University of Georgia Solar Panel Installation Analysis

Andrew Schoppenhorst	B.B.A. Supply Chain Management
Anika Akbar	A.B. Economics
Aarya Oza	B.S. Electrical and Electronics Engineering
Charlie Eidex	B.B.A. Finance
Jan Joho[1]	B.B.A. Economics, B.B.A. Finance, A.B. German
Jeffrey Parmet	A.B. Political Science
Joslyn McKlveen[2]	B.B.A. Economics, M.S. Business Analytics
Justin Strickland	B.B.A. Finance
Nathan Shear	B.B.A. Finance
Nishant Patel	B.B.A. Finance, B.B.A. MIS
Sabina Ashurova	A.B. Economics, M.S. Business Analytics
Sahil Patel	B.B.A. Economics
Will Hooper	B.B.A. Finance

This report, written by members of the organization Terry Student Researchers, demonstrates that the University of Georgia has a multitude of options to begin transitioning towards renewable energy. This report is meant to start a serious conversation among university officials and students on how the University of Georgia can build up its renewable energy capacity while reducing its dependency on energy sources with adverse effects on the environment. We urge the university to hire outside counsel to test the conclusions of this report and present the third-party findings to the University community. The report was written with the intent to be conservative in its assumptions regarding costs and revenue streams to minimize the risk of overestimating the present-day technological aptitudes and progress of both the renewable energy industry and the University.

For any questions, comments, or concerns, please email terrystudentresearchers@gmail.com

[1] President of Terry Student Researchers; Project Manager
[2] Vice President of Terry Student Researchers

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1. Introduction

1.1 Introduction

Over the last decade, the University of Georgia has made significant progress to become a sustainable institution. UGA has exceeded the Governor's Energy Challenge, set more strenuous goals, reduced its energy consumption through infrastructure investment, and developed initiatives to decrease energy use even further. In the same vein, UGA has installed several solar panel arrays including the Solar Tracking Demonstration Project and Jackson Street Building Array. While these projects are admirable and important for research purposes, they provide only a small reduction in UGA's total emissions. More than ever, it is important to continue expansion of our solar resources to meet UGA's emission goals and nullify our impact on the environment as a campus.

This report is centered around two main concepts. The first is in-depth cost analysis evaluating the return on investment if UGA were to self-purchase solar panels and install them on UGA buildings (section 2 of the report). The second is an examination of a PPA agreement at Emory University that would allow UGA to forgo the intensive capital investment required to purchase solar panels, yet still reap the benefits (section 3 of the report). Our findings are summarized in the conclusion (section 4 of the report).

1.2 Background

With more environmental disasters taking place and impacting communities, renewable energy has been a popular topic of discussion as a vital step towards addressing the world's climate problems. Within our local community, Athens Clarke County's mayor, Kelly Girtz, has pledged to switch to 100% clean and renewable energy use by 2035.[i] By 2050, Athens transportation and all other energy needs will be met with 100% clean and renewable energy sources.[1] Also by 2050, ACC plans to generate 60% of its renewable energy locally.[1]

The integration of renewable energy sources can be seen through Georgia's electrical grid. Looking at the current state of the electricity sector in Georgia, approximately 8% of fuel for electricity comes from renewable resources.[ii] The remaining energy primarily comes from natural gas, nuclear power, and coal fuel.[3] For solar energy, Georgia uses both utility-scale and small-scale photovoltaic cells.[3] Electricity generated from solar photovoltaic cells has increased by 948% from 2014 to 2018, yet solar energy is still less than two percent of the state's electricity generation mix.[3] Georgia Power spokesman John Kraft said that compared to separated, rooftop systems, "utility scale solar is currently the most cost effective, and these large-scale installations provide the most value for Georgia Power customers."[iii] Being located in a state that is leading solar power development in the United States, UGA is well positioned to utilize local expertise and resources to build out its solar capacity.

UGA has pledged to purchase 10 percent of energy from renewable sources and generate 10 percent consumed energy through on-site using renewable sources by 2020.[iv] Within the 2020 Strategic Plan, UGA has also committed to "evaluating on-site renewable energy opportunities for all capital projects."[5]

UGA has made many efforts to implement solar panels throughout campus such as the 1 megawatt solar array located at the UGA Club Sports Complex on South Milledge Avenue.[5] The College of Environment and Design has 76 solar panels on its roof, generating approximately 30,000 kWh of electricity per year.[5] There are also eight free-standing solar panels at the UGArden Teaching and Demonstration Farm. However, while UGA has various implementations of solar energy throughout campus, solar energy continues to account for only a fraction of UGA's energy sources.

