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Geothermal Energy: A Sustainable Alternative and its Advocates

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ABSTRACT

Faced with unprecedented levels of environmental crisis, countries around the world have turned to various new forms of sustainable energy to meet the growing demand for electricity in modern life. While the deployment of hydroelectric, wind, and solar power is becoming more widespread, each of these technologies presents notable limitations. This paper argues that geothermal energy has superior potential compared to other renewable energy sources. The analysis elaborates the advantages of geothermal resources across four dimensions: its extensive historical use as an energy source; the renewed focus it has garnered in recent years; the scope of international collaboration in its development; and its successful implementation in local communities. The study concludes that identifying a viable alternative energy source is imperative for mitigating environmental degradation and ensuring the sustainability of human life on Earth. By highlighting the multifaceted benefits and potential of geothermal energy, this paper underscores the necessity of embracing geothermal resources as a key component of the global transition to sustainable energy.

Introduction

Over the past few centuries, human activities have increasingly disrupted the Earth's natural balance to its limits. From the scientific revolution of the 17th century to the technological advancements of recent decades, innovations such as smartphones and the Internet have become integral to modern life. However, these advancements have come at a significant environmental cost. Technological progress has often resulted in the exploitation of natural resources and wildlife, disrupting ecosystems and pushing the Earth towards ecological thresholds.

Now having pushed the Earth to the brink of destruction, we are finally seeing nature's retaliation. With rising sea levels, higher temperatures, and intense natural disasters, we are realizing that nature is a force to be reckoned with. From time immemorial, human beings have lived with nature, not against it, in the development of our civilizations. Continuing this symbiotic relationship is crucial, as opposing natural forces will ultimately lead to our detriment.

One of the most pressing challenges humanity faces is the need for sustainable energy. Energy drives our homes, industries, and a myriad of other facets of modern life. Traditionally, fossil fuels have been the predominant energy source. Despite their efficiency, fossil fuels release vast quantities of carbon dioxide (CO2) into the atmosphere, contributing to the greenhouse effect, ozone layer depletion, global warming, and acid rain, which in turn destroy habitats and disrupt ecosystems. They also aren’t sustainable, taking hundreds of millions of years to replenish their reserves.

So what can we do to remediate the situation? There are many things that we can do to help at both individual and collective levels. Simple actions such as reducing waste, recycling, and minimizing the use of single-use plastics can contribute to environmental sustainability. Supporting your local agriculture can reduce greenhouse gas emissions associated with the transportation of commercial goods and diminish reliance on genetically modified organisms, which are often environmentally harmful. However, climate change has gotten too out of hand for just small actions to fix, and we all must make changes in our lifestyles to compensate.

One notable change is the robust growth of electric vehicles (EVs) that reflects a significant effort to combat the climate crisis among the general population. Without question, EVs are an effective way for individuals to contribute to preventing climate change as transportation is a major source of global carbon emissions. For this reason, there are many government grants and tax breaks for people to purchase electric or hybrid vehicles, making them more affordable.

At present, several departments, agencies, and offices in the U.S. government have provided various and valuable assistance to help promote EVs, ranging from the Departments of Transportation, Energy, Commerce, and Agriculture to Environmental Protection Agency, Small Business Bureau, Internal Revenue Service, and Departments of Labor and Housing and Urban Development. Moreover, created under the Bipartisan Infrastructure Law, there is the Joint Office of Energy and Transportation. The Office is focused on "supporting the planning and deployment of electric vehicle technologies, such as charging stations, electric school bus fleets, and zero-emission transit." (U.S. Department of Transportation, 2024).

While Tesla is a leading manufacturer of EVs in the U.S., the trend has expanded globally. Most car manufacturers in the world now offer a range of electric and hybrid models. This shift demonstrates a significant industry-wide commitment to sustainable energy solutions. Due to these government incentives and support, the sales of electric and hybrid vehicles have increased significantly. Using Tesla's global sales data as an example, as seen in Figure 1 below, we can see that it has risen from 254,530 in 2018 to 1,845,985 in 2023, a growth of an impressive 625.25% over the past five years (Tridens technology, 2024).

While EVs offer numerous environmental benefits, they are not without challenges. The production and disposal of EV batteries pose significant environmental and resource concerns, including the mining of rare earth elements and battery recycling. Furthermore, the current infrastructure for EV charging is still under development, which can limit the practicality of EVs for long-distance travel and in areas with less robust infrastructure. For example, the varying quality of the soil can be an obstacle to building cost-effective charging stations. Finally, much of the electricity that EVs use is still generated from burning fossil fuels.

