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Title:

Author(s):

U.S. Clean Carbon Costs: An Investigation of Georgia Markets and Solar Technology

Carnell Tate

Correspondence:
ctate28@students.kennesaw.edu
Kennesaw State University:
Bagwell Center for the Study of
Markets and Economic
Opportunity, Kennesaw, GA
Full list of author information is
available at the end of the article

Abstract:

This paper investigates how geographical variations affect energy costs throughout the United States by using a Levelized Cost of Energy (LCOE) model. The objective was to deconstruct a nationwide LCOE model and investigate the assumptions that are made on a state level; in this case, Georgia was the chosen sample to exhibit how challenges in solar technology affect the cost of clean carbon energy.

Part I Energy Costs in the United States

Introduction:

Economists have tried to predict the cost of generating electricity so as to provide cost-effective solutions to long term energy demands. The cost of electricity is measured per unit of energy and is given by a kilowatt-hour or megawatt-hour.

The Levelized Cost of Energy (LCOE) allows different methods of power generation to be assessed in their costs. Power generating assets require an upfront investment to which also can be expensed for their lifetimes [1]. The aim is to keep the levelized cost of electricity as low as possible. The LCOE offers a powerful metric for policymakers, researchers, and others to compare sources of energy when considering the long-term cost-benefit analyses [2].

Data

The University of Texas at Austin conducted an economic analysis entitled, “New U.S. Power Costs: by County, with Environmental Externalities” to determine regional differences between energy prices of sources across the United States [3]. This research used an LCOE model in marketplaces of competing for energy sources. The objective was to have a standardized way to predict the price of electricity and map the differences across statewide counties while also included environmental costs.

The limitations of this research excluded the other important regional characteristics, such as in-depth comparisons between local regions, which dictate the energy market, and how they could accurately be incorporated into the current model. The UT Austin paper was far too broad to regard these localized characteristics; therefore, many assumptions were made [3] to constrain the study and make the analysis more concise.

Methodology and results:

To create a nationwide LCOE model for all energy types -coal, petroleum, natural gas, nuclear, wind, and solar- several assumptions were made so as to simplify the calculation. For my calculations, I used a simple LCOE equation that excluded the environmental costs for each energy source because I only want to conduct a financial analysis without environmental cost's analyses [4].

Traditionally, researchers and modelers express an LCOE in \$/kWh, and this number represents the sum a power generating asset can produce for every kWh of electricity [5]. This paper specifically dives into regional differences in electricity costs across the state of Georgia. The assumptions in this model were either fixed costs, capital costs, transmission costs, and plant financing lifetimes.

The average useful lifespan of most energy technology's rage between 25 years to 40 years. In many studies, 25 years are the standard for estimating the lifetime of a plant and it is the financing and payment schedule [6]. When estimating budgets, government agencies will commonly oblige that all projects must be evaluated at a specific rate. For example, the U.S. Office of Management and Budget (OMB) declared that federal projects be evaluated at 10% with no inflation adjustment [7]. Making rates standardized increases consistency of economic decisions, and varying projects and reduces gamesmanship so that no region or municipality receives unfair advantages over others [8]. For research purposes, federal discount project's rates will be used so as to standardize the calculations. In Georgia, most utility-scale projects are commissioned by Electric Membership Cooperatives (EMCs) which are public entities [8]. Thus, a discount rate of 10% will be used in this model.

The interest rate and the lifetime of the plant are used to calculate the capital recovery factor. In short, the capital recovery factor is the ratio between the current value of the asset to the value of the asset after interest [7].

The capital cost represents the initial investment required to develop a power generating asset. This part of the LCOE equation involves land development, construction, and engineering to successfully complete. The U.S. Department of Energy's Federal Energy Management Program (EFEMP) developed data to estimate the installed cost for all conventional energy types. Overnight capital costs for all plant types were taken from the EFEMP and used in the National Renewable Energy Lab (NREL) 2015 Annual Technology Baseline Database [6].

There is a useful tool online developed by the NREL called the Transparent Cost Database gives detailed tables and graphs for the costs of each variable in the LCOE depending on the technology and different parameters such as the size and lifetime. These numbers were also used as an average for the model in the paper [6]. However, to regionalize these results on a county-by-county basis, these averages were then multiplied by geographic multipliers used by [3].

