3. The geothermal capacity factor has shown a -5% change, without altering the fact that geothermal power plants tend to have amongst the highest capacity factors, in spite of the large capital investments required.

In conclusion, overall development has been slow, which is unsurprising considering that fossil fuels are a major competitor. The initial high investment costs of geothermal projects, the difficulty in securing funding for surface exploration and drilling operations, several environmental, social and administrative constraints, and the fact that geothermal project costs are highly site-sensitive are four parameters that multiply the barriers and render these projects less attractive. At the same time, technologies that exploit conventional geothermal resources may require further enhancement to access high-quality resources at greater depths. Nevertheless, the costs of electricity production from geothermal technologies are becoming increasingly competitive and are expected to keep declining through 2050 [92], while most of the aforementioned challenges can be addressed through public financing and the development of public companies to exploit geothermal resources. [93] Moreover, research and development on innovative, low-cost drilling techniques, as well as geothermal resource mapping, could assist in lowering development costs and reducing uncertainties that arise during the

---

[91] Taylor, et al. (2021).

[92] IRENA (2017).

[93] Ito, Ruiz (2017).

exploration period, making geothermal projects more economically viable. Most importantly, the accelerated deployment of geothermal energy can strengthen the growing global trend toward clean energy and significantly contribute to the national energy needs of a greater number of states.

2.3 The geopolitics of geothermal energy

2.3.1 Geopolitics

The origins of the word “geopolitics” can be found in the Greek words “γη” (earth, land) and “πολιτική” (politics). The term geopolitics was introduced in 1899 by the Swede Rudolf Kjellen (1864-1922), who further promoted it in 1916 in his study entitled “The State as a Living Form”, arguing that the effectiveness of the state as a geographical entity was both “the most important factor in its success and the most powerful justification for its existence”. [94] Geoffrey Parker, in his book “Geopolitics: Past, Present and Future” (1997), provides an inclusive definition, recommending that geopolitics is the study of international relations from a spatial or geographical perspective. [95] In addition, geopolitics is a theory of spatial relationships and historical causation that draws attention to the significance of geographical patterns in political history. [96] Geopolitics can also be perceived as power relations over map, as straightforwardly defined by Dr. Athanasios Platias.

To properly approach the multidimensional and complex concept of geopolitics, we must deconstruct it in 4 levels of analysis: geography, political geography, geopolitics, and geostrategy. [97]

Firstly, the term geography refers to the description and distribution of land and sea features, as well as to the ways in which people and countries organize their economic and other activities within an area. [98] In the field of International Relations, geography can be viewed in three distinct ways; first, as an objective of policy, a prize in a conflict, the state of control over territory exercised by a state. In this case, every state struggles to defend its delineated borders from external attack. Second, geography is viewed as an environment, both natural and historical. Third, geography can be interpreted as a theatre of military action. [99] In all circumstances, geography, either in terms of climatic conditions and topography, or in terms of natural resources, is one of the inputs of power.

Secondly, political geography is the science that merely describes the arrangement of global space features related to issues of spatial organization, without analyzing the relationships between them. Political geography examines a great number of different

---

[94] Koliopoulos (2010).

[95] Gray, Sloan (2013).

[96] Gray, Sloan (2013).

[97] Arvanitopoulos, Hephaistos (2009).

[98] Arvanitopoulos, Hephaistos (2009).

[99] Gray, Sloan (2013).

elements in the relationship between politics and places, such as geographical location, demography, economy, political power, the quantity and quality of wealth-producing resources, import dependency, consumption habits, the energy status of a state, the degree of industrialization, or the penetration in foreign markets. [100]

Geopolitics is the concept that follows the previous two in our analytical hierarchy. With geopolitical analysis, we observe, correlate, and compare the elements mentioned above, both fixed and variable, in order to draw conclusions about the structure of the international system and the distribution of power within it, and thus assist political leadership in formulating national strategy and foreign policy. Moreover, geopolitical analysis can serve as a tool to interpret the relationship between political power and geographical environment and evaluate a state's security problems using geographical terms. [101]

Lastly, regarding the concept of geostrategy, it can be interpreted as the analysis that, apart from examining geopolitical factors, introduces strategic and tactical criteria in order to shape national strategy and fulfill national aspirations. [102] In strategy, the geographical elements that constitute the inputs of power are converted to outputs or control over others. All in all, after the diagnosis of the power structure in the international system, the geopolitical analysis makes it possible to proceed to the selection and combination of political and military means to fulfill national strategic goals.

The traditional geopolitical approach originally dealt with the context of space and power and the correlation between them [103], nevertheless numerous theoreticians and strategists have dealt with the notion of geopolitics using a different hermeneutic lens. For instance, the idea of the state as a living organism that develops by occupying space, then shrinks and finally disappears from the map, dominates in the work of the German F. Ratzel. [104] Karl Haushofer, a German army officer, is to some extent responsible for the bad reputation attributed to geopolitics, as he developed the concept of the vital space, which holds that great powers should seek territorial expansion to ensure their survival. [105] Furthermore, A. Mahan, the theoretician of naval power and one of the most popular geopolitical analysts, argued that control of certain bodies of water had a particularly important economic and military value [106], a judgment that is also valid in the energy field, as access to the sea and the sea routes is indispensable for the

---

[100] Arvanitopoulos, Hephaistos (2009).

[101] Arvanitopoulos, Hephaistos (2009).

[102] Arvanitopoulos, Hephaistos (2009).

[103] Koliopoulos (2010).

[104] Koliopoulos (2010).

[105] Koliopoulos (2010).

[106] Gray, Sloan (2013).

exploitation of valuable marine resources, the control of chokepoints, as well as for energy imports and exports. Moreover, in Nicholas Rodger's viewpoint, geographical conditions influence the interconnection between geography and strategic policy. [107] Apart from that, Rodger places emphasis on the key dynamic role of technology in the relationship between the geographical environment and the decision-making process. [108] The strategic and geopolitical value of geography is also noted by Murray, who pointed out that mistakes at the tactical and operational level can often be corrected in time, while at the strategic level, where geographical factors play a critical role, mistakes tend to live forever or to be altered by war. [109]

Perhaps the most prominent geopolitical analyst is the British geographer Sir Halford Mackinder, whose theory contradicts the one of the American Nicholas J. Spykman, both describing post-war American strategy in the Euro-Atlantic area. Within 4 decades, Mackinder developed his influential geopolitical view of global politics underlining that geopolitics, geography, and strategy serve together. His strategic thought can be encapsulated by the heartland theory, that evolved over time and was presented and published in three versions: In "The Geographical Pivot of History" (1904), in "Democratic Ideals and Reality" (1919), as well as in "The Round World and the Winning of the Peace" (1943). [110] Key points used by Mackinder to develop, expand, and then refine his geopolitics were following: (a) the perception of the world as a "closed" political system, where changes in one part affect the whole system, (b) the relationship between physical and political geography, (c) the continuous struggle between land and sea powers, (d) the effect of technology on the political cohesion of continental-sized states, and (e) the impact of population and demographic trends on the global balance of power. [111] Most importantly, Mackinder focused on the link between history and geography, because, in addition to providing strategic opportunities, geographical features often govern or, at least, guide history. In fact, as he pointed out, the greatest events in the world's history are related to the greatest features of geography. [112] The significance he placed on understanding the impact of geography in history is justified by the need to understand the past before interpreting the present and predicting future trends around the globe. [113]

Mackinder also emphasized the strategic importance of continental land masses in contrast to maritime space and pointed out the inherent potential that surrounds the Asian part of the Russian Empire, since this area is not accessible neither from the north,

---

[107] Gray, Sloan (2013).

[108] Gray, Sloan (2013).

[109] Gray, Sloan (2013).

[110] Sempa (2015).

[111] Sempa (2015).

[112] Sempa (2015).