Therefore, we need a paradigm shift against climate change at a larger scale by shifting from fossil fuels to renewable and sustainable energy sources, such as hydroelectric, solar, wind, and geothermalenergy.

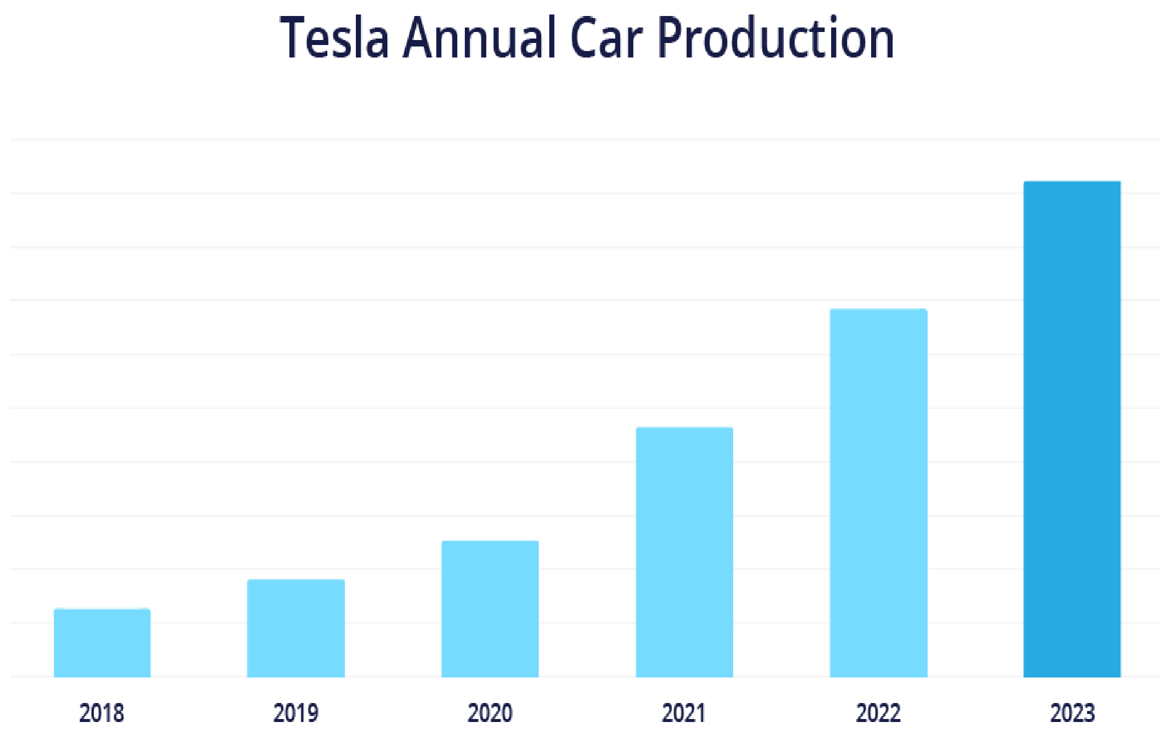

Figure 1. Tesla Annual Car Production from 2018 to 2023

Current Forms of Sustainable Energy: Pros and Cons

Hydroelectric Energy

Hydroelectric power leverages the force of gravity to generate electricity. Water flowing downhill converts potential energy into kinetic energy, which is then harvested to produce electricity. This energy can be harnessed from various water bodies, including creeks, streams, rivers, and oceans. The mechanisms used to capture this energy range from simple water mills to sophisticated hydroelectric plants designed to enhance efficiency. For example, water mills in rivers or streams use the flow of water to spin generators, while tidal mills on beaches exploit tidal movements to generate electricity. This process is not only consistent but is also completely renewable due to the Earth's water cycle. However, small-scale hydroelectric power generation is relatively inefficient and expensive compared to other energy sources. Moreover, the construction of large dams and reservoirs, while capable of generating significant power, often incurs substantial financial costs and can have detrimental environmental impacts by altering local ecosystems. Finally, these large dams and reservoirs can cause water loss to be more prevalent, can displace small towns and cities, and lead to toxic buildup of pollutants from upstream (Topping, 1998).