Yearly, the Energy Information Administration (EIA) publishes a broad projection for the average costs for transmission in the U.S. for electricity and the fixed operations and maintenance costs for each technology. The fixed operations and maintenance costs vary per region and these regional variations were given on a county by county basis by the EIA.

The transmission cost remains constant at \$2254 per Megawatt-mile, and when converted to simply dollars-per-mile, the cost becomes \$4Million dollars per mile 10. Transmission lines are high voltage connections between the generator and the service provider or distributor, who then converts the high voltage power into lower voltages for consumer use. These higher voltages increase the efficiency of power delivery, and when estimating transmission costs, the distance of transmission line that determines the cost the transmitter must incur 11.

To model an LCOE, the units of measurement must be expressed on a dollars-per-energy basis. To begin, an installed capacity factor each plant must be assumed. Here, the standard size for this model will be 1 MW of installed power capacity. To give an idea for how much power this means on an intuitive level, 1 MW can serve about 650 homes 12. This would be about a small group of residential neighborhoods and will be a reasonable scale to modularize this model.

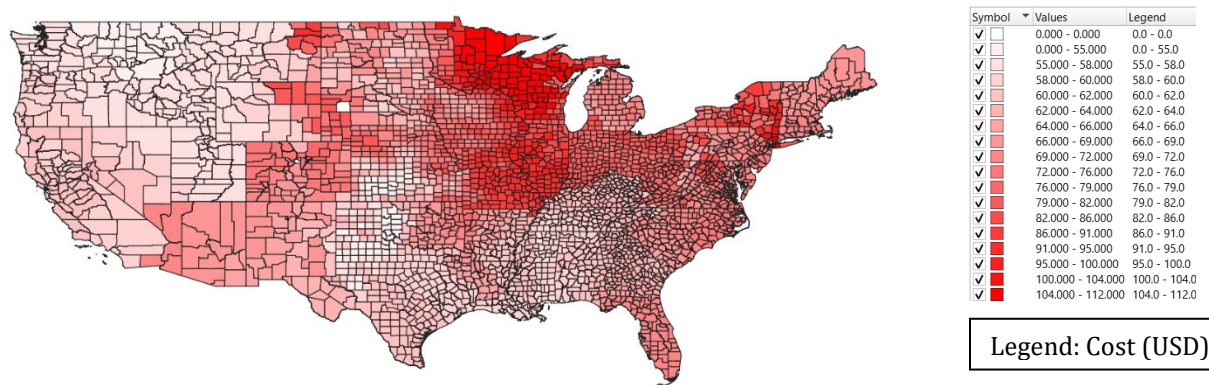
With these assumptions in play, the calculated cost factors of this model will be used to estimate the capital recovery factor, the capital cost with interest during construction (IDC), and the fixed operations and maintenance cost.

For the capital recovery factor (CRF) taken from a discount rate of 10% and a plant lifetime of 25 years, the value was 11.02%. For the capital cost with IDC, a couple of variables need to be derived. First, the capital cost (\$/kW) must be

multiplied by the installed capacity (kW) to get the dollar amount it takes to install the 1 MW project. Then, this amount is multiplied by the CRF and divided by the annual power generated.

To get the annual power generated, the maximum power capacity (1MW) is then multiplied by the capacity factor. The capacity factor is only needed for technologies that require fuel. Thus, the five-year average capacity factor values for coal, natural gas, and nuclear power plants were gathered from EPA's Emissions and Generation Resource Integrated Database (eGrid) 13. For a coal plant that operates 27 hours out of the 168 hours available in a week, its capacity factor would be 16%.

To visually represent costs across the country, I used QGIS, which is a Geospatial Information System (GIS) software that can model spatial distribution for various metrics. Here, I mapped out the cost of energy for each county in the United States



U.S. Clean Carbon Costs (QGIS)

Generalized LCOE Equation

$$LCOE = (\Pi_{capitalcost} \times CRF + O\&M_{fixed}) / (365 \times 24) + O\&M_{variable} + HR \times \Pi_{fuel}$$

To demonstrate the sensitivity of each variable in the LCOE, several scenarios can be manipulated. First, the discount rate (vertical columns) seems to have the most effect on the cost with the maximum percent difference being 60% while the plant lifetime (horizontal rows) had the least effect with 16% being the maximum percent difference. A diagram of 9 permutations for solar energy in Cobb County, Georgia is shown below. The percent difference represents the difference between the lowest or highest value in the corresponding row or column. So for the 47% difference, that would be between the \$235.43 (7% discount rate) and \$346.19 (13% discount rate) prices under a constant plant lifetime of 20 years.