[113] Sempa (2015).

thanks to glaciers, nor from the south, thanks to mountain ranges, starting from the Caucasus and extending to the Himalayas and the Altai mountains. [114] In 1904, Mackinder named this area “Pivot Area”, while in 1919 he renamed it “Heartland”, after expanding the region to include Central Europe (Figure 2.10 and 2.11). The main difference between the 1904 and 1919 versions was the emphasis placed on Central Europe, which was predicted to become the future fulcrum of the balance of power in a conflict between sea and land powers. [115]

The Heartland is surrounded by an inner semicircle, named “inner or marginal crescent”, that comprises the great civilizations of History and is occupied by Germany, Turkey, Iran, India, and China, and an outer semicircle including Western Europe, America and Africa. [116] The “outer or insular crescent” includes the United States, the British dominions (Canada, Newfoundland, South Africa, Australia and New Zealand), Great Britain and Japan, thus it represented the realm of sea power. [117] As a result, Mackinder considered the Heartland a large, geopolitically unified area with landmasses with geographical depth and natural protection, easy access to canals, straits, economically exploitable rivers and industrially developed areas, yet with no contact with open seas. [118]

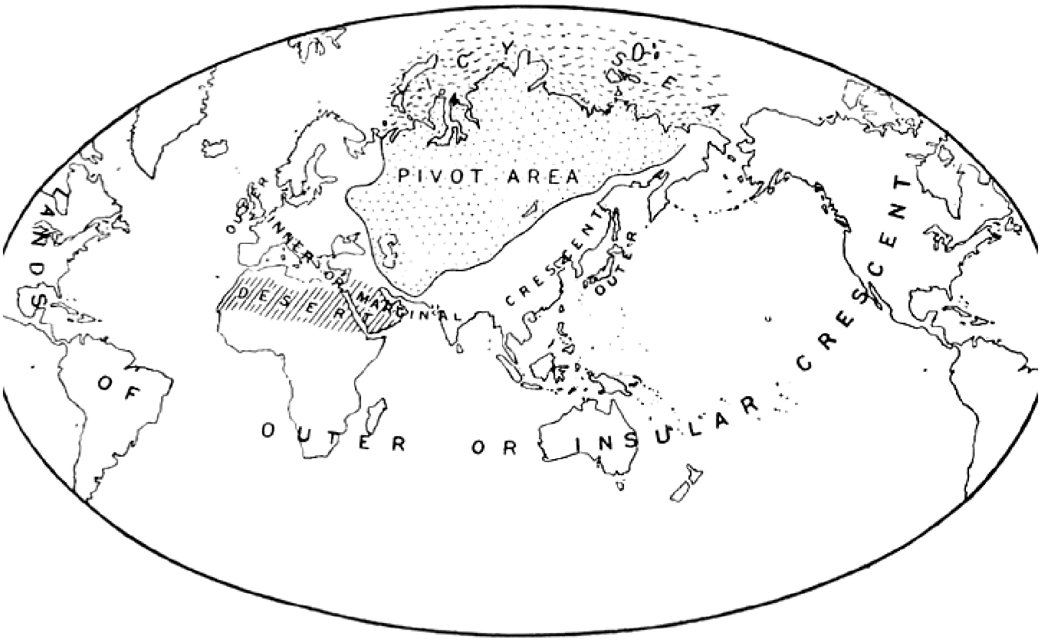

Figure 2.10: Mackinder’s 1904 view of the World [119]

---

[114] Koliopoulos (2010).

[115] Gray, Sloan (2013).

[116] Koliopoulos (2010).

[117] Venier (2021).

[118] Arvanitopoulos, Hephaistos (2009).

[119] Mackinder (1942).

Figure 2.11: Mackinder's Pivot in 1904 and 1919 [120]

Throughout history, the inhabitants of the Heartland have made efforts to gain access to the seas, exerting pressure on the states of the Eurasian perimeter, an achievement that would make the Heartland dominant in the so-called "World Island", that is, in Eurasia and the African continent. [121] This observation led Mackinder to phrase his famous axiom: *"Who rules East Europe controls the heartland; who rules the heartland commands the World-Island; who rules the World-Island commands the World."* [122] What Mackinder feared was that a hostile power or a coalition of powers, profiting by technological advances in the field of transportation, would gain effective political control of the Eurasian land mass (the World Island), significantly influence world politics and use its resources to overwhelm the insular powers. [123] Russia's domination in the world natural gas market and energy exports, especially in the EU, and its use of energy as a geopolitical instrument to maximize power seem to verify Mackinder's greatest geopolitical nightmare.

Nonetheless, among its weaknesses, Mackinder's point of view was refuted during World War II, as Germany managed to occupy Eastern Europe and most of the European USSR, and not only failed to conquer the world, but was itself conquered by the power that controlled the Heartland. Thus, in 1943, in the middle of the war, Mackinder once again reconsidered his statement, adding the following: apart from the traditional Heartland, which he now identified with the entire territory of the USSR, there is also the Atlantic Community that works as a counterweight to the Heart (i.e.

---

[120] Ismailov, Papava (2010).

[121] Arvanitopoulos, Hephaistos (2009).

[122] Gray, Sloan (2013).

[123] Sempa (2015).

the Soviet Union and its allies) and consists of the US-Canada, Britain and France.[124] Its emergence is justified by the need of an alliance of naval powers in the Atlantic area to balance continental powers.

Among those who disagreed was the American N. Spykman, who wrote his texts in opposition to Mackinder, but reached conclusions that complemented the former's analysis. Without questioning what Mackinder had said, he emphasized the importance of power distribution not in continental Europe, but mostly in the periphery of Eurasia.[125] Spykman's theorem is as follows: *"Who controls the rimland, rules Eurasia; who rules Eurasia controls the destinies of the world".*[126] Both Mackinder and Spykman's theory intersect in the region of Western Europe. US diplomat George Kennan, partially based on Spykman's analysis, proposed the containment doctrine, a policy of halting the USSR, by creating a series of defense alliances, the most prominent of which being NATO.[127]

Figure 2.12: Mackinder's Heartland and Spykman's Rimland Theory, 2019[128]

Contemporary geopolitics have synthesized to a great extent elements from the above theories. The first is the enormous importance of maritime communications for military and economic purposes. The second is the geopolitical potential of Eurasia. Thirdly, the control of the production and circulation of energy sources is still considered a

---

[124] Koliopoulos (2010).

[125] Arvanitopoulos, Hephaistos (2009).

[126] Arvanitopoulos, Hephaistos (2009).

[127] Koliopoulos (2010).

[128] Gilchrist (2019).

prominent geopolitical element, capable of influencing the balance of power in the international system. [129] Today's most insightful analysts of international affairs rely on the broad shoulders of giants, none broader than Sir Halford Mackinder's, whose geopolitical thought matured into the three masterful works, between 1904 and 1943. His aim was to prove that geopolitics, geography, and strategy serve together, as well as that the political implications of new technology and the existence of certain geographical patterns of political history go hand in hand. [130] The Heartland theory constitutes his most important legacy in terms of strategic thought, while his geopolitics is timeless and enduring because of its empiricism.

As examined in this subsection, all the elements of Mackinder's geopolitics are present: (a) the world as a closed political system, proven by the rapid diffusion of the Russian-Ukrainian war's repercussions in energy, economy and society, (b) geography's constraints and opportunities, (c) the unity of the ocean, (d) Eurasia as the great continent, where some of the geopolitically strongest states exist, (e) the role of technology in man's relation to geography, and (f) the importance of studying history in its geographical context. Mackinder's theory might have been refuted in the case of Germany, during World War II, nonetheless, in the twenty-first century, China's Belt and Road Initiative comes to verify Mackinder's thesis that, despite the lack of control of the sea, industrialized heartland powers build rails, have a mobility advantage, dominate the Rimland, and change the order in Eurasia and the world.

Regarding energy, it is one of geography's most prominent configurations and a cornerstone of international relations and politics, as it constitutes a component of grand strategy, that is, an end, a means and a way of achieving national targets. The interaction between geopolitics and energy can be found in at least 6 of Mackinder's points: (1) the distribution of natural resources, (2) the role of technology, (3) the changes of the physical environment, (4) the value of sea power, (5) the world as a "closed political system", and (6) the ability of natural resources to shift power. These standpoints are discussed in greater depth below:

1. To begin with, in the "Pivot paper", Mackinder noted that the global balance of power is the product of geographical conditions, both economic and strategic, and of the organization and characteristics of the competing peoples. [131] Therefore, not only the earth's surface, the weather and climate, but also the distribution of natural resources are all parts of physical geography that historically have an effect on man in society.

2. Technological progress, discoveries, and science revolutionize man's relationship with geography, and hence with natural resources, and alter the strategic

---

[129] Koliopoulos (2010).

[130] Gray, Sloan (2013).

[131] Sempa (2015).

relationship between land and sea powers.[132] This is true at the present time, since resource-rich states with technological knowhow and robust economies are typically less import dependent and turn their resource wealth and export revenues into long-term economic growth that spreads its benefits in the country. The shale gas revolution in the US is a characteristic example, as it has rendered the county less vulnerable to energy embargoes and changed its status from an energy importer to one of the biggest producers and exporters of LNG.