Terry Student Researchers submits this report to request the University of Georgia bring in independent council within the next 2 years to evaluate renewable energy investments on campus, specifically the installation of solar systems on university buildings. Enclosed you will find a detailed proposal for how this transition may begin at the University of Georgia and an evaluation of the financial outlook of installing such solar panels on select campus buildings.

2. Financial Model

2.1 Current Electricity Use at UGA

In 2019, UGA purchased a total of 308,957,654 kilowatt-hours of electricity between the main and health sciences campuses for a total cost of $16.2 million.[v] The University's current agreement with its utility provider, GA Power, involves a standard reduced rate for 50% of our electricity while the other half fluctuates on a Real Time Price tariff. On average, the unit cost is 4.5 cents per kWh compared to the average residential cost of 11.6 cents per kWh. The University's Real Time Price Tariff can increase up to 10 times during peak energy usage.

Georgia Power's mix of primary fuel sources in 2018 were as follows: Natural Gas/Oil (46%), Coal (25%), Nuclear (22%), Renewables (5%), and Hydro (2%).[5] They also own and operate the 1 MW solar farm on UGA property. In 2019, this array generated 1,667,450 kWh to offset 0.5% of the campus's annual electricity consumption. This is a fraction of the 2020 goal of 10% renewable energy sources.

2.2 Financial Analysis

The following section contains the financial analysis portion of the report. It reviews the financial impact of installing solar panels on 5 different university buildings. First, we will review the model that we constructed to evaluate the initiative. That is followed by smaller discussions on specific features of the model that reviews in detail the individual assumptions we used and how we derived them.

2.3 Calculations Walkthrough

To determine the financial cost of installing solar panels on the University of Georgia's campus, we developed a financial model that examines the yearly profit or loss generated by such an installation. This will allow us to determine whether the complete project exhibits a positive or negative return on investment.

The model has two main segments: 1) a yearly net revenue generation estimate, and 2) a purchase and installation cost estimate. The revenue generation estimate evaluates the financial resources that are saved by using electricity from installed solar panels, rather than purchasing directly from GA Power. The cost estimate portion looks at the cost of installing solar systems on UGA buildings.

In our estimations, we will assume a 20-year lifespan for solar systems. This is 10 years shorter than the 30-year lifespan that is recognized by the U.S. Department of Energy National Renewable

Energy Laboratory (NREL)[vi]. The shorter lifespan allows us to maintain a more conservative estimate of our financial calculations.

2.3.a Yearly Net Revenue Generation Estimate

The yearly net revenue generation estimate uses a variation of the following three step formulas to create 8 different revenue stream estimates. These different revenue steam estimates depend on adjustments to select variables within the formulas. These adjusted variables are highlighted in the formulas below in blue.

[1] Total Solar Sum = [Roof Space (m^2)] x [Infrared Radiation Per m^2 Per Year]

[2] Electricity Produced = [Total Solar Sum] x [Panel Efficiency] x [Deflating Multiple]

[3] Yearly Net Revenue = [Electricity Generated] x [1 - Efficiency Loss] x [Current Cost per kWh] - [Maintenance Cost]

In the following points, we will be discussing the definitions of the variables, how they were derived, and any meaningful information.

Roof Space	The roof space was calculated by examining the usable roof space on a per building basis, free of existing roof installations. The infrared radiation per year was sourced from NASA POWER solar radiation analysis. See *Viable Installation Areas* section for a comprehensive overview.
Infrared Ration per m^2 Per Year	See *Athens Sunlight Analysis* section for a comprehensive overview.
Panel Efficiency	The efficiency rate of a solar panel depends on factors including the solar cell efficiency, the area's climate, and its latitude. Typical solar panels fall between 15% and 20% efficiency.[vii,viii] In this model, we will use a low case of 15% and a high case of 19%, essentially presenting a substantially more conservative analysis of potential revenues from electricity generation.
Deflating Multiple	See *Deflating Multiple* discussion section for a comprehensive overview.
Efficiency Loss	See *Efficiency Loss* discussion section for a comprehensive overview.
Current Cost per kWh	Georgia Power currently buys back electricity at a price of 17 cents per kWh. The University of Georgia currently pays about 0.0524 cents per kWh calculated from FY 2019 prices and quantities used.
Maintenance Cost	We have chosen a low yearly maintenance cost of $2,000 and a high

	yearly maintenance cost of $4,000. This cost does not fluctuate with system size, rather it is tied to each building. See *Maintenance Discussion* for a comprehensive overview.