Plant lifetime	20 years	25 years	30 years		
	Cost \$/KWh	Cost \$/KW	Cost \$/KWh	% difference	
Discount rate				(Between lifetimes)	
7%	235.43	215.61	203.55	16%	
10%	288.7	271.86	262.42	10%	
13%	346.19	332.5	325.54	6%	
% difference	47%	54%	60%		
(Between discount rates)					

Solar Energy LCOE scenarios

Part II Energy Costs In Georgia

Introduction

When talking about energy utility costs in Georgia, it is impossible to disregard the enormous impact the Georgia Public Service Commission (PSC) has. The PSC regulates common goods and services that are deemed “public” which include electricity, telephone services, and natural gas. In Georgia, the only investor-owned utility is Georgia Power, which is a subsidiary of the Southern Company. Other subsidiary companies of Southern Company include Gulf Power, Alabama Power, Mississippi Power, Southern Gas, Southern Power, and thirteen other companies and they serve over 2 million people ¹⁵. As far as the remainder of the country, Georgia Power’s structure represents a typical utility company in the United States where the generation, transmission, and distribution are all done in-house.

Whereas, the Intertransmission System (ITS) in Georgia is operated by publicly owned companies called Electric Membership Cooperatives. There are 41 electric membership cooperatives (EMC) in Georgia, and they service about 4.1 million

people in the state 11. Unlike Georgia Power, separates the methods of electricity production through three companies.

Under Georgia law, public goods must be regulated so as to prevent companies from abusing their consumers. If one cannot have lights, electricity, communication, or fuel, it is much more difficult to be a productive person or business and they are at the mercy of whoever is providing these to you; therefore, these goods and services must be protected. Very few, government agencies have the magnitude of influence on everyday life than the commission does. For this reason, watchful eyes and public perception closely monitor the activity of the PSC because people tend to care about how much they are paying for these public goods.

The PSC has full jurisdiction to balance Georgia's needs for reliable services at reasonable and competitive prices for its consumers. When setting these prices, the Public Service Commission is under no obligation to provide a price that guarantees a profit for the service providers. Under the commission's philosophy, the profitability should be determined by the marketplace and capitalism. The level of prudent decision making and sound business decisions should be the tool that gives the service provider the opportunity to profit from their enterprise.

In 1991, the Georgia legislature required the first Integrated Resource Plan. Simply put, an integrated resource plan assesses the needs and demands for power over the next 20 years [8]. The utility market changes rapidly. One year a neighborhood or town could have a population of 5,000 people and then three years later it could double to 10,000 and without a forward-looking plan, those extra 5,000 people could cause a shortage in the amount of power that the community can distribute at a reasonable price. Hot topics such as climate change also dictate the need to provide accurate, cost-based solutions in order to create a greener planet. The last Integrated Resource Plan Proposal was June 2016, and since they are updated every three years, the next one will be proposed this June of 2019.

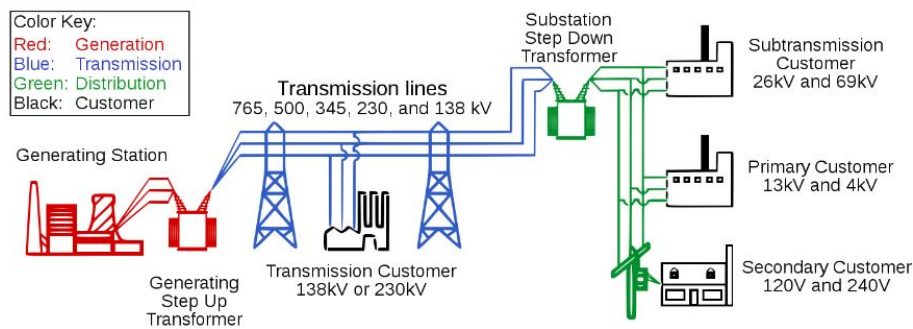
Much like an Integrated Resource Plan (IRP), this model tries and predict the cost of electricity for the state of Georgia, and thus provides a relevant economic contribution for not only academic purposes but serves to advance the private and public sector as well.