3. Furthermore, due to man's interference, the physical environment undergoes changes that affect his posterity in the long term.[133] For instance, resource depletion, as well as environmental degradation of a region due to anthropogenic pollution or even overgrazing, and their socio-economic repercussions prove the validity of this statement, as they threaten human health and compromise the natural ecosystems and environment, both in the short run and in the long run.

4. At the same time, in his effort to accentuate the dominant value of sea power in the modern world, Mackinder used the terms "unity" of the "ocean highway".[134] The British geographer seems to agree with Mahan's concept of the command of the sea, according to which one needs natural resources, technology, prime location, population, territory, and mentality towards the sea to control it.[135] The sea has always been a playing field among state and non-state actors for numerous reasons; it covers 70-75% of the planet, where the largest unexplored energy resources exist, it is surrounded by the biggest population, it constitutes a source of energy and a field where energy installations, such as offshore wind farms, can be developed, and it makes trade cheaper. Nowadays, sea power is indispensable for transporting energy from one edge of the world to another and it produces power and wealth from the control of strategic choke points, the majority of which are located within Mackinder's "inner creasing" and on the boarders of Spykman's "Rimland" (Figure 2.13). As straightforwardly stated by Dr. Athanasios Platias, *"Who controls the choke points commands the sea; who commands the sea controls energy and trade"*. Apart from that, geography, and the open sea in particular, provide natural protection, as in the case of the US, a country surrounded by two friends and two oceans.

---

[132] Sempa (2015).

[133] Sempa (2015).

[134] Sempa (2015).

[135] Platias (2019).

Figure 2.13: Major Chokepoints, 2019 [136]

The importance of sea route control in human evolution was understood millennia ago, long before Mackinder and Mahan, in ancient Greece. During that time, Themistocles, the naval strategist and creator of the Athenian maritime empire, understood the power of the sea in containing a land power, the Persians, and in generating wealth from the control of strategic points and trade. In addition, in the works of Herodotus, the "Father of History", and in those of Homer, it was made clear that the Ocean, a word used to represent the open seas (i.e., the Mediterranean), was the zone in which all of this period's major civilizations and the two main modern religions, Christianity and Islam, evolved and spread, reaching the Black Sea. [137] Moreover, the ancient Greeks used sea routes to colonize, explore and conquer new areas, as observed during the Trojan War. More precisely, contrary to the simplistic explanation that such strenuous effort was made for the sake of the Helen of Troy alone, the Achaeans had a triple target: (a) to gain control of the Hellespont strait that had prominent geographical position, (b) to gain unhindered access to the Black Sea, and (c) to obtain absolute control over trade with the populations that lived on its shores. [138] As a result, the Trojan War, as one of many examples, represents the prominent geopolitical significance of geographical factors and especially of sea routes, not only for trade, but also for shaping history.

5. Further to this, of equal importance is the perception of the world as a "closed political system", where nothing happens in one part without producing results in every other part. This notion is most relevant at the moment, as the full-scale

---

[136] Platias (2019).

[137] Poukamisas (n.d.).

[138] Poukamisas (n.d.).

invasion in Ukraine launched by Russia has produced severe socioeconomic repercussions on a global scale, by rocketing energy prices and manufacturing costs in unprecedented levels and posing security dilemmas in heavily dependent EU member-states.

6. Lastly, but most importantly, Mackinder successfully predicted that natural resources would be one of the principal power shifting factors of modern age. He foresaw that the age of European dominance of international politics was coming to an end, and, in consequence, the balance of power would shift to continental-sized states with huge populations and vast natural resources, such as Russia and the United States. [139] Indeed, resource-rich states, such as the US, China, or the OPEC member countries, perceive their vast energy resources as a geopolitical instrument, used in times of regional or international crisis. In these circumstances, partnerships may often be unfavorable, creating dependencies between technological giants, capable of exporting, producing and transporting energy, on the one hand, and import dependent entities, often lacking technological knowhow on the other. EU's straggle to phase out its resilience on Russian energy is a typical example.

In conclusion, geopolitics aims to emphasize that political predominance results from the combination of power in the sense of human and material resources and of geographical configurations, within which this power is exercised. Indeed, the factors of geography, space and distance represent significant variables considered by interacting parties in nearly all international transactions. [140] Also, geography can be described as the mother of strategy, [141] and, even though human genius sometimes temporarily overcomes the restraints it poses, nature reasserts her supremacy in the long run. [142]

Spykman associates geopolitical analysis with defense and security issues, since the physical characteristics of the territory, such as geographical depth or natural protection by mountainous masses, have a direct impact on how a state's security objectives are met. [143] Overall, geopolitical theory, whose nature is dynamic as a result of technological advancement, has a triple role; it can serve (a) as an interpretative tool, by suggesting a view of international politics defined by the geographical layout of land and sea features, and (b) as a policy science explaining the structure of security

---

[139] Sempa (2015).

[140] Gray, Sloan (2013).

[141] Gray, Sloan (2013).

[142] Sempa (2015).

[143] Arvanitopoulos, Hephaistos (2009).

problems. It can also be used (c) as a tool of political warfare to justify political decisions. [144]

2.3.2 Geothermal energy in global politics

Scientific research attempts to link the worlds of geopolitics and renewables have emerged, especially during the last decades, due to the urgent need to reduce dependence on fossil fuels and mitigate climate change. The literature is extensive with analysis on the significant geopolitical value of renewable energy sources in general, nevertheless the distinct geopolitical contribution of geothermal energy has barely been scratched and reviewed. Thus, to our knowledge, and as of 2022, this study is among first to analyze the geopolitical role of geothermal energy, which can potentially become a game changer of global politics.

To begin with, the International Renewable Energy Agency (IRENA) addresses the issue of energy security through the expansion of renewables in its analysis on the geopolitics of the energy transformation that shape a "New World", enumerating key-countries and alliances that work in this direction. [145] Renewable energy sources have grown at an extraordinary rate over the previous decade, outpacing all other energy sources and exceeding all expectations. The global energy transformation, based on renewables, energy efficiency and electrification, requires changes in the global energy systems, and is expected to have a significant impact on geopolitics, with social, economic, and political ramifications.

In the new geopolitical reality that is currently being formed, renewable sources, including geothermal energy that has been gradually growing, are the means for meeting 4 determining requirements: reliability, democratization, economic growth, and food security. Regarding the first one, in contrast to the geographic concentration of fossil fuels, which is negatively correlated with national wealth and security as it makes states either import or export dependent, geothermal energy is local and always available, ensuring reliable and stable access. With respect to the second requirement, renewables can also be considered as "*a powerful vehicle of democratization*" [146], as they facilitate decentralization of energy supply, empower local communities, multiply local economic and fiscal benefits, and limit external interference in a country's domestic affairs. Furthermore, the IRENA's report highlights that energy efficiency facilitates economic growth with lower energy inputs. Finally, it adds a distinctive parameter of security, that of food security. Extreme weather events, such as severe droughts, and fluctuations in energy prices often have a negative impact on water and energy supplies, posing critical hazards to food availability, accessibility, affordability,

---

[144] Gray, Sloan (2013).

[145] IRENA (2019).

[146] IRENA (2019).

and storage over time. Thus, the integration of renewables in agriculture, such as geothermal energy for food drying, can improve agricultural yields, reduce post-harvest loss, and, by extension, enhance food security.

Iceland is an example of the benefits that come with an economic transition based on renewables. Despite being one of Europe’s highly energy dependent countries during the 20th century, Iceland transitioned to a country with a high standard of living, producing 100% of its electricity from hydro and geothermal energy. [147] Iceland's effective development of renewable energy sources enabled it to strengthen its energy security, broaden its economic base, and attract new industries to support its national economy. Likewise, Brazil, Costa Rica, New Zealand and Kenya are also among the countries that cover more than 80% of their electricity needs via a combination of hydro, geothermal, wind, biomass and solar energy. Finally, according to IRENA's analysis, rapid deployment of renewables, which has already begun to change the traditional map of energy geopolitics, necessitates political will, multilateral cooperation, and taking advantage of both the declining cost and the technological innovations. [148]

In a more recent report, IRENA sheds further light on the value of geothermal energy for a green energy transition. [149] Geothermal energy resources, which are widespread around the world, represent an excellent alternative in the energy transition process toward cleaner sources, supporting the global decarbonization agenda and mitigating the climate crisis effects, both two pressing geopolitical issues that require immediate attention. Indeed, since geothermal power plants do not depend on burning fuels but instead directly use the energy stored underground, they produce negligible greenhouse gas emissions during their operation (Figure 2.14).