These inputs were fed into the model to provide us with yearly net revenue estimates. This provides us with an understanding of the yearly cash flows. Now, we shift towards estimating the up-front costs of installing the solar panels.

2.3.b Purchase and Installation Cost Estimate

Costs can be broken up into different categories including the cost of installation and purchase of a solar system. These vary based on system choices. Installation prices fluctuate based on mount type, roof steepness, and other factors. Purchase cost varies on panel type, panel brand, and battery selection as well as system size.

To achieve an estimate for the cost per watt of solar panel installation, we sourced data from NREL, the International Renewable Energy Agency (IRENA), and the Solar Energy Industries Association (SEIA).

In 2018, NREL published a comprehensive benchmarking study on the state of U.S. solar system costs in 2018. In this study, they examined the dollar cost per watt for 11 different states. The graph is depicted below.

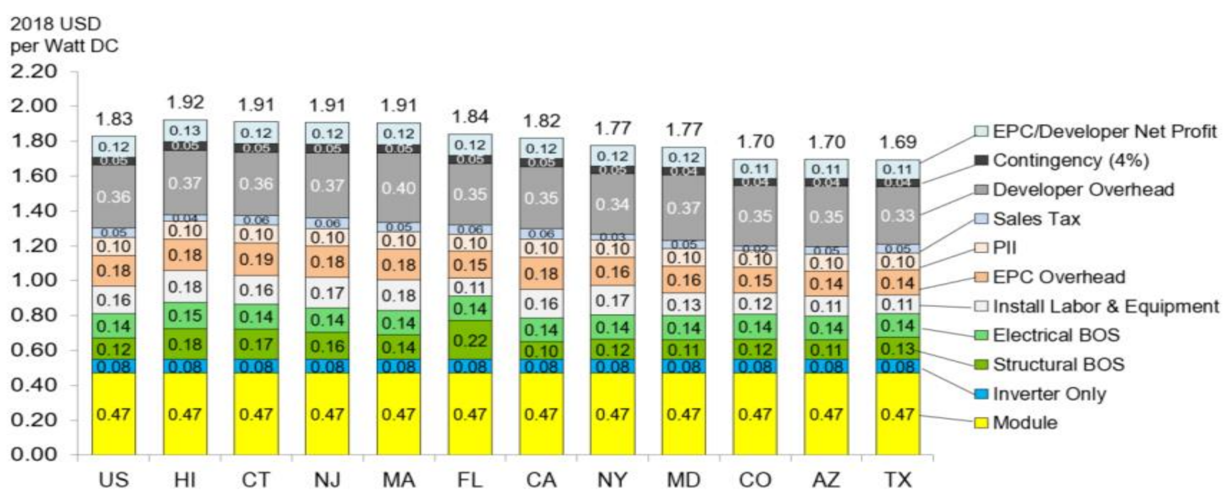


Figure 21. Q1 2018 benchmark by location: 200-kW commercial PV system cost (2018 USD/Wdc)

These benchmarking costs form our assumptions of our dollar cost per watt estimate. Since Georgia is not represented in this study, we will be taking the straight median of all these costs to form the baseline dollar cost per watt for Georgia. This gives us a 2018 dollar cost per watt of $1.77. It should be noted that were Georgia to be studied, we theorize that its dollar cost per watt would be lower than the median, given that its regulatory and labor environment are closer to states like Arizona and Texas than states like Massachusetts and Connecticut. Additionally, while we could have used the U.S. average rather than a median of the individual states, we believe that would be even more out of balance with the state of the solar industry in Georgia given that Georgia's solar industry is very developed and integrated. Using the U.S. average would have placed more weight on states that are lagging on solar power.

Now that we have a 2018 value for the dollar cost per watt for solar power, we want to adjust this to achieve a 2020-dollar cost per watt. According to the 2019 Renewable Energy Generation Costs report published by IRENA, the electricity costs from utility-scale solar PV fell 13% from 2018 to 2019[ix]. According to a SEIA study looking at the U.S. Solar Market 2020, the cost of solar fell by slightly over 18% between 2018 and Q3 2020. We will continue with our spirit of making conservative estimates so we overestimate rather than underestimate the cost and assume that the cost of solar fell by 13% between 2018 and 2020, the low bar of the 13-18% range given by the two reports. This gives us an estimate of $1.5399 per watt to install commercial solar capacity.