Data:

For the purposes of this paper, a preliminary cost model will be explored using the assumptions calculated from the national data to predict the price of electricity and map the differences for the state of Georgia. This statewide model uses local transmission data gathered from the Georgia Transmission Corporation (GTC) to improve the accuracy given by the national model given above.

Due to land costs and safety concerns, many power plants are located far from load centers such as cities. To improve the efficiency of transmitting electricity over long distances, the voltage leaving a generator is stepped up and transmitted over high-voltage-transmission lines. Transmission is likened to a “highway” for the electrical grid. Equal access to transmission by various power providers is a vital part of electrical competition [2].

ITS System Diagram (Georgia Transmission Corporation)



Source: U.S. Department of Energy

Methodology and results:

I had the pleasure of visiting the Georgia Transmission Corporation (GTC) on April 2nd of 2019, and the entire transmission system for the state was shown to me. The national average transmission cost calculated by the EIA was given in units of dollars per Megawatt-Mile, which represents the sum it costs to transmit one megawatt of electricity per mile. Given these units, I had to ask the workers of the GTC the relevant variables in order to derive a unit that can be plugged into an LCOE model for Georgia.



Georgia Transmission Corporation Onsite Tour (2 April, 2019)

Firstly, GTC owns 3,410 miles of transmission in the state. Next, the revenue of the company is divided into two parts: The Dedicated Cost of Service Revenue and the Transmission Revenue. The Dedicated Cost of Service represents the cost it takes to operate GTC in terms of labor, land acquisition construction and engineering costs, and maintenance costs ¹¹. The Transmission Revenue represents the costs it takes to physically transmit electrons across the lines. Both of these combine equally the total revenue generated by GTC.

The words revenue and cost are used interchangeably because GTC is a nonprofit corporation and all of their expenses are billed to whichever Electric Membership Corporation receives their transmitted power. Thus, the only revenue that GTC generates comes directly from their costs of operation ¹¹.

The next variables from GTC involve engineering based calculations. In physics, power is simply the amount of energy delivered per unit of time. The maximum load for a utility company is the maximum amount of power that the transmission lines can handle. In a perfectly efficient world, this level of capacity could be used with no problem, but electricity demand fluctuates and flirting with this maximum capacity could potentially fry the entire grid. The annual energy transmitted for 2018 was 40 Million Megawatt-hours (MWh). To get the average capacity, in Megawatts (MW), one must simply take this energy (MWh) and divide it by the number of hours in a year, which is 8760 hours. Thus, the average power capacity of the GTC is 4566 Megawatts [11].

The engineering division during the GTC tour gave me a comprehensive idea of what transmission engineering looks like. The main control room shown on the previous page displays the status of all the various lines and substations. Whenever there is an issue, a signal indicates the status of the control room. Once the issue gets recognized, a technician is dispatched to the location to investigate it. The transmission system itself lacks a homogenous construction; some parts are brand new or newly repaired, other parts are decades old [11]. Many times a city increases in population and new lines have to be sent to this area to meet the load requirements. In this case, the cost of construction for transmission lines is about \$1.03 million per mile.

Further investigation would be needed to compare non-profit transmission costs to investor-owned transmission costs, and also pinpoint the exact reason why the national average is so much higher than GTC's. However, my hypothesis would be the fact that GTC operates under a non-profit corporation and bills their entire expense sheet to an EMC rather than directly to their customers. The logic would be since GTC only has to focus on transmission services, as a public company, they incur fewer costs because of their domain and privileges as a government agency. The lower cost could also be from the bulk number of customers they service for each region, or because the costs from other non-transmission related expenses, waste, and other budgeting excesses become null. Lastly, the lower cost could be regional. Higher electrical loads are more efficient, and a greater ratio of high demand region's services by GTC could result in a lower cost.

Part III Solar Technology and Energy Costs

Case Study 1

Introduction

In this exercise, the efficiency of a parabolic dish cooker was investigated. When developing solar technologies, solar efficiency directly computes into the cost. Firstly, Professor Richard Wagner and I used to parabolic dish to conduct this experiment. The idea was to record the amount of energy over time that was absorbed by a pot of water within the dish and compare that to the actual power delivered by the sun during that time of day.