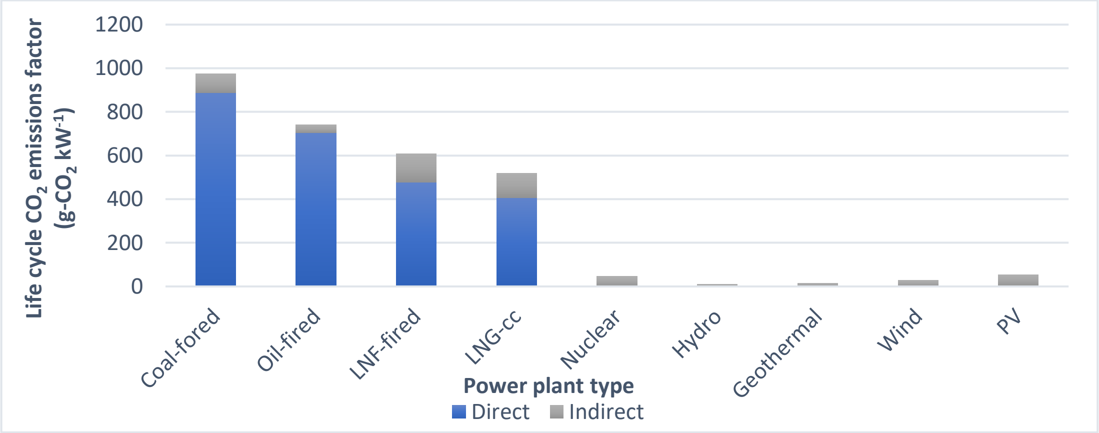

Figure 2.14: Emissions of different power plant types during their life cycle [150]

---

[147] IRENA (2019).

[148] IRENA (2019).

[149] Global Geothermal Alliance (2021).

[150] Anderson, Rezaie (2019).

In addition, geothermal power plants are capable of supplying firm baseload generation and reliable reserves, while operating in a flexible manner, maintaining grid stability with minimal added cost to the system. [151] At the same time, geothermal energy's reliability is also associated to its high resilience to extreme climate events, such as strong winds, periods of drought, or "black swans", which are becoming more frequent as climate change progresses, threatening to even disrupt energy supply. IRENA's 2021 research lays equal emphasis on the competitive levelized cost of geothermal electricity generation in comparison to other renewables and fossil fuels, demonstrating that geothermal energy is resilient to price volatility and fuel price shocks. However, it is made clear that in order for it to become a catalyst for the transition to a more sustainable economic model, collaboration and support from the public sector and stakeholders are required to create a suitable financial and regulatory environment.

It has also been argued that the attempt of consumer countries to shift away from fossil fuels is driven by local environmental and social concerns, as well as concerns about resource depletion or scarcity. [152] States aim to increase their energy security and reduce their dependence on energy imports from often unreliable hydrocarbon exporters. In this context and given that engineers recognize decarbonization as a feasible scenario by 2050, state efforts toward greater source diversification and promotion of low-carbon technologies will eventually lead to the deployment of renewable energy sources, such as geothermal energy, that are currently playing a marginal role in power generation. It is apparent, however, that energy transition will occur differently depending on country and region, but it will have a significant impact on all global, regional, national, and local levels. [153] In conclusion, it is clarified that a flexible multilevel architecture, capable of fostering new technologies and knowhow and adapting the existing institutional and regulatory framework, is required to guide the transition.

Regardless of the fact that renewable energy is the fastest-growing type of energy globally, according to BP, fossil fuels accounted for 84% of the world's primary energy consumption in 2019 and will continue to meet the majority of the world's energy needs until 2050, with the 2019 percentage breakdown being as follows: oil (33%), coal (27%), natural gas (24%), hydropower (6%), renewables (5%), and nuclear power (4%). [154] Greater integration of renewables into the global energy mix is more critical than ever, as evidenced by the US Energy Information Administration's forecast that worldwide energy demand, primarily from the industrial sector, is expected to double between 2018 and 2050. [155] In that scenario, despite being vital to a country's survival,

---

[151] Global Geothermal Alliance (2021).

[152] Hafner, Tagliapietra (2020).

[153] Hafner, Tagliapietra (2020).

[154] Cergibozan (2021).

[155] Cergibozan (2021).

the use of energy will cause 4 major problems; first, the overuse of fossil fuels, exacerbating the climate crisis' effects and global warming; second, resource depletion, which is approaching, as oil, gas, and coal are expected to be completely consumed by 2052, 2060, and 2090 respectively, making it impossible for countries to cover their energy needs in the long term; third, price volatility in energy commodities, responsible for economic instability in both national and global level. The fourth problem is the inequitable geographic distribution of fossil fuel reserves among countries, which forces them to rely either on energy imports or energy exports, raising their economic vulnerabilities. [156]

Empirical evidence from 23 OECD countries, from 1985 to 2016, showed the significance of renewable energy sources in lowering the aforementioned risks and counterbalancing geopolitical tensions, which can be confirmed by at least five reasons. [157] To begin with, renewable energy offers an environmentally friendly alternative to conventional energy, which is responsible for life-threatening amounts of greenhouse gas emissions. Moreover, unlike coal, oil, and natural gas, renewable energy sources, including geothermal resources, are more equitably distributed among countries that can potentially become energy self-sufficient. [158] An added advantage that distinguishes geothermal energy from other clean energy sources that are often confined by weather conditions, is its systems' remarkable resistance to extreme weather events, such as droughts, or lack of winds, which makes it weather independent. Apart from that, while oil tanker accidents or accidents during extraction are not common, they are an example of technological risk with significant financial, political, and environmental ramifications that geothermal systems do not have. Finally, whereas fossil fuels will be exhausted in due course, geothermal energy is not subject to depletion, and it is harnessed and consumed domestically. Therefore, it can eliminate unexpected cutoffs of energy imports, enhance security of supply, limit conflicts and reduce dependence on energy imports from often unstable environments. That said, the question of security of energy demand arises, since the wide-scale adoption of renewable sources over fossil fuels, as stipulated by the Kyoto Protocol, will significantly lower exporters' revenues. Therefore, for these countries, energy demand security is as important as energy supply security.

Consequently, it is evident that the use of renewable energy could be instrumental in reducing energy security risks and increasing sustainability in the OECD countries examined, that can turn to renewable or hybrid energy systems, exploiting their abundant renewable resources. Policies in favor of energy efficiency, as well as projection studies that examine the possible long and short-run effects of renewable energy sources should also accompany this fastest-growing type of energy.

---

[156] Cergibozan (2021).

[157] Cergibozan (2021).

[158] Cergibozan (2021).

The significance of geothermal energy in ensuring energy security has also been evaluated in a research regarding sustainable energy transition in Dominica, an island within the Ring of Fire and a member-state of the Organization of Eastern Caribbean States (OECS). [159] An investigation of techno-economic and environmental assessments reveals the possibility of producing clean and affordable energy using geothermal resources across the Eastern Caribbean Region. In specific, Dominica is the very first out of 6 OECS member-states with great geothermal potential, as it can satisfy more than 20 times its projected power demand by utilizing solely its untapped geothermal resources, thanks to its geographic position in the volcanic arc of the Caribbean region. In fact, research results reveal 70% cheaper power by 2030, as well as a 99.5% reduction in national life cycle GHG emissions, if 100% of the Dominican geothermal energy was exploited.

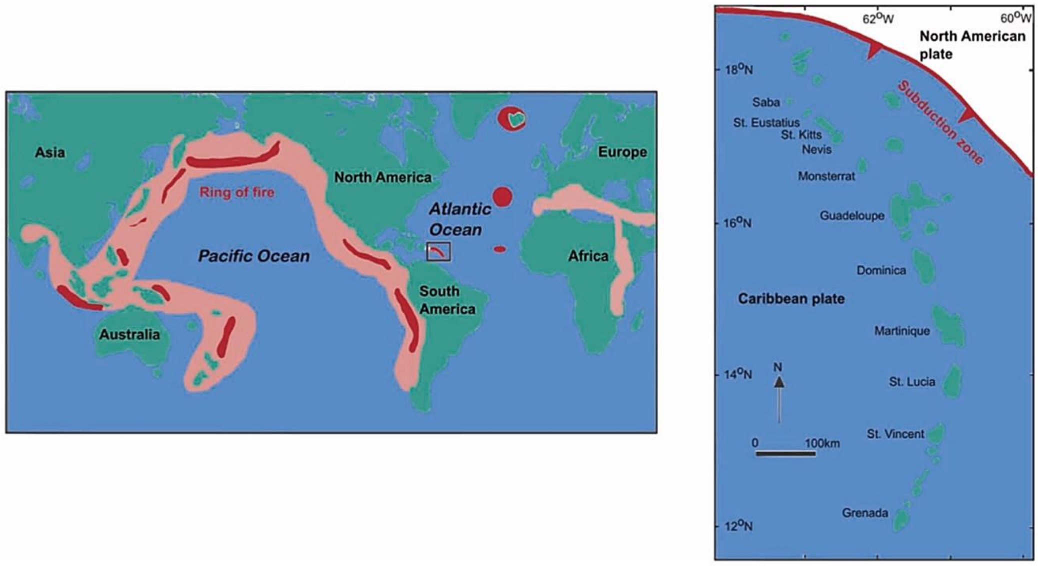

Figure 2.15: Global geothermal activity map and the OECS region [160]