Once we have the dollar cost per watt, we can create an estimate for the total installation cost per building. First, we find the size of each system in watts using the following formula:

[4] System Size in kW = [Electricity Produced] / [Infrared Radiation Per m^2 Per Year]

The Electricity Produced variable is the average of the electricity produced when we assume a 15% and 19% panel efficiency (essentially it assumes a 17% panel efficiency). To find the dollar cost of installing solar panels, we use the following formula:

[5] Installation Cost = [System Size in kW] x 1000 x [Cost Per Watt]

By multiplying the system size in kW by 1000, we can find the system size in Watts. As it was established before, the Cost Per Watt is $1.5399, so the formula can also be rewritten as:

[6] Installation Cost = [System Size in Watts] x $1.5399/Watt

In order to get a more comprehensive picture of the range of possible installation costs, we created high and low scenarios for each using 5% variances in the installation cost. The high case assumes that installation will cost 5% more than the baseline calculation, and the low case assumes that installation will cost 5% less than the baseline calculation. See the formula below for a theoretical explanation:

[7] Installation Cost (High Case) = [System Size in kW] x 1000 x [Cost Per Watt] x [1.05]

[8] Installation Cost (Low Case) = [System Size in kW] x 1000 x [Cost Per Watt] x [0.95]

2.3.c Net Present Value

At this point, we have found the yearly net revenues as well as an installation and purchase cost estimate. We want to combine these cash flows into a singular value that can tell us whether the investment would provide a positive or negative ROI. We will be using a Net Present Value calculation to achieve this.

Net Present Value (NPV) is a method of evaluating cash flows that takes into account the basic financial principle of the time value of money that revenue collected in the future does not hold the same value as revenue collected today (i.e. $100 dollars today is worth more than $100 in one year due to interest which could be earned or the investment value of that $100). The NPV method compares the future cash flows, which are discounted to account for time value of money, against the initial investment that is required for a project. As a rule of thumb, projects which exhibit a positive NPV are value producing projects which should be accepted.

The formula for generic DCF is exhibited below:

$$NPV = -(Initial\ Costs) + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \frac{CF_3}{(1+r)^3} + \cdots + \frac{CF_t}{(1+r)^t}$$

The NPV formula starts by subtracting the initial costs that are incurred in year 0. This includes the cost of purchasing and installing the solar panels. This is shown in the formula through the *(Initial Costs)* variable. The NPV will then tell us how much the yearly discounted cash flows will offset the initial costs.

The CF variables are the yearly net revenue cash flows for every year in the projection period. The time variable is given by *t*. As we established, given that the time frame of this analysis is 20 years, t=20. The r variable is the discount rate. The discount rate is what will express the time value of money features of an investment. The higher the discount rate, the lower the value of a payment in the future.

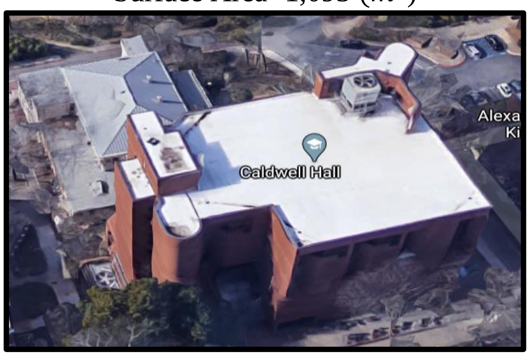
To determine an appropriate discount rate, we chose the 5-year annual return for the University of Georgia. This is equal to 5.0%[x]. We believe this to be an accurate representation of the long-term return that the University could expect if they were to invest their money through the foundation rather than invest it in purchasing and installing solar panels.

We can plug all the variables into the equation to determine the net present value of the investment.

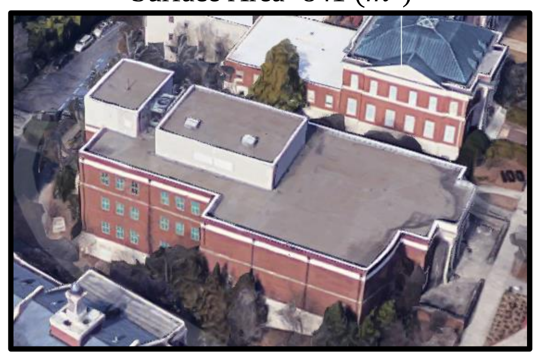
2.4 Viable On-Campus Installation Areas

The installation process of solar panels begins with determining the most viable areas on UGA's campus. The process to do so involved using Google Earth's satellite imaging to determine each suitable rooftop across campus. This considered factors such as slope and type of roof. Steeper roofs, and roofs built out of materials such as slating are less than ideal for solar panel installation as it can drive up the costs and is more difficult to install. Therefore, we compiled a list of buildings that primarily had flat roofs with an abundance of free rooftop space. Once a list of the most feasible buildings was chosen, the process of calculating their surface areas consisted of using the measurement tool in Google Earth. Google Earth's measurement feature allows one to draw lines with precise measurements and calculate the surface area when the lines connect. We took into account structures such as ventilation machines and access points on the buildings when calculating available surface area given that solar panels need to be installed around those structures. Therefore, our final calculation includes only the surface area of the rooftops on campus where solar panel installation may take place. Below are precise surface area measurements of what we considered to be the most practical rooftops for solar panel installation.