Solar Energy

Solar energy, a sustainable and efficient energy source, harnesses sunlight through photovoltaic (PV) cells. These cells convert sunlight into electrical charges, which then generate electricity. Solar panels are particularly advantageous because they produce new, carbon-neutral energy, reducing reliance on fossil fuels. The U.S.

federal and state governments have implemented various programs to subsidize the cost of installing solar panels, making them more accessible to individuals and families. Despite these benefits, there are some drawbacks to solar panels. Solar panels are ineffective during cloudy or rainy days and require regular maintenance, such as cleaning, wiring replacements, and obstruction removal. Additionally, large solar farms occupy considerable space, which is often unavailable in urban or suburban areas, limiting their capacity to serve high-density community energy needs. Thus, the primary challenges of solar energy are its dependency on sunlight, maintenance requirements, and spatial constraints in densely populated areas.

Wind Energy

Wind energy, another sustainable and efficient energy source, offers a solution to some of the limitations of both hydro and solar power. Wind turbines generate electricity by capturing the kinetic energy of the wind. The wind's force turns the blades of the turbine, which are connected to a drive shaft that powers an electric generator. Unlike solar energy, wind energy is not dependent on weather conditions like sunlight and can be harnessed continuously. However, wind energy requires large tracts of land for turbine installation, which can disrupt landscapes and thus is impractical for urban or suburban environments. Despite being consistent and efficient, wind energy's extensive spatial requirements and potential landscape alterations limit its applicability in populated areas.

In summary, while each sustainable energy source—hydroelectric, solar, and wind—offers unique advantages, they also present specific challenges. Hydroelectric power is limited by its environmental impact and cost, solar energy by its dependency on weather and spatial needs, and wind energy by its land requirements. Geothermal energy, however, stands out for its reliability and low environmental impact, and is becoming a viable and sustainable energy source A comprehensive approach, integrating multiple renewable energy sources and addressing their respective challenges, is essential to create a sustainable and resilient energy system capable of mitigating climate change and promoting environmental stewardship.

Geothermal Energy and Its Advantages

Geothermal energy presents a more sustainable solution that addresses the limitations of hydroelectric, solar, and wind power. This analysis will elucidate why geothermal energy is particularly valuable alternative energy source.

Geothermal energy harnesses heat from the Earth's interior. Geothermal power plants extract fluids from underground reservoirs, bringing them to the surface to produce steam. This steam drives turbines, generating electricity. There are three primary types of geothermal power plant technologies: dry steam, flash steam, and binary cycle. The selection of technology depends on the state and temperature of the subsurface fluid and the depth of the reservoir. Geothermal energy offers continuous production, regardless of weather conditions, making it a reliable and flexible energy source. It also occupies relatively little space, making it suitable for communal energy production, which is cost-effective compared to individual energy generators like solar panels (Office of Energy Efficiency & Renewable Energy, 2024).

The most common geothermal power plant technology is the flash steam power plant. Fluids at temperatures above 182°C (360°F) are pumped from deep underground to a low-pressure tank at the Earth's surface. The sudden pressure change causes the fluid to rapidly convert, or "flash," into steam. This steam drives a turbine connected to a generator. If any liquid remains, it can be flashed again in a second tank to extract additional energy through another pressure change.

Dry steam power plants are the oldest type of geothermal power plant and rely on hydrothermal fluids that are already mostly steam. Because naturally found steam is rare, these power plants are only useable in certain areas but follow a similar process. The steam if drawn directly to a turbine, driving a generator that produces electricity. When the steam condenses back into liquid, it is usually reinjected back into the reservoir it came from (Office of Energy Efficiency & Renewable Energy, 2024).

Binary cycle geothermal power plants, another viable option, utilize lower-temperature geothermal resources. In these plants, geothermal fluids pass through a heat exchanger with a secondary fluid that has a lower boiling point than water. The modest heat from the geothermal fluid causes the secondary fluid to flash into steam, which then drives the turbines and generates electricity. This method is advantageous for its efficiency and suitability for lower-temperature resources (Office of Energy Efficiency & Renewable Energy, 2024).

There are many advantages of geothermal energy as a better sustainable energy alternative. Its long history of utilization and technological evolution, recent resurgence of research and development, global adoption and collaborative efforts, and an example of local implementation and efficacy will be the focuses of this section.

Historical Utilization and Technological Evolution

Geothermal energy has a longstanding history of use. Hot springs, utilized for relaxation and bathing, date back to Paleolithic times. Notable historical sites like Bath in England and Huaqing Chi in China demonstrate ancient uses of geothermal energy. Additionally, people have also developed systems to use it for floor heating. The world's oldest such heating system can be found in Chaudes-Aigues, France. The system is said to have been in use since the 15th century. Since the early 19th century, there were efforts to use geothermal resources industrially, such as a geyser steam to extract boric acid from volcanic mud in Italy. The first geothermal power generator, created by Prince Piero Ginori-Conti in Italy in 1904, paved the way for the world's first commercial geothermal power plant (Stober & Bucher, 2021).