Dominica, similar to the rest of the neighboring islands, faces 4 challenges that jeopardize its energy security. First and foremost, the current pattern of energy consumption, not only in the Caribbean but also globally, is unsustainable and reliant on finite, depleting fossil fuels, which are responsible for the high levels of greenhouse gases. Secondly, apart from being highly dependent on fossil fuels, all the islands are electrically isolated with only a small percentage of local resources aligned to the energy production. [161] Their dependence, in combination with the longstanding problem of high and volatile oil prices in the global market, increases the cost of power generation and the vulnerability to energy price shocks. Equally important is the fact that, while Small Island Developing States (SIDS), including Dominica, contribute the

---

[159] Bhagaloo, et al. (2021).

[160] Bhagaloo, et al. (2021).

[161] Bhagaloo, et al. (2021).

least to global greenhouse gas emissions, they will be among the first to be deeply threatened by deteriorating climatic conditions and are already affected by the effects of climate change, such as rising sea levels and extreme weather events. Lastly, in the event of a natural disaster, the isolated grids with a single electricity source, along with the aging infrastructure on these islands, render them vulnerable to long-lasting power outages, putting pressure on other dependent sectors, such as healthcare and transportation.

Taking the aforementioned challenges into account, geothermal energy is considered capable of providing the answer, since it is *"controllable, firm, flexible, and capable of reliably replacing power from fossil fuels"*, with *"low operating and management costs in the long term"*, offering *"economic stability in comparison to the nation's present-day diesel-powered power plants"*. [162] Contrary to fossil fuels, geothermal energy is unaffected by seasonal and daily fluctuations, or climatic conditions, hence it is proven to be "*the most reliable renewable energy resource for the region*". [163] Indeed, the OECS region, apart from being endowed with various forms of renewable energy, it is situated in an active region around the Caribbean plate, with ideal geological conditions for geothermal energy to be harnessed. Moreover, geothermal systems have lower environmental impact and the second highest capacity factor after nuclear energy [164], supporting Dominica's GHG mitigation commitments, with annual avoided GHG emissions reaching 0.30 million tons CO_2/year by 2027. Finally, given Dominica's increased geothermal energy potential of up to 1390 MW, that surpasses national demand, energy storage platforms and energy trade can be used in the case of excess power generation, in order to promote partnership in the region. In other terms, despite the higher costs of both storage and transmission technologies, compared to the fossil-based technologies currently used, power can be traded with nearby islands that have much higher power needs, in an interconnected grid via subsea transmission.

It is, thus, evident that the abundance of geothermal energy in Dominica and other neighboring islands is considered capable of improving energy security, by reducing the dependence on imported fossil fuels. Research results confirm the ability of geothermal energy to provide clean and affordable energy production across the Eastern Caribbean Region, which is an urgent need in view of the foreseeable and threatening implications of climate change in the region. For this reason, despite slow development due to the lack of guidance, as well as economic, political, and social barriers, Dominica has pledged to meet 100% of its energy needs through renewables by 2030, representing a successful example of renewable energy penetration.

---

[162] Bhagaloo, et al. (2021).

[163] Bhagaloo, et al. (2021).

[164] US Department of Energy (2021).

2.4 Discussion and results

In this subsection, we elaborate on our findings, with special focus on the geopolitical value of geothermal energy. In the first place, Table 2.9 summarizes the key points of the literature that was thoroughly analyzed for the purpose of this dissertation, while, in the second place, the chapter concludes with a roundup of the geopolitics of geothermal energy and the restrictions it faces.

Table 2.9: The geopolitical significance of geothermal energy in key points, deriving from the review of the literature

Authors / Institutions	Key points
IRENA, 2019.	i. Geothermal energy is a gradually growing renewable energy source that can promote reliability, economic growth and food security. ii. Geothermal energy is reliable as it is produced locally and constantly available. iii. It promotes democratization, as it facilitates decentralization of the energy supply, empowers local communities, multiplies local economic and fiscal benefits and limits external interference in a country's domestic affairs. iv. The integration of geothermal energy in agriculture, i.e., for food drying, can improve agricultural yields, reduce post-harvest loss and enhance food security. v. Geothermal energy, in combination with hydro, wind, biomass and solar energy, covers the electricity needs of Iceland, Brazil, Costa Rica, New Zealand and Kenya by more than 80%.
IRENA, 2021.	i. Geothermal energy resources are widespread around the world and contribute to the acceleration of the green energy transition process, as they represent an excellent alternative that supports the global decarbonization agenda. ii. Geothermal power plants do not depend on burning fuels, but instead directly use the energy stored underground and, therefore, produce negligible greenhouse gas emissions during their operation. Consequently, geothermal energy contributes to mitigating the adverse effects of climate change.

	iii. Geothermal power plants also operate in a flexible manner and can ensure grid stability with limited additional costs, by providing firm baseload generation and reliable reserves. iv. Geothermal energy also shows high resilience to extreme climate events, such as strong winds, periods of drought, or “black swans”, which are becoming more frequent due to climate change. v. Geothermal electricity generation has a competitive levelized cost in comparison to other renewables and fossil fuels.
Hafner, Tagliapietra, 2020.	National concerns about resource depletion or scarcity, as well as state efforts toward greater diversification of sources and promotion of low-carbon technologies oblige states to orient their attention to renewable energy sources. Geothermal energy can assist in increasing energy security and reducing dependence on energy imports from often unstable or unfriendly exporters, despite currently having a marginal role in power generation.
Cergibozan, 2021.	i. Greater integration of renewables is urgent, as worldwide energy demand, primarily from the industrial sector, is expected to double between 2018 and 2050, creating several major fossil fuel-related problems. ii. Empirical evidence from 23 OECD countries, over the period of 1985-2016, has demonstrated how renewables, including geothermal energy, can counteract these risks. iii. In specific, geothermal energy constitutes an environmentally friendly alternative that is far from producing life-threatening levels of greenhouse gas emissions. iv. Unlike conventional energy, geothermal resources are more equitably distributed among countries which can potentially become energy self-sufficient. v. Unlike other renewables confined by weather conditions, geothermal energy shows strong resistance to extreme weather events, thus it could be characterized as a weather independent source of energy. vi. Major technological accidents with financial, political and environmental repercussions, such as oil tanker accidents or

	accidents during oil extraction, are also absent in geothermal systems. vii. Finally, geothermal energy is not subject to depletion and it is harnessed and consumed domestically. Therefore, it can eliminate unexpected cutoffs of energy imports, enhance security of supply, limit conflicts and reduce import dependency.
Bhagaloo, et al. 2021.	i. The Eastern Caribbean Region faces challenges that put its energy security at risk. However, the region is situated around the Caribbean plate, were ideal geological conditions make it possible to support a clean and affordable energy production from geothermal resources. ii. Dominica, which is located within the Ring of Fire, has significant geothermal potential and can meet more than 20 times its projected power demand with only its untapped geothermal resources, mitigating the challenges that threaten its energy security. iii. Geothermal energy is seen as a *“controllable, firm, flexible, and capable of reliably replacing power from fossil fuels”* source of energy, with *“low operating and management costs in the long term”*, offering economic stability. iv. Once again, emphasis is placed on its reliability, thanks to its resilience to seasonal and daily fluctuations and climatic conditions. v. Geothermal systems also have low environmental impact and offer the second highest capacity factor after nuclear energy. vi. Given Dominica’s tremendous geothermal energy potential that surpasses the national demand, excess power generation can be stored or traded, promoting partnership and creating an interconnected grid via subsea transmission. vii. Most importantly, the exploitation of the geothermal abundance in the Eastern Caribbean Region would enhance energy security and reduce dependence on imported fossil fuels.