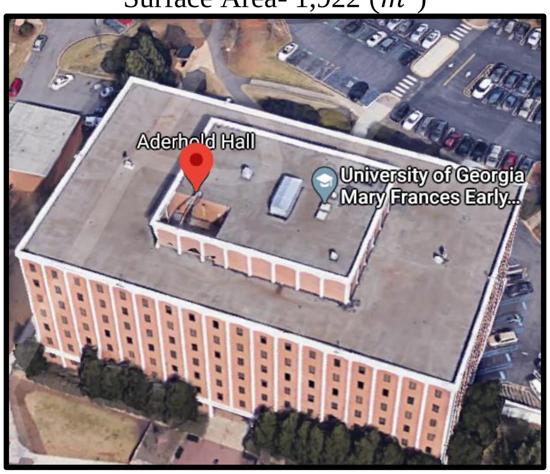
Caldwell Hall
Surface Area- 1,093 (m^2)



Sanford Hall
Surface Area- 841 (m^2)



Aderhold Hall
Surface Area- 1,922 (m^2)



Psychology and Journalism Building
Surface Area- 4,157 (m^2)

Chicopee Complex
Surface Area:16,718 (m^2)

We have identified these five buildings as the strongest candidates for installing a solar system on the rooftops given their flat roofs and large swaths of uninterrupted roof space.

2.5 Athens Sunlight Analysis

Effectiveness of solar power is reliant on peak sun hours in a given location. Peak sun hours are defined by hours during the day in which the intensity of sunlight is 1,000 watts per square meter. Using NASA's POWER (Prediction of Worldwide Energy Resource) system, we were able to gather data points for downward thermal infrared (longwave) radiation in kWh/m^2/day. Thermal infrared radiation can be converted to peak sun hours per day when divided by 1 kW/m^2. Our data represents monthly averages per day from 2014-2018 centered on the MLC roof. We took a 5 year trailing average to estimate an average peak sun hours per day and per month from this point that can then be generalized to the full UGA campus. Each square meter on the UGA campus receives approximately 3028.02 hours per year of effective sunlight for solar energy production.[xi] To convert back to energy production we multiply this value by 1 kW/m^2, which results in 3028.02 kWh/m^2 each year.

Sun Hours	2014	2015	2016	2017	2018	AVG/Day	AVG/Month
January	6.13	6.61	6.55	7.27	6.30	**6.57**	**203.67**
February	6.94	6.57	6.82	7.32	8.14	**7.16**	**200.48**
March	7.13	7.81	7.64	7.44	7.23	**7.45**	**230.95**
April	7.93	8.47	7.86	8.25	7.71	**8.04**	**241.20**
May	8.64	8.66	8.59	8.64	9.17	**8.74**	**270.94**
June	9.61	9.65	9.54	9.63	9.68	**9.62**	**288.60**
July	9.55	9.97	10.13	9.92	9.92	**9.90**	**306.90**

August	9.46	9.74	10.25	9.81	9.70	**9.79**	**303.49**
September	9.62	9.21	9.36	8.87	9.83	**9.38**	**281.40**
October	7.88	8.03	8.03	8.15	8.44	**8.12**	**251.72**
November	6.74	7.85	7.31	7.35	7.47	**7.34**	**220.20**
December	7.12	7.79	7.40	7.21	7.34	**7.37**	**228.47**

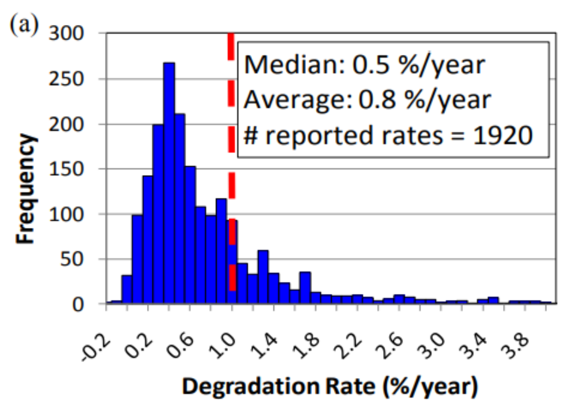
2.6 Deflating Multiple

Despite a stated efficiency rating on a solar panel, the efficiency is affected by additional internal and external factors. Internally, reflectance and thermodynamic efficiency play large roles. Reflectance efficiency is a measure of how much sunlight is reflected versus absorbed; this tends to be around 1-2%. Thermodynamic efficiency measures how well the energy absorbed can be converted into energy. Additionally, product factors such as inverter losses must also be considered.