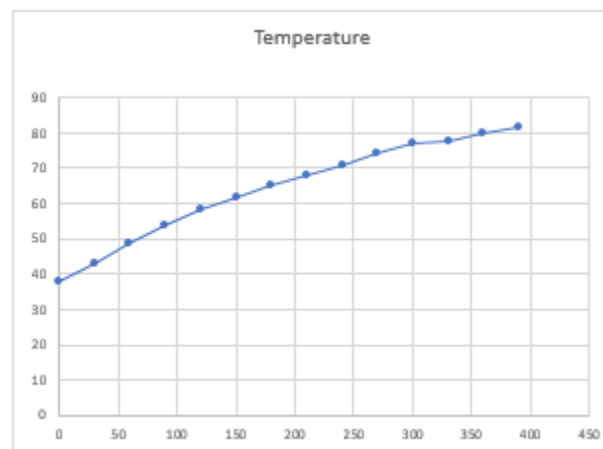
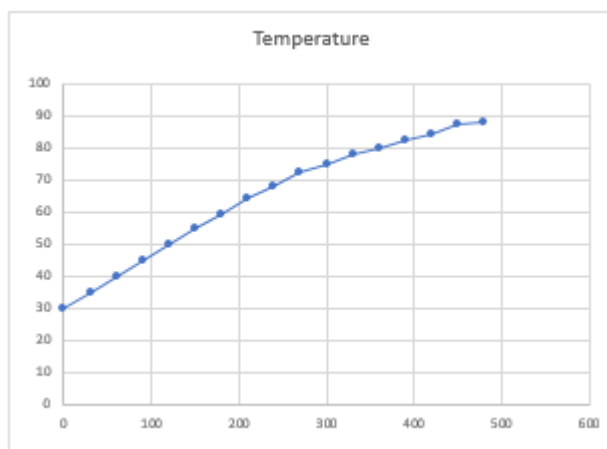
Utilizing the data taken with the parabolic dish cooker, on a single graph, I plotted temperature vs. time for both heating trials. Then, I determined the linear range for each of the curves that have the highest slope and calculate the slope of each of the curves in the linear range.

Next, I took the average of the two slopes and used this value to determine the rate at which energy is being transferred into the pot of water. The pot contained 500mL of water. The main equation for the experiment is shown below:

$$Q = m * c * \Delta T$$

Heat equals mass times the specific capacity of the substance times the change in temperature. Power is the rate at which energy is being transferred, so the slope of the energy graphs I plotted would be the power the dish is delivering to the pot.

Then on a diameter of 4 feet, I determined the theoretical rate at which the dish should be able to collect the energy from the Sun assuming a 100% efficiency and a direct energy value of 1000W/m². Then using the results from the power delivered to the pot versus theoretical power that strikes the dish, I determined the efficiency was about 27% which represented the rate at which the parabolic dish solar collector system was able to convert the Sun's energy to heat and transfer it into the water contained in the cooking pot.



Parabolic Dish Temperature Time Series

Case Study 2

Introduction

The Marietta Campus contains two solar arrays for academic purposes. The electric power produced by the Q-building solar array was monitored for several hours on October 29th, the results of which are shown in Table 3.1. The system's solar array contains 4 solar panels, each of which includes 11 solar modules. Each solar module has a surface area of 1.6 sq meters. Additionally, the panels are tilted at an angle of 15° such that they are aligned east-west and facing the south.



Kennesaw State University Photovoltaic Panels

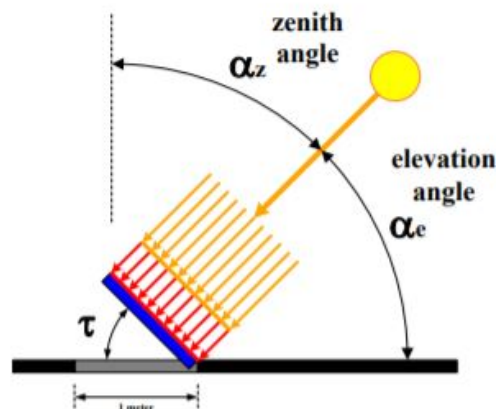
Data

Using the AM1.5G total global irradiance (ITG) value of 1000 W/m^2 for when the Sun was at its peak elevation angle (which occurs $\sim 12:20 \text{ pm}$) and the total surface area, A_{array} , of the solar array, calculate: I calculated the total amount of solar power, P_{solar} , that was incident upon the array, and the overall efficiency of the photovoltaic system. (η or efficiency = $P_{\text{electric}} / P_{\text{solar}}$). The ITG value assumes that the array was aligned such that the surface of the panels was orthogonal to the direct-path of solar energy. Although the array was pointing south, I had to account for the actual tilt angle of the panels ($\tau = 15^\circ$) when calculating the actual global surface irradiance, I_{surface} , that will be incident upon the surface of the solar array.