Technically speaking, geothermal energy has its own pros and cons and demands careful evaluation to ensure that it is optimally used for a clean energy transition. It is a sustainable, environmentally friendly energy source for direct and indirect applications, that is stable, requires no fuel during energy production and is available in abundant supply. Geothermal energy is a scalable solution, as it can be used in both small and large-scale installations, depending on the availability and location of geothermal reserves. In addition to its low operation and maintenance costs and high-capacity factors, ranging from 60% to more than 90%, offsetting the high initial cost, geothermal is also gaining ground thanks to its potential contribution to the hydrogen economy, by providing pathways for hydrogen production. Nonetheless, geothermal energy is location specific and needs high temperatures to operate. Moreover, although it is suggested that geothermal reservoirs are permanent, some experts indicate that they can be depleted when the water is extracted faster than it can be replenished by nature. Apart from this sustainability issue, environmental concerns also arise, regarding increased water use, seismicity and release of gases, such as sulfur dioxide, that can be harmful if poorly treated. Last but not least, in cases where geothermal energy sites are located further from the population, a vast network of distribution systems is necessary, increasing the overall cost.

Theoretically speaking and as regards to the geopolitical value of geothermal energy, it can be attributed to the following factors:

1. As an infinitely available energy resource that is naturally replenished on a human timescale, geothermal, by its very nature, is not affected by global depletion of resources, and it does not face shortages when the weather is not “cooperating”, as in the cases of wind and solar energy. Additionally, it does not deal with challenges related to storage and transport, such as theft, as in the cases of oil and gas, or digital hijacking and terrorist attacks on energy infrastructure, as it is produced domestically. Therefore, it enhances security of supply, and remains resilient to fluctuations of availability, price shocks and price volatility.
2. Secondly, as a renewable energy source that emits negligible greenhouse gases, geothermal energy can assist in mitigating the foreseeable and threatening climate change impacts, including extreme weather events, such as heat waves, heavy precipitation, rise of sea level, decrease in water resources, destruction of coastal habitats, forced displacement, increased hunger and poor nutrition, all of which are equally pressing issues affecting national and global security.
3. Moreover, unlike conventional energy, geothermal resources are more equitably distributed in terms of geography among countries that can potentially become energy self-sufficient. As a result, greater use of geothermal energy can reduce import dependency on often unstable or unfriendly exporters.
4. A logical entailment derives from the previous statement: since energy is locally produced rather than imported, there should not be abrupt cutoffs in energy supply

or abuse of power, in terms of resources. As a result, energy will no longer be used as a geopolitical instrument to exercise influence and impose political will, a method historically used by a state or a group of states, among which Russia against Ukraine and Europe, and OPEC members against the West.

5. Finally, this “peaceful” renewable energy source can promote democratization, partnership, and exchange of knowhow, with mutual benefits that deter conflicts.

Points 1 to 5 indicate that geothermal energy can alter the dependence relations between producer and consumer countries, mostly benefitting the latter group, minimize external pressure and influence on a country’s energy sector, and, consequently, enhance overall energy security, by counteracting challenges our planet is currently coping with. This source has huge potential for growth, as the size of the global geothermal energy market is expected to reach USD 95.82 billion by 2029, from USD 62.65 billion in 2022 and USD 59.40 billion in 2021. [165] In fact, this market experienced higher than anticipated demand during the global COVID-19 pandemic, showing resilience and adequate performance. [166] Hesitancy, limited policy support during pre-development and resource exploration stages, and price-related competition from fossil fuels, solar, wind, and natural gas have evidently decelerated faster expansion. However, environmental considerations, energy security concerns, surging energy prices due to the curtailment of Russian fossil fuel exports, advances in deep-drilling technology, and policies such as the REPowerEU Plan or the US Inflation Reduction Act, both passed in 2022, shall benefit geothermal energy’s expansion and bring renewables at the forefront of our energy future.

---

[165] Fortune Business Insights (2022).

[166] Fortune Business Insights (2022).

Chapter 3: Conclusions and recommendations

3.1 Summary

The objective of this thesis was to conduct a review of the literature on the geopolitical significance of geothermal energy, which has received little academic attention, and so fill a salient gap in our understanding of this renewable energy source's geopolitical potential. In Chapter 2, we reviewed the basic technical characteristics of geothermal energy, concerning its distribution, installed capacity, applications, technologies and costs.

In specific, geothermal energy is a safe, reliable, recyclable, low-carbon renewable energy source, that resides just beneath our feet and uses the Earth's tremendous amount of usable heat to provide almost carbon-free electricity, heating and cooling, without burning fossil fuels. It is a scalable solution, capable of providing low-cost, "always-on" capacity in regions with medium to high-temperature conventional geothermal resources near the Earth's surface, with low operation and maintenance costs and one of the highest capacity factors, ranging from 60% to more than 90%, offsetting its high initial cost.

Geothermal resources have been harnessed for direct heat for millennia and for electrical power since 1904, nevertheless the global community has only recently begun to show greater interest on their exploration. As of 2020, geothermal energy was used directly for heating, cooling, agriculture, and industrial processes in 88 countries, up from 28 countries in 1995, and indirectly for electricity production in 26 countries, several located within the "Ring of Fire", one of the world's most active geothermal areas encircling the Pacific Ocean, that hosts a large percentage of the global geothermal energy production. Even though geothermal energy is used for electricity production in fewer states, it is encouraging to note that new countries are expanding the group, such as Belgium, Chile, Croatia, Honduras, and Hungary, which generated geothermal power for the first time, between 2015 and 2020.

According to the available data, 1.020.887 TJ/yr of geothermal energy were consumed in direct applications in 2020, reporting a 72.3% increase over 2015, while global electricity production reached 94 TWh, after steadily rising during the past two decades. Furthermore, in terms of energy production taking place between 2000-2020, the USA, Indonesia, the Philippines, Turkey, New Zealand, Mexico, Kenya, Italy, Iceland, Japan, and Costa Rica represent the leading countries in descending order, accounting for 90.453 GWh in 2020 and representing almost 95% of total geothermal electricity production at the end of the same year, thanks to their abundant and untapped resource availability.

Regarding the global geothermal installed capacity, it reached roughly 15.6 GW in 2021, more than doubling the capacity of 2010, with 38 countries reporting an installed capacity of over 100 MWt. Both in terms of installed capacity and direct geothermal use, Asia and Europe are the leaders, as 57 countries located in the Eurasian continent accounted for 77.5% of the world's installed capacity and 80.8% of the direct-uses, with China, the USA, Sweden, Turkey, Japan, Germany, Iceland, Finland, France, and Canada standing out as major producers and consumers of geothermal fluids for direct applications.

As far as installation costs for geothermal power plants are concerned, they have been following an increasing trend from 2015 and onwards, with a brief interruption in 2019 and 2020, when they slightly decreased. The average installed cost for geothermal energy globally, between 2010 and 2021, ranged from USD 2700/kW to USD 5500/kW, with the 2021 cost being USD 3991/kW.

This thesis revealed that research and development on innovative, low-cost drilling techniques, combined with the necessary collaboration, adjustments in the existing institutional and regulatory framework and the public sector's engagement, are expected to offset fossil fuel competition, lower development costs, and reduce uncertainties, making electricity production from geothermal technologies increasingly competitive and economically viable. Most importantly, increased geothermal energy deployment at a time when countries are struggling to diversify their energy sources, decarbonize their economies until 2050 and alleviate the negative impacts of climate change will enhance the growing global trend toward clean energy and make geothermal energy a means of improving energy security. Therefore, a section of this chapter was devoted to an assessment of the geopolitical importance of this renewable source, which can potentially become a game changer of global politics.

In the final subsection of this dissertation, we sought to contribute to the literature by gathering and enumerating in the framework of a comprehensive table the highlights deriving from five reports and research papers of prominent international institutions and researchers on the geopolitical value of geothermal energy.

3.2 Conclusions

The global community is facing a major energy crisis, signifying that energy transition and diversification in power generation, heating, buildings, and transportation must take place at a faster pace, in order to improve energy security and mitigate the adverse effects of climate change. By addressing environmental, technological, economic, political, and supply and demand concerns, greater use of renewable energy can counterbalance geopolitical tensions and deter the emergence of new energy crises. Nonetheless, energy transition requires navigating its own set of challenges; hence, the transition from conventional energy is much more than a change in sources, as it entails changes in systems, infrastructure, and management.

In the new energy mix leaning toward renewable and affordable energy, that can guarantee a secure, stable and unhampered supply, geothermal is not high in the alternative energy radar. However, experts view geothermal power as an essential component of the global green-energy future that needs to be the part of the larger scheme. With applications in several economic sectors, geothermal energy provides safe, reliable, firm, and flexible energy, with negligible greenhouse gas emissions and low operating and management costs, while its comparative advantages and considerable potential for growth offset the disadvantages that can be handled through technological progress and collaboration.