Externally, solar panels are affected by environmental factors. Panels must remain clean, although rain will typically clean them without human intervention. Shade, cloud cover, and direction also have strong effects on the efficiency of a solar panel. Panels also function more effectively in cooler weather.[xii] These factors are accounted for in the chosen deflating multiple of 0.9, allowing for a 10% reduction in electricity production due to these factors.

2.7 Efficiency Loss Discussion

Solar panel degradation is when the efficiency of a solar panel's capacity to generate electricity decreases over time. There are many different causes such as light-induced degradation, potential-induced degradation, or aging-related degradation which we will not be discussing in depth here. We can turn to the following histogram created by the National Renewable Energy Laboratory in 2012.[xiii]



The median degradation rate per year is 0.5%. This was reaffirmed in a 2015 study NREL conducted.[xiv] In our model, we will use 0.5% per year as the low rate of efficiency loss per year. For the high rate, we decided to use 1.0% efficiency loss per year. In the study conducted, 78% of all panels observed were below 1.0% per year so we are confident that the bounds of 0.5% and 1.0% create an accurate picture of the technological capabilities of the solar panels.

2.8 Maintenance Discussion

With solar projects, there are costs to plan for beyond the initial solar installation. For solar systems to perform at their optimal rate, they must undergo routine maintenance and care. UGA could choose to train their maintenance crews to perform routine system inspections or choose to hire an outside company. Panels must be cleaned at a rate depending on their location and proximity to things like trees or sources of debris. The cost of these cleanings depends on the frequency, location of panels, and scale of the project. Additionally, several panels, inverters, and other hardware will inevitably fail and need to be replaced each year. There may also be repair costs if a portion of a solar system needs to be repaired due to normal wear and tear or due to an exogenous event.

To combat these costs of failing hardware, the University could invest in solar panel insurance. However, we have not included this cost in our analysis.