In the U.S., modern utilization began in the early 20th century with geothermal district heating systems in Boise, Idaho, and Klamath Falls, Oregon. By the early 21st century, the U.S. had become a leader in geothermal energy development. According to Jonathan Cross and Jeremiah Freeman (2010) in their report to the Department of Energy, 2008 was a watershed year because the U.S. Department of Energy "revived its Geothermal Technologies Program (GTP) with new funding that made substantial new investments in geothermal research, development, and technology demonstration." In the same year, the U.S. Department of Interior's Bureau of Land Management also "significantly increased the amount of Federal land available for geothermal exploration, development and worked to streamline the complex permitting and leasing process." From that time to the present, these government initiatives have resulted in significant progress in the development of geothermal energy in the U.S. As of 2019, the U.S. leads the world in the production of geothermal power capacity -- of the 15.4 gigawatts (GW) produced worldwide, the U.S. accounts for 23.86%, or 3.68 GW (Wikipedia, 2024).

Resurgence in Geothermal Energy Research and Development

Over the past two decades, more than two dozen books on geothermal energy research were published, in addition to three academic journals including Geothermal Energy Science, Geothermics, and Geothermal Energy. The first two journals were established by the International Geothermal Association founded in 1988. Jonathan Cross and Jeremiah Freeman's report to the Department of Energy cited above is included in the book entitled *Geothermal Energy: The Resource under Our Feet* (Malloy, 2010). As its title suggests, this book aims to educate readers about the efficacy of geothermal energy as a clean and sustainable energy source. Its introductory chapter written by Green and Nix (2008) stated that "the Earth houses a vast energy supply in the form of geothermal resources. Domestic resources are equivalent to a 30,000-year energy supply at our current rate for the United States!" They then report that "In fact, geothermal energy is used in all 50 U.S. states today." However, they acknowledge that geothermal energy has not reached its full potential at the time, due to the challenges in "resources, technology, historically low natural gas prices, and public policies". They presented the benefits of using geothermal energy including the construction of geothermal heat pumps (GHPs) is relatively easy by drilling a shallow well about 5 km deep and geothermal energy is environmentally friendly: "Geothermal power plants emit little carbon dioxide, very low quantities of sulfur dioxide, and no nitrogen oxides" (Green & Nix, 2008).

The book also advocated for adopting geothermal energy as a sustainable energy source, stating that "heat is naturally present everywhere within the Earth and is inexhaustible for all intents and purposes." At the same time, it also advocates the development of Enhanced Geothermal Systems (EGS), which is to drill deeper "wells into hot rock and fracturing the rock sufficiently to enable a fluid (water) to flow between the wells." The reservoir created in this way is better because after the fluid generates electricity, it returns to the reservoir. "The plant will have no greenhouse gas emissions other than water vapor that may be used for cooling" (U.S. Department of Energy, 2008).

In the decade since the publication of book *Geothermal Energy: The Resource under Our Feet*, EGS has seen a rapid pace of progress in the industry. This advancement is shown in Ingrid Stober and Kurt Bucher's *Geothermal Energy: From Theoretical Models to Exploration and Development* in its second edition of 2021. This book has an entire chapter devoted to EGS, explaining how its techniques, procedures, and strategies work. In the end, it also provides some recommendations. In addition, the book offers a detailed chapter discussing environmental issues related to EGS, including seismic impacts. This suggests that in recent years, EGS has become at the forefront of the industry of geothermal energy. It is a testament to how geothermal energy has evolved to this day (Stober & Bucher, 2021).

Global Adoption and Collaborative Efforts

Geothermal energy's development has become an international endeavor. Since the early 21st century, the U.S. has become the leader in the industry. However, it is followed closely by countries in many parts of the world, such as Indonesia, the Philippines, Turkey, New Zealand, and Mexico. All of these countries have produced more than a thousand megawatts in 2022 (Wikipedia, 2024). China has had the highest growth rate of developing geothermal energy in the production of electricity from renewable resources (Stober & Bucher 2021). The increasing international use of renewable energy as an alternative to fossil fuels reinforces the significant value of geothermal energy. One obvious factor is that it is easily accessible from "under our feet". Stober and Bucher (2021) concur in their book that "Geothermal energy has the potential to become a significant source of energy in the future because it is available everywhere and withdrawals are continuously replenished. From a human perspective, the resource is essentially unlimited".