Except for its competitive technological and economic advantages, compared to both conventional and other renewable sources, geothermal energy possesses an exceptional geopolitical value. In specific, it is, by its very nature, not affected by global depletion of resources and challenges related to storage and transport, thus it enhances security of supply, and remains resilient to availability shocks and price volatility. In addition, as geothermal resources are more equitably geographically distributed among countries and locally consumed, it is possible to reduce import dependency and eliminate abuse of power in terms of resources. As a result, energy will no longer be perceived as a geopolitical tool to impose will, as used in all energy crises. Geothermal also aids in mitigating climate change that inevitably acts as a multiplier of geopolitical risk, causing extreme weather events, destruction of coastal habitats, forced displacement, food insecurity, hunger, and social unrest. Overall, despite its current marginal role, geothermal energy can alter the dependence relations between importers and exporters of energy, minimize the use of fossil fuels, often imported from unstable suppliers, and, most importantly, enhance overall energy security.

Having reviewed the specific technical characteristics, technologies and applications of geothermal energy, as well as its considerable geopolitical potential, the author’s purpose in regard to the concept of geopolitics was:

i. to define it,

ii. to accumulate the thoughts of prominent theoreticians and strategists, such as Themistocles, G. Ratzel, K. Haushofer, A. Mahan, N. Rodger, Murray, H. Mackinder, and N. Spykman, viewing global politics through their unique hermeneutic lens,

iii. to trace diachronic elements that synthesize modern geopolitics, especially from Sir Halford Mackinder’s theory, and, finally,

iv. to reveal the correlation between geopolitics and energy, the latter being a component of grand strategy, an end, a means and a way of achieving national targets.

In this context, the exhaustive review of international bibliography revealed the following important key points:

1. The traditional geopolitical approach originally dealt with the context of space and power and the correlation between them.

2. Sir Halford Mackinder, perhaps the most prominent geopolitical analyst, developed his thesis that geopolitics, geography, and strategy serve together, and focused on the link between history and geography, whose interaction is responsible for the greatest events in history, both in terms of politics and geopolitics.

3. All the elements of Mackinder's geopolitics are present and relevant to this day: (a) the world as a closed political system, as proven by the rapid diffusion of the Ukrainian war's repercussions in all domains of life, (b) geography's constraints and opportunities, (c) the unity of the ocean, (d) Eurasia as the great continent, home to some of the strongest nations in terms of geopolitics, and (e) the role of technology in altering man's relation with geography.

4. Especially six of Mackinder's standpoints reveal the correlation between geopolitics and energy:

    i. Not only the earth's surface and climate, but also the distribution of natural resources are all parts of physical geography that influence individual and state behavior.

    ii. The role of technology is crucial for resource rich states with knowhow and robust economies, as it usually renders them less import dependent and capable of turning their resource wealth into long-term economic growth. As a result, thanks to technology, they enjoy a strategic advantage, used in times of regional or international crisis. In such cases, transactions between exporters and importers of energy may often be unfavorable for the latter group, creating dependencies.

    iii. Mackinder also noted that the physical environment undergoes changes that affect future generations, which is still true given that resource depletion and environmental degradation threaten human health and have socio-economic repercussions.

    iv. Mackinder used the terms "unity" of the "ocean highway" to emphasize the value of sea power. Indeed, nowadays, sea power is indispensable for transporting energy from one edge of the world to another and it produces power and wealth from the control of strategic choke points. "Who controls the choke points commands the sea; who commands the sea controls energy and trade", as straightforwardly stated by Dr. Athanasios Platias.

    v. Moreover, the Russian-Ukraine war has rocketed energy prices and manufacturing costs in unprecedented levels and has posed security dilemmas in heavily dependent EU member-states, confirming Mackinder's view of the world as a "closed political system", where nothing happens in one part without affecting every other part.

    vi. Lastly, Mackinder successfully predicted that natural resources would be one of the principal factors to increase power, as proven by the fact that the

> balance of power has shifted to continental-sized states with huge populations and vast natural resources, such as Russia and the United States.

On a final note, renewable energy is the best investment we can make for powering a safer future and improving the overall quality of life, while honoring, at the same time, the responsibility to preserve our planet and humanity. While it is impossible to halt the environmental threats overnight and fully safeguard energy, which will not cease to be a goal, a weapon and a necessity, it is obvious that geothermal energy can be instrumental in reducing the spillover effects that energy security risks cause, holding the key for a least problematic supply and demand pattern. Certainly, what remains to be observed is the level of adaptation of the international community to the arising circumstances and needs, as well as the ability of the states to decipher the new energy puzzle with the least possible losses in the ever-progressing international system.

3.3 Limitations and recommendations for further research

The aim of this research was to provide a comprehensive review of the literature on the geopolitics of geothermal energy, filling the literature gap that existed, in contrast to the abundance of information on the geopolitics of renewables. The limited availability of data on the geopolitical significance of this specific energy source and the dominance of mostly technical reports in the literature were the most troubling issue we dealt with.

Nonetheless, while recognizing the limitations of our analysis, we believe that we largely achieved our initial aim and came to some valuable findings.

If we were to extend our research, we would include two additional tasks:

a) A chapter dedicated to case studies of the leading countries and regions in terms of geothermal energy production and installed capacity.

b) A unit where a calculation of the energy security index in the above countries and regions would be carried out.

List of references

Anderson, A., Rezaie, B. (2019). Geothermal technology: Trends and potential role in a sustainable future. Applied Energy 2019. Retrieved on March 20th, 2022, from https://www.sciencedirect.com/science/article/pii/S0306261919307706?via%3Dihub

Arvanitopoulos, K., Hephaistos, P. (2009). Euro-Atlantic Relations [in Greek]. Poiotita. Retrieved on June 30th, 2022.

Beardsmore, G., Dumitrescu, I., Harrison, B., Sandiford, M., Webster, R. (2016). Victorian Geothermal Assessment Report 2016. Melbourne Energy Institute. Retrieved on December 20th, 2021, from https://www.researchgate.net/publication/333773876_Victorian_Geothermal_Assessment_Report_2016/figures?lo=1

Bhagaloo, K., Ali, R., Baboolal, A., Ward, K. (2021). Powering the sustainable transition with geothermal energy: A case study on Dominica. Sustainable Energy Technologies and Assessments. Retrieved on March 2nd, 2022, from https://www.sciencedirect.com/science/article/pii/S2213138821009243

Bitsa, D. (2019). The challenge of renewable energy sources as a leader to the New Energy Order. University of Piraeus. Retrieved on September 2nd, 2022, from https://dione.lib.unipi.gr/xmlui/handle/unipi/12517

Cergibozan, R. (2021). Renewable energy sources as a solution for energy security risk: Empirical evidence from OECD countries. Renewable Energy, An International Journal. Retrieved on March 2nd, 2022, from https://www.sciencedirect.com/science/article/abs/pii/S0960148121016384

Coro, G., Trumpy, E. (2020). Predicting geographical suitability of geothermal power plants. Journal of Cleaner Production. Retrieved on December 20th, 2021, from https://www.sciencedirect.com/science/article/pii/S0959652620319211

Fortune Business Insights. (2022). Geothermal energy market size, share and COVID-19 impact analysis. Retrieved on September 2nd, 2022, from https://www.fortunebusinessinsights.com/geothermal-energy-market-106341

Ghazvini, M., Sadeghzadeh, M., Ahmadi, M., Moosavi, S., Pourfayaz, F. (2019). Geothermal energy use in hydrogen production: A review. International Journal of Energy Research. Retrieved on March 22nd, 2022, from https://doi.org/10.1002/er.4778

Gilchrist, M. (2019). The Great Game Reinvigorated: Geopolitics, Afghanistan, and the Importance of Pakistan. RealClear Defense. Retrieved on January 30th, 2022, from https://www.realcleardefense.com/articles/2019/08/15/the_great_game_reinvigorated_geopolitics_afghanistan_and_the_importance_of_pakistan_114667.html

Global Geothermal Alliance. (2021). Geothermal: The Solution Underneath. Retrieved on February 10th, 2022, from https://www.globalgeothermalalliance.org/-/media/Files/IRENA/GGA/Publications/Geothermal---The-Solution-Underneath.pdf

Goetzl, G. (2020). Differences between deep and shallow geothermal energy. GeoERA. Retrieved on December 20th, 2021, from https://geoera.eu/blog/muse-differences-between-deep-and-shallow-geothermal-energy/

Gray, C., Sloan, G. (2013). Geopolitics, Geography and Strategy. Routledge. Retriever on June 30th, 2022.