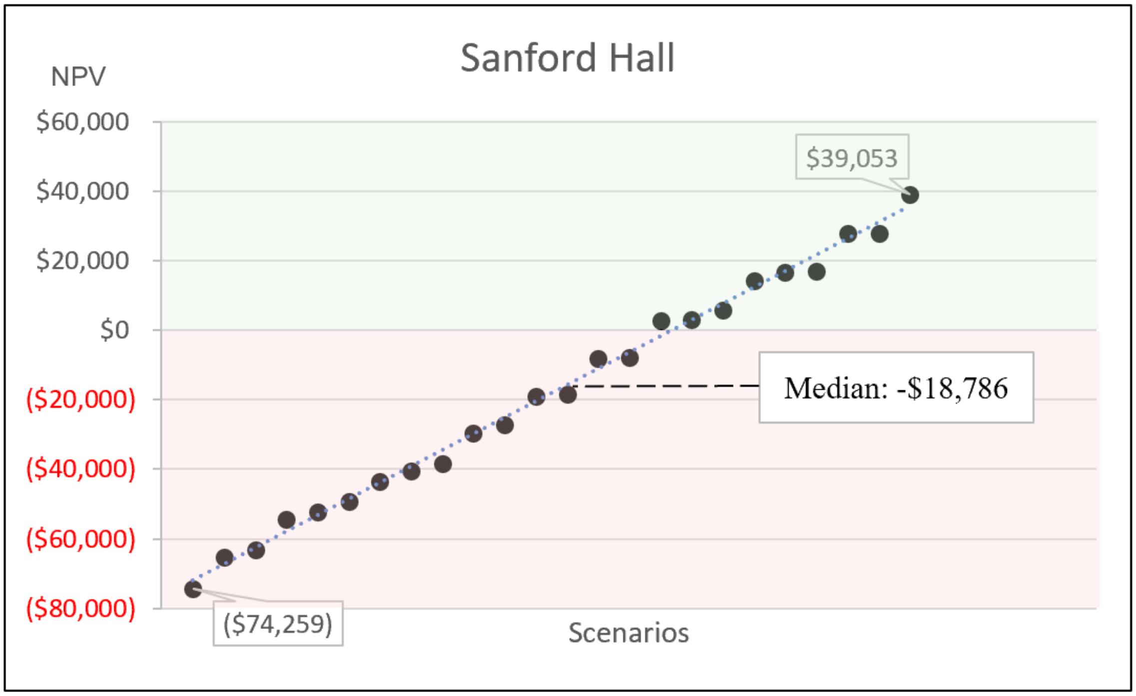
2.9 Results

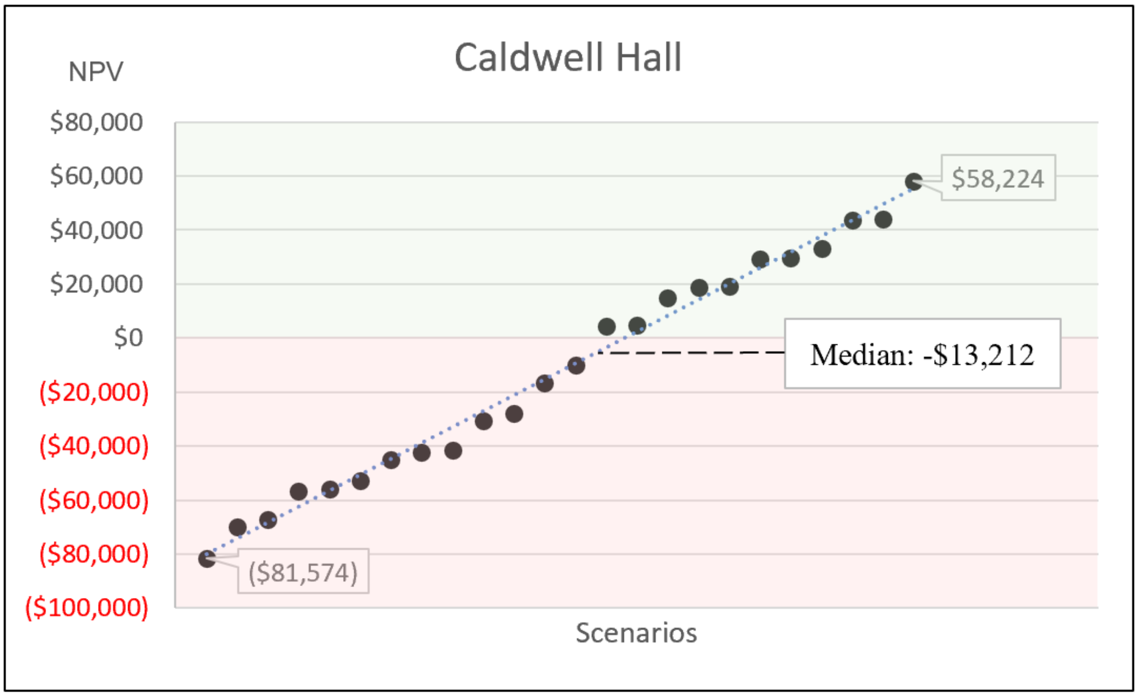
Once we determined accurate estimates of all the variables and created out financial model, each building we selected had 24 different estimates of the net present values of the cost to fully install and operate solar panels for a 20 year period. We have created a graph for each building depicting the range of net present values. Each dot marks a scenario. The vertical axis represents dollar values. On each graph, the highest, lowest, and median values are marked.