New Perspectives on Geothermal Energy Exploration and Evaluation of Geothermal Potential, edited by Renato Somma and Daniela Blessent in 2022, is another recent publication on the use of geothermal resources. It is not only a newer publication, but also international in its perspective, as it draws on examples of industry development from many parts of the world, including Canada, Djibouti, China, Sweden, Croatia, Italy, and Spain. The book presents a variety of ways and places where the geothermal energy industry has been developed, from the Reus-Calls sedimentary basin in Spain and the high-temperature borehole thermal energy storage facility in Linköping, Sweden, to the unconventional hydrocarbon gas reservoir in Velika Ciglena, Croatia, and the crustal and geothermal implications associated with the upper mantle structure in Guangdong, China. Because of these geographic variations, the development of geothermal energy has faced different challenges. The book explains in detail how these challenges are being addressed by scientists using different engineering techniques (hydraulic, chemical, and thermal stimulation). By presenting these in-depth and interdisciplinary research cases, the authors hope to improve our knowledge of geothermal resources as a "clean, base-load, and renewable energy". In particular, these research findings have shown that "deep geothermal resources can be hosted in highly heterogeneous volcanic complexes, sedimentary basins, or old basement rocks" (Somma & Blessent, 2022). In other words, the book is a good illustration of the fact that geothermal resources are everywhere and limitless. These examples highlight the global reach and adaptability of geothermal energy technologies.

Local Implementation and Efficacy

Geothermal energy's everywhere-ness, or its ubiquity, has also found proof in a South Jersey community, and this author's school in particular. Indeed, what prompted my attention to the usefulness of geothermal resources as an effective alternative to our energy needs was my realization that two buildings on my campus have been supported by geothermal wells for the past three decades. As someone who has taken classes in the buildings for three years, I've experienced geothermal energy's potential firsthand. My experience confirms that two previous points. One is that geothermal energy is not new, and has been put in use for many decades, especially in the United States. The other is that geothermal energy is both safe and efficient, as evidenced by my experience in the buildings it powers. To illustrate its benefit using this specific example, I researched the plant in our school to gather information. After weeks of research, I was finally able to get the original blueprint that contained essential information of the layout and production capabilities of these wells. To satisfy the electricity needs of these two buildings, seven bores were made that drilled a total of 22 wells—10 for one building and 12 for another. These wells are 350-400 feet deep, which is much shallower than the two-kilometer, or 6562-foot, average depth of geothermal wells (World energy Council, 2024). This finding suggests that it is not necessary to drill deep wells to provide electricity to a school building, saving both human and financial resources.

How much has the geothermal system saved on the electricity that would otherwise be needed to power these two school buildings? Unfortunately, our school has not kept accurate usage data for the 26 years since the wells were installed. However, a good estimate was found with google search that the average electricity consumption of a school building in the United States is about 10 kWh per square foot on an annual basis. Using this estimate, these two buildings together are about 25,000 square feet in size, so they will consume 250,000 kWh of electricity in a year. In the 26 years since the geothermal wells were installed, our school has saved the cost of 13,000,000 kWh in electricity.

Geothermal energy stands out as a robust alternative to traditional energy sources. Its historical roots, recent technological advancements, global adoption, and local implementation all attest to its potential as a sustainable and efficient energy source. By leveraging geothermal energy, we can address the limitations of hydroelectric, solar, and wind power, contributing to a more resilient and environmentally friendly energy future.

Conclusion

The degradation of our environment has reached a point of almost no return, requiring us all to take immediate action. This crisis has been caused primarily by the emission of greenhouse gasses into the atmosphere over the past few centuries, resulting in adverse impacts that threaten all living organisms on Earth.

However, the growing awareness of environmental deterioration has spurred the development and innovation to address this problem. Alternative sustainable energy sources, such as hydroelectric, solar, and wind power, have emerged as better options than fossil fuels. While these alternatives offer substantial benefits, they also present certain limitations.

Geothermal energy provides its unique advantages. Unlike hydro, solar, and wind power, geothermal energy provides a consistent and reliable energy supply, unaffected by locations and weather conditions. It occupies minimal space and offers a flexible solution for communal energy production. Additionally, geothermal energy is environmentally friendly, emitting minimal greenhouse gasses and having a smaller ecological footprint.

The above mentioned four aspects related to geothermal energy exploration, including its long history, the recent boom of research development, the emerging trend of international collaboration, and the success of a specific local example, this paper further argues that it is now time for us to consider geothermal energy more seriously in our quest to address the environmental crisis. By leveraging its advantages and potential, we can make significant strides towards a sustainable future. Saving the Earth through the adoption of geothermal energy means safeguarding our world and securing a better future for generations to come.

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