Hafner, M., Tagliapietra, S. (2020). The Geopolitics of the Global Energy Transition. Lecture Notes in Energy. Retrieved on February 10th, 2022, https://library.oapen.org/bitstream/id/826718b9-f036-4a35-926e-6f5e32b78162/2020_Book_TheGeopoliticsOfTheGlobalEnerg.pdf

Hutter, G.W. (2021). Geothermal Power Generation in the World 2015-2020 Update Report. Retrieved on December 20th, 2021, from https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01017.pdf

International Energy Agency. (n.d.). Energy security. Retrieved on September 2nd, 2022, from https://www.iea.org/topics/energy-security

International Energy Agency. (2021). Geothermal power. Retrieved on December 20th, 2021, from https://www.iea.org/reports/geothermal-power

International Energy Agency. (2019). Renewables 2019 – Analysis and forecast to 2024. Retrieved on December 20th, 2021, from https://iea.blob.core.windows.net/assets/a846e5cf-ca7d-4a1f-a81b-ba1499f2cc07/Renewables_2019.pdf

International Geothermal Association. (n.d.) Geothermal power database. Retrieved on December 20th, 2021, from https://www.geothermal-energy.org/explore/our-databases/geothermal-power-database/

International Renewable Energy Agency. (2019). A New World: The geopolitics of energy transformation. Retrieved on February 10th, 2022, from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jan/Global_commission_geopolitics_new_world_2019.pdf

International Renewable Energy Agency. (n.d.). Geothermal. Retrieved on December 20th, 2021, from https://www.irena.org/Energy-Transition/Technology/Geothermal-energy

International Renewable Energy Agency. (2017). Geothermal power: technology brief. Agency. Retrieved on December 20th, 2021, from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Aug/IRENA_Geothermal_Power_2017.pdf

International Renewable Energy Agency. (2015). Renewable energy capacity statistics 2015. Retrieved on December 20th, 2021, from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_RE_Capacity_Statistics_2015.pdf?rev=31b8998cf00241dd96c125ef2328346b

International Renewable Energy Agency. (2016). Renewable energy statistics 2016. Retrieved on December 20th, 2021, from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_RE_Statistics_2016.pdf?rev=224fb9675347422295643c4eb44fd78c

International Renewable Energy Agency. (2020). Renewable energy statistics 2020. Retrieved on December 20th, 2021, from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Renewable_Energy_Statistics_2020.pdf?rev=3a5e14b11fe6434dbc3e59b7bbacd6e7

International Renewable Energy Agency. (2021). Renewable energy statistics 2021. Retrieved on December 20th, 2021, from http://bitly.ws/zBYn

Ismailov, E., Papava, V. (2010). Rethinking Central Eurasia. Central Asia-Caucasus Institute & Silk Road Studies Program. Retrieved on June 30th, 2022, from https://www.researchgate.net/publication/256044062_Rethinking_Central_Eurasia

Ito, T., Ruiz, C. (2017). Geothermal Power: Technology Brief. International Renewable Energy Agency. Retrieved on March 20th, 2022, from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Aug/IRENA_Geothermal_Power_2017.pdf?rev=93a543c24d274b778f8135a7711599f7

Jaganmohan, M. (2022). Geothermal energy capacity worldwide from 2009 to 2021. Statista. Retrieved on June 30th, 2022, from https://www.statista.com/statistics/476281/global-capacity-of-geothermal-energy/

Jaganmohan, M. (2022). Average installed cost for geothermal energy worldwide from 2010 to 2021. Satista. Retrieved on March 20th, 2022, from https://www.statista.com/statistics/1027751/global-geothermal-power-installation-cost-per-kilowatt/

Jaganmohan, M. (2021). Ranking of largest geothermal plants worldwide as of January 2021. Satista. Retrieved on March 20th, 2022, from https://www.statista.com/statistics/525206/geothermal-complexes-worldwide-by-size/

Kanoglu, M., Yilmaz, C., Abusoglu, A. (2016). Geothermal Energy Use in Hydrogen. Production Journal of Thermal Engineering. Retrieved on March 20th, 2022, from https://jten.yildiz.edu.tr/storage/upload/pdfs/1636986334-en.pdf

Koliopoulos, K. (2010). The art of strategy from antiquity to the present day [in Greek]. Poiotita. Retrieved on June 30th, 2022.

Kurek, K. A. (2021). Geothermal resources and local development in Poland. Wageningen University. Retrieved on December 20th, 2021, from https://www.researchgate.net/publication/350877572_Geothermal_resources_and_local_development_in_Poland/figures?lo=1

Franza, L., Bianchi, M., Bergamaschi, L. (2020). The geopolitics of RES: Global trends. Istituto Affari Internazionali. Retrieved on September 2nd, 2022, from http://bitly.ws/zBWe

Lund, J., Toth, A. (2020). Direct utilization of geothermal energy 2020 worldwide review. Geothermics. Retrieved on December 20th, 2021, from https://www.researchgate.net/publication/346999421_Direct_utilization_of_geothermal_energy_2020_worldwide_review

Mackinder, H. (1942). Democratic ideals and reality: a study in the politics of reconstruction. National Defense University Press Publications. Retrieved on June 30th, 2022, from https://www.files.ethz.ch/isn/139619/1942_democratic_ideals_reality.pdf

Mahmoud, M., Ramadan, M., Naher, S., Pullen, K., Abdelkareem, M., Olabi, A. (2021). A review of geothermal energy-driven hydrogen production systems. Thermal Science and Engineering Progress. Retrieved on March 22nd, 2022, from https://www.sciencedirect.com/science/article/pii/S2451904921000160

Masum, M., Ali Akbar, M. (2020). The Pacific Ring of Fire is Working as a Home Country of Geothermal Resources in the World. IOP Science. Retrieved on December 20th, 2021, from https://iopscience.iop.org/article/10.1088/1755-1315/249/1/012020

Moyaa, D., Aldásd, C., Kaparaju, P. (2018). Geothermal energy: Power plant technology and direct heat applications. Renewable and Sustainable Energy Reviews. Retrieved on March 20th, 2022, from https://www.sciencedirect.com/science/article/pii/S1364032118304830?via%3Dihub

Office of Nuclear Energy. (2021). Nuclear Power is the Most Reliable Energy Source and It's Not Even Close. Retrieved on March 2nd, 2022, from https://www.energy.gov/ne/articles/nuclear-power-most-reliable-energy-source-and-its-not-even-close

Paravantis, J., Kontoulis, N., Ballis, A., Tsirigotis, D. (2018). A Geopolitical Review of Definitions, Dimensions and Indicators of Energy Security. Retrieved September 2nd, 2022, from https://www.researchgate.net/publication/330879521_A_Geopolitical_Review_of_Definitions_Dimensions_and_Indicators_of_Energy_Security

Platias, A. (2019). Geopolitics & Grand Strategy in the 21st Century [in Greek]. University of Piraeus. Retrieved on June 30th, 2022.

Poukamisas, G. (n.d.). Greece’s geopolitical dilemmas in the beginning of the 20th century [in Greek]. Aegean University. Retrieved on June 30th, 2022, from http://bitly.ws/zBWk

Sempa, F. (2015). The Roots of Mackinder’s Geopolitics. Foreign Policy Research Institute. Retrieved on June 30th, 2022, from http://bitly.ws/zBWm

Taylor, M., Ralon, P., Al-Zoghoul, S., Epp, B., Jochum, M. (2021). Renewable Power Generation Costs in 2020. International Renewable Energy Agency. Retrieved on March 20th, 2022, from https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020

United Nations. (2021). Theme Report on Energy Transition. Retrieved on September 2nd, 2022, from https://www.un.org/sites/un2.un.org/files/2021-twg_2-062321.pdf

U.S. Environmental Protection Agency. (n.d.). Geothermal Heating and Cooling Technologies. Retrieved on March 20th, 2022, from https://www.epa.gov/rhc/geothermal-heating-and-cooling-technologies

Venier, P. (2021). Mackinder’s map of the natural seats of power (1904). Géostratégie. Retrieved on June 30th, 2022, from https://geostrategie.ca/2021/05/02/mackinders-map-of-the-natural-seats-of-power-1904/

Kalliopi Lennax
Athens, Greece
e: lennaxkalliopi@gmail.com

EDUCATION

	University of Piraeus Piraeus, Attica
2020-2022	M.Sc. in Energy: Strategy, Law and Economics
2016-2020	B.A. in International and European Studies

EXPERIENCE

2017-present	Private Tutor

PUBLICATIONS

	Energy and Environmental Policy Laboratory
2021	Overview of China’s energy policy