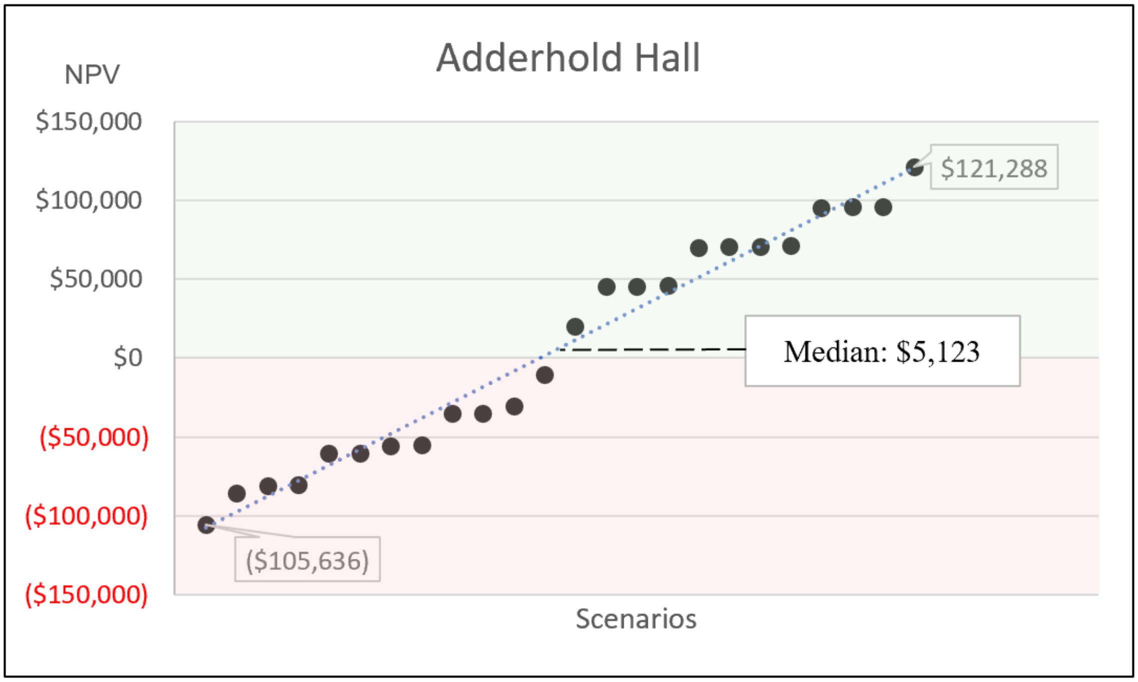
Three out of the five buildings we analyzed have a positive 20-year net present value return on investment. These are Adderhold Hall ($5,123), Journalism ($54,556), and the Chicopee Complex ($332,373). Both Sanford and Caldwell hall have negative net present values, however, they are not particularly large. Both are under -$20,000.

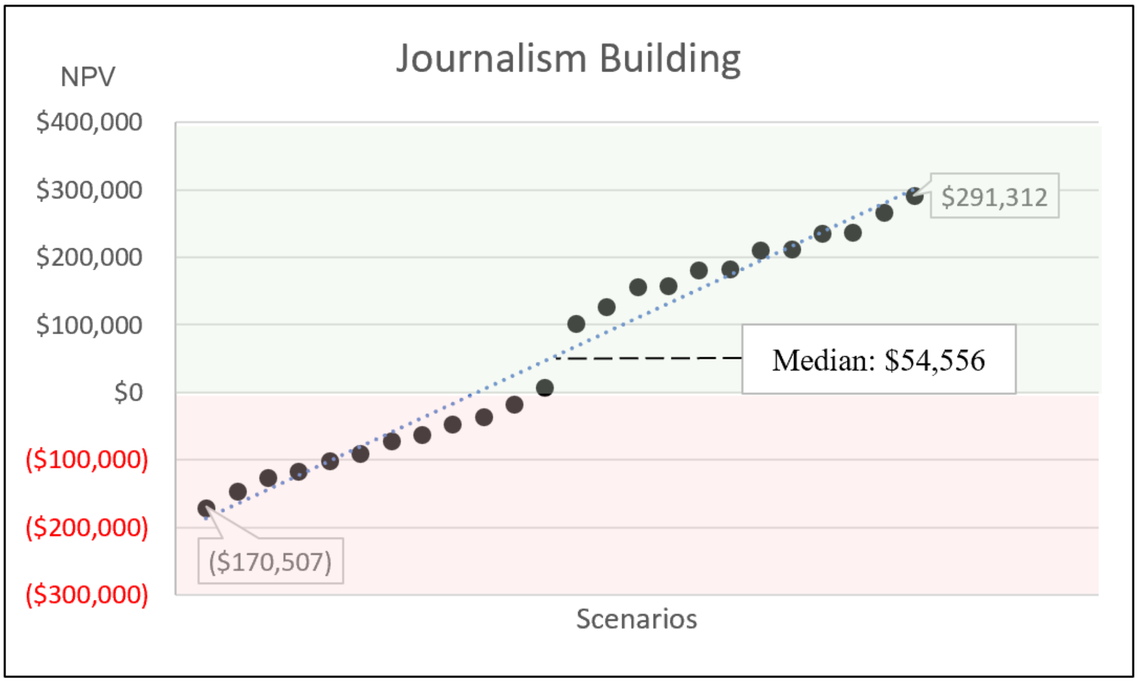
Medians only tell part of the story. For each building, there are positive and negative return scenarios. But overall, the results are highly promising and merit a closer look.