I then determined the elevation angle (α_e) for the Sun at each time for which the solar array's electric power was recorded, then after utilizing the solar position plot, I determined the azimuth angle (α_a) for the Sun at each time for which the solar array's electric power was recorded. In layman terms, I modeled the motion

of the sun based on the time of day and related this to the power that can be delivered to the surface of the Earth. After the elevation angles, I then determined the air mass (AM) through which the solar energy must travel to reach the solar array at each time for which the solar array's electric power was recorded. After the air mass values, I next determined the total global irradiance (ITG) that would be incident upon the solar array at each time for which the solar array's electric power was recorded. The total global irradiance, elevation angle, and azimuth angle values with the tilt angle of the array (τ), were then all computed to determine the global surface irradiance (I_{surface}) that will actually be incident upon the surface of the solar array at each time for which the solar array's electric power was recorded.

Lastly, the surface irradiance values with the total surface area of the array, I could then calculate the actual rate at which solar energy, P_{solar} , is incident upon the array at each time for which the solar array's electric power was recorded.



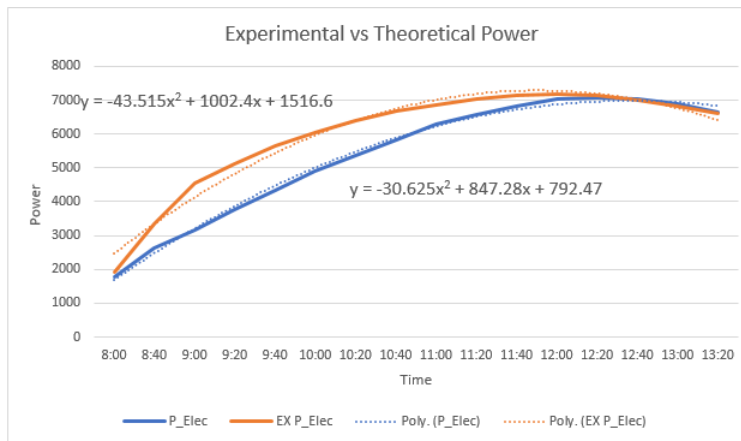
Solar Irradiance Factors

Methodology and Results

Assuming that the array will operate at a constant efficiency, I utilized the solar power values with the array efficiency value calculated to determine the theoretical electric power $P_{\text{elec}}(\text{theory})$ that the array should produce at each time for which the solar array's electric power was recorded.

Using Excel, I plotted both the measured electric power and the theoretical electric power vs. time for the Q-building's solar array (on the same graph) and used the 2nd-order, polynomial, best-fit curves that represent each data set [10]. A comparison between the theoretical electric power $P_{\text{elec}}(\text{theory})$ values to the measured electric power $P_{\text{elec}}(\text{measured})$ values at each time for which the solar array's electric power was recorded by a relative difference calculation and can be seen in the graph below.

The solar efficiency of this experiment can then be used in an LCOE by multiplying it to the capital cost. A Solar LCOE without an efficiency, multiple assumes 100% capture of the energy that reaches its surface, and thus a much more cost-effective asset. Additionally, solar costs vary greatly from model to model and as technology advances, accurate models for solar efficiencies must be updated occasionally to stay relevant.



Solar Efficiency Time Series

Conclusion

Using the data generated from the solar experiments above, a preliminary cost model for solar technology can be estimated for Georgia. In conclusion, the findings of this paper support the idea that transmission costs do not grossly affect the overall cost of electricity.

When doing a preliminary LCOE for Georgia, the national average for transmission costs only produce about a 3% increase in LCOE compared to the more cost effective Georgia average for transmission costs. However, this paper did not dive into residential and commercial-scale solar costs which, typically, deliver a load on site and do not require transmission due to their self-serving setup. Admittedly, more research is needed on other aspects of the LCOE such as the capital cost, and the various efficiencies of different technologies.

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Author Information

Carnell Tate is an undergraduate mechanical engineering major at Kennesaw State University, class of 2020. He can be reached at ctate28@students.kennesaw.edu