PROVIDING A GRAVITATIONAL ENERGY STORAGE SYSTEM FOR RELIABLE GRID-INDEPENDENT RENEWABLE ENERGY DEPENDENCY

INVESTIGATING SOCIAL INFLUENCE ON THE DEVELOPMENT OF GRID-INDEPENDENT RENEWABLE ENERGY SYSTEMS

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

"Roughly 20% of US energy-related greenhouse gas (GHG) emissions stem from heating, cooling, and powering households" (Goldstein et al., 2020). The portion of American domestic electricity usage that contributes to these GHG emissions is mostly sourced from the public grid. 60% of utility-scale electricity generation in the US is powered by fossil fuels (U.S. Energy Information Administration, 2023), which is to say that in a household that relies on the grid for its power supply, a minority of the power it consumes is generated cleanly. Small-scale renewable energy options, such as photovoltaic cells and geothermal installations, have presented a promising opportunity for households to sever their dependency on non-renewably sourced electricity, but renewable energy, particularly on the domestic scale, is plagued by reliability issues resulting from the intermittent nature of renewable energy sources (Chomsky, 2023). Solar cells, for example, only generate useable energy while illuminated and are incapable of storing this energy in any useful quantity. Because a solar panel is illuminated by the sun only during the day, a house depending entirely on solar panels for its electrical supply would have no access to electricity at night and limited access on cloudy days. Thus, for a grid-independent renewable energy solution to be feasible, an energy storage system must be installed. With a mode of energy storage available, surplus energy produced during periods of electrical generation can be stored for use during periods of renewable energy unavailability. For example, if an illuminated solar panel is generating electricity at a higher rate than electricity is being used, the electricity not used can be stored for use when the rate of electrical use exceeds that of electrical generation, as is likely to be the case at night or on a cloudy day. A promising, sustainable energy storage technology in need of further research is the gravitational energy storage system. In the interest of progressing towards providing homeowners with the opportunity to eliminate their dependency on unclean, grid-sourced energy, the technical goal of this project will be to devise a gravity-based home-scale energy storage system. Gravitational energy storage is a promising, sustainable energy storage technology in need of further research, particularly on the residential scale. This system will be designed with a partial focus on underground implementation, which will correspond to a spatially compatible geothermal energy unit and a method for their combined implementation. The STS research portion of this project will investigate, using the STS theory of the social construction of technology, the influence of social demands on the technological goals of developers. What incentives of renewable home energy systems are promised to consumers by their producers and what is the degree to which these incentives satisfy social demand?

Technical Topic

There are numerous ways to store energy, the most recognizable perhaps being the electric battery, which stores electrical energy using an internal chemical potential difference. Lithium-ion batteries are a common form of electric battery and are considered to be a promising solution for renewable energy storage (Masse, 2019), but they are expensive and lack relative longevity. While it tends to require more space and to be more difficult to install, I believe that the energy storage method with the best potential to combine affordability, longevity, safety, and reliability is a system that stores gravitational energy.

Gravitational energy can be stored by forcing matter upward (into a position of higher gravitational potential) using an energy surplus; once stored, this energy can be recovered by allowing gravity to act on the controlled matter and using the matter's momentum to generate electricity (Hurst, 2023). Compared to utility-scale lithium-ion energy storage, a utility-scale gravitational energy storage (GES) system is half the cost per unit of energy and lasts a minimum of almost three times as long. Also, while lithium-ion batteries deteriorate in terms of "performance level" at a rate of about 2% per year and are manufactured through means with a high potential for environmental damage, gravitational energy storage is not subject to any lifetime decrease in "performance level" and is virtually harmless to the environment. (Gravity Power). Though this data is based on analysis of the utility scale, it can be extrapolated that most of the advantages (lack of performative deterioration, lifetime, and environmental friendliness) would also apply on a smaller scale. Cost analysis may differ depending on the scale, but, considering that the technology of GES is not dependent on any rare materials, it is reasonable to assume that GES maintains its relative affordability on a smaller scale. The potential home-scale utility of GES is further supported by an article by Maksymilian Homa et al. comparing the different methods of energy storage. The authors reference a simulation of a small-scale, gravity-based energy storage technology with an energy capacity of 11 kWh, an efficiency of 90%, a lifetime of 50 years, and a relatively low volumetric footprint of about 500 cubic meters, concluding that it "presented a promising solution for small scale storage applications." (2022).

For a residentially oriented GES technology to be easily containable and for materials and installation to be cost effective, my deduction is that the most versatile technical solution is a solid mass attached by pulley to a motor/generator; the mass can then be lifted by the motor, powered by surplus energy, or allowed to fall, using its momentum to run the generator. However, the more common implementation of a GES seems to comprise a piston in a shaft filled otherwise with water; given an energy surplus, water is pumped below the piston to elevate the piston, and given an energy deficit, the piston is allowed to fall, forcing the water below it up through a turbine to generate electricity (Elsayed et al., 2022). Both the weight-and-pulley and the piston methods will be explored; each will likely be more advantageous under different circumstances. Two modes of installation will be developed: one above ground and one below ground. I expect the above ground option to be the cheapest, as it avoids the expense of excavation. I do not expect the piston-based system to be practical above ground, as a large quantity of water would need to be both contained and insulated, likely incurring expensive materials and installation. Both systems discussed can be implemented underground, but whichever system is more space efficient will likely be the only practical underground solution, as excavation is expensive and a smaller apparatus requires less excavation. The underground implementation has two key advantages: it is practically invisible from above ground and can be combined with a geothermal heat pump system to maximize the value of excavation.

Geothermal energy can significantly decrease the emissions attributed to a given household by heating and cooling using only electricity, which can be generated renewably. Geothermal heat pump systems use between 25% and 50% less electricity than conventional electric temperature regulation systems. They use 72% less total energy than standard air-conditioning and 44% less energy than air-source heat pumps. (U.S. Department of Energy). By using less energy, geothermal temperature regulation supports the viability of a sustainable, grid-independent home by lowering the home's demand for renewable energy. By extension, a GES coupled with a geothermal heat pump can be of a lower capacity than one standing alone, as a geothermally heated home requires less energy over a given period of potential demand for stored energy. A geothermal energy system uses the temperature difference between under and above ground to regulate the temperature of a home. The temperature 30 ft below ground is always about 55˚F (U.S. Department of Energy); when the air in a home is above 55˚F, heat from the home can be pumped underground to cool the home, and when the home is below 55˚F, heat from underground can be pumped into the home to increase its temperature. Geothermal energy installation is relatively expensive, averaging around $25,000 (Parsons, 2021). Anywhere from $6,000 to $15,000 of cost is incurred by the excavation required to install a geothermal unit (Hansen, 2023). An implementation of geothermal pumping will be designed to utilize a similar excavation strategy to that of the underground GES, so that the cost of excavation will cover a significant portion of the installation cost of both systems.

STS Topic

My STS research concerns how the personal advantages of renewable grid-independency are presented to homeowners by the producers of these technologies and the degree to which these advantages are effective motivators. Only 44% of Americans reported a "great deal" of environmental concern as of 2022 (Saad). The feeling of obligation to eliminate one's contribution to environmental decay is not universally shared, so it cannot be counted on as the sole motivator for increased sustainability. Instead, sustainable options must be of enough personal incentive to eliminate trepidation among their potential proponents. A 1984 paper by Pinch and Bijker proposes the STS theory of the Social Construction of Technology (SCOT), which maintains that all technological development is born from social stimuli. Under SCOT, my research question can be extended. To inquire as to the advantages presented to consumers by the developers of a technology is to investigate how the development of that technology responds to social demands. The relatively low enrollment of consumers in grid independent technologies (under 4% of U.S. homes were equipped with solar panels as of 2020 (EIA)), indicates that the social demands upon which the development of home renewable energy systems is based have largely not been met. A failure to achieve mass appeal must be followed by improving the performance of the demanded technology or decreasing its cost, sometimes relying on the introduction of new, supplementary technologies.

To examine the relationship between social demand for, technological development of, and proposed advantages of grid-independent renewable energy technologies, I will investigate companies' advertising strategies, review literature regarding the state of these technologies and how they are perceived, and conduct local interviews of homeowners of renewably powered homes, other homeowners, and employees of a local energy company. Attempting to appeal to consumers, New Mexico Solar Group states that solar energy is environmentally friendly, is renewable, saves money, increases home value, provides financial return, and provides grid independency (2021). They also advertise their "excellent" financing options. These incentives are NM Solar's response to social demand; in other words, these are the points that NM Solar expects to be priorities among their potential consumers. Another important form of grid-independent renewable energy is geothermal temperature regulation. Forbes, with the goal more to neutrally inform than to advertise, details both the advantages and disadvantages of solar energy. The advantages they reference are fairly congruent with those advertised by NM Solar, but Forbes, anticipating the scrutiny of its readers, also describes key disadvantages to solar power: high upfront costs, sunlight dependence, space constraints, environmental impact of manufacturing, relocation difficulty, material scarcity, and recycling difficulty (2023). The article ends with the assertion that the pros of solar still outweigh the cons. Forbes, though not attempting to sell anything, may do a better job of persuading people in favor of solar energy precisely because they are not trying to sell anything; they give what appears to be an impartial analysis and ultimately conclude that given their full consideration, it is better to have solar panels than not. This is a good indication of the actual, not just perceived, benefit of solar energy as an off-grid renewable energy source. However, as is in line with the theory of SCOT, it is not the state of the technology that will satisfy the consumer, but rather the alignment of the technology with the consumer's preconceived demand.

Interviews will also be conducted to bolster my research. I will approach homeowners in the Charlottesville area. Owners of homes with no grid-independent renewable energy source will be asked questions along the lines of: "What would it take for you to install a renewable energy system?" Owners of homes with access to renewable energy will be asked questions along the lines of "What did it take for you to install a renewable energy system?" and "Was it worth it?" Their responses will be used to improve my point of reference regarding the specific social demands that influence the construction of technology. I will broaden my reach as much as possible, but my interviews will likely only yield a localized representation of public opinion. Thus, I will also review previous research detailing these opinions on a broader scale, or at least among a different demographic. One resource that appears conducive to this research is a 2022 article by Friman et al. exploring the topic of educating juveniles to "prepare the public… to accept distributed energy systems and renewable energy." Not only is this article in support of the specific technology for which I am advocating, decentralized renewable energy, but it takes a new approach to applying the philosophy of SCOT: by educating youth, the authors are attempting to directly shape future social demands to align with the technology that they believe to be broadly beneficial. This is, by extension, the social influence of the authors on future technology.

I will also interview my roommate, who works in project development at Apex Clean Energy, a renewable energy company aiming to "speed and shape the energy transition" by "expanding the renewable frontier across North America" (Apex Clean Energy, 2023). As my roommate has explained, Apex cannot do business without many peoples' cooperation, in large part because they perform many of their operations on leased private land. Owners of the land on which Apex operates are financially compensated at different rates during retention, construction, and operation. While Apex implements renewable energy technologies on a much larger scale than those at the core of my investigation, speaking with Apex employees may provide important insight into potential consumers' specific financial demands and how these demands change with the circumstances of a project and how they have changed overtime. Through this and other references to pricing and how it is perceived, I aim to deduce somewhat of a universal measure of the price of cooperation in the context of renewable energy. I can then compare this price with established figures of expected return on investment in grid-independent, renewable power generation to determine how close the financial state of these technologies is to satisfying social demands. For instance, a geothermal cost analysis page from North American GeoThermal suggests that a geothermal heating system can pay for itself in as little as 4 years, saving around $1400 annually (2023). I will investigate whether such a claim is promising enough for this technology to be perceived by consumers as satisfactory.

Conclusion

Though the electrical infrastructure of the United States has become more sustainable in recent years, over half of its power is still generated by the burning of fossil fuels. Homes powered by the grid are thus dependent upon mostly unclean energy, and without a rapid evolution of the power industry, there is no guarantee that this energy will become much cleaner anytime soon. Rather than wait for this evolution to take place, homeowners can implement their own renewable energy generation systems, instantly eliminating the full extent of their emissions contributions. However, in order for such an installation to be both practical and grid independent, it must be coupled with an energy storage system. This project aims to devise a gravity-based energy storage plan, the underground configuration of which will facilitate the integration of a geothermal energy system for sustainable temperature control. My research will investigate the personal advantages of a home-scale renewable energy system as posed by those responsible for its development and marketing and whether these advantages are sufficient according to socially constructed expectations. The widespread implementation of grid-independent renewables would be a crucial step towards the reduction of residentially attributed emissions. If every home in the U.S. invested in this technology, emissions sourced from residential energy consumption could be fully eliminated; according to 2020 data, this would cut total U.S. energy-related emissions by 20%. However, widespread investment has not occurred, indicating that the benefits of this implementation are not perceived by the public as sufficient. My STS research can thus be extended to explore the necessary improvements to home renewable energy for it to be adopted with public enthusiasm. In the same vein, the ultimate goal of my technical project is to provide a fully renewable home energy plan with enough reliability and economic incentive for the homeowner's obvious choice to be the most sustainable.

References

Apex Clean Energy | Leading U.S. Renewable Energy Company. (2023). Apexcleanenergy.com; Apex Clean Energy. https://www.apexcleanenergy.com/

Chomsky, R. (2023, July 6). *The Reliability Debate: Renewables*. Sustainable Review. https://sustainablereview.com/the-reliability-debate-renewables/

Choosing and Installing Geothermal Heat Pumps. (2020). Energy.gov; U.S. Department of Energy. https://www.energy.gov/energysaver/choosing-and-installing-geothermal-heat-pumps

Crail, C. (2022, September 13). *Thinking About Solar Energy? Here Are The Major Pros And Cons*. Forbes.com; Forbes. https://www.forbes.com/home-improvement/solar/solar-energy-pros-and-cons/

Electricity generation, capacity, and sales in the United States - U.S. Energy Information Administration (EIA). (2023, June 30). Www.eia.gov; U.S. Energy Information Administration. https://www.eia.gov/energyexplained/electricity/electricity-in-the-us-generation-capacity-and-sales.php#:~:text=In%202022%2C%20about%2060%25%20of

Elsayed, M. E. A., Abdo, S., Attia, A. A. A., Attia, E.-A., & Abd Elrahman, M. A. (2022). Parametric optimisation for the design of gravity energy storage system using Taguchi method. *Scientific Reports*, *12*(1), 19648. https://doi.org/10.1038/s41598-022-20514-y

Friman, H., Banner, I., Sitbon, Y., Einav, Y., & Shaked, N. (2022). Preparing the Public Opinion in the Community to Accept Distributed Energy Systems and Renewable Energy. *Energies*, *15*(12), 4226–4241. https://doi.org/10.3390/en15124226

Geothermal Heat Pumps. (n.d.). Energy.gov; U.S. Department of Energy.

https://www.energy.gov/eere/geothermal/geothermal-heat-pumps#:~:text=A%20heat%20pump%E2%80%94When%20ambient

Goldstein, B., Gounaridis, D., & Newell, J. P. (2020). The carbon footprint of household energy use in the United States. *Proceedings of the National Academy of Sciences*, *117*(32). https://doi.org/10.1073/pnas.1922205117

Hansen, S. (2020, October 21). *Cost to Install a Geothermal Heat Pump*. Costimates.com; Costimates. https://www.costimates.com/costs/heating-air-conditioning/geothermal-heat-pump/

Homa, M., Pałac, A., Maciej Żołądek, & Rafał Figaj. (2022). Small-Scale Hybrid and Polygeneration Renewable Energy Systems: Energy Generation and Storage Technologies, Applications, and Analysis Methodology. *Energies*, *15*(23), 9152–9152. https://doi.org/10.3390/en15239152

Home. (n.d.). Gravitypower.net; Gravity Power. https://www.gravitypower.net

Homes and buildings in the West and Northeast have the largest share of small-scale solar. (2022, October 25). Www.eia.gov; U.S. Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=54379#:~:text=In%202020%2C%203.7%25%20of%20U.S.

Hurst, R. W. (n.d.). *Gravity Energy Storage: An Innovative Approach to Renewable Energy Storage*. Www.electricityforum.com; The Electricity Forum. Retrieved August 10, 2023, from https://www.electricityforum.com/td/energy-storage/gravity-energy-storage

Lydia, S. (2022, April 5). *A Seven-Year Stretch of Elevated Environmental Concern*. Gallup.com; Gallup. https://news.gallup.com/poll/391547/seven-year-stretch-elevated-environmental-concern.aspx#:~:text=WASHINGTON%2C%20D.C.%20%2D%2D%20For%20the

Masse, R. (2019, July 15). *How do lithium-ion batteries work?* Theconversation.com; The Conversation. https://theconversation.com/how-do-lithium-ion-batteries-work-99164?gclid=Cj0KCQjwldKmBhCCARIsAP-0rfy1r1GJw30IrbKG2tRcCrk3ATl8F_u-5CYGLu5-gfi_Rhhq4GRSPC0aAt-fEALw_wcB

Parsons, J. (2021, January 27). *How Much Will a Geothermal Heating and Cooling System Cost for My Home in 2021?* Www.climatemaster.com; ClimateMaster. https://www.climatemaster.com/homeowner/news/geothermal-energy/geothermal-energy/2021-01-27-how-much-will-a-geothermal-heating-and-cooling-system-cost-for-my-home-in-2021

Pinch, T. J., & Bijker, W. E. (1984). The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology might Benefit Each Other. *Social Studies of Science*, *14*(3), 399–441. https://doi.org/10.1177/030631284014003004

Reasons Why Homeowners Should Transition to Solar Power. (2021, June 10). Nmsolargroup.com; New Mexico Solar Group. https://nmsolargroup.com/reasons-why-homeowners-should-transition-to-solar-power/

Save Money with Geothermal. (2023). Northamericangeo.com; North American GeoThermal. https://northamericangeo.com/about-geothermal/financial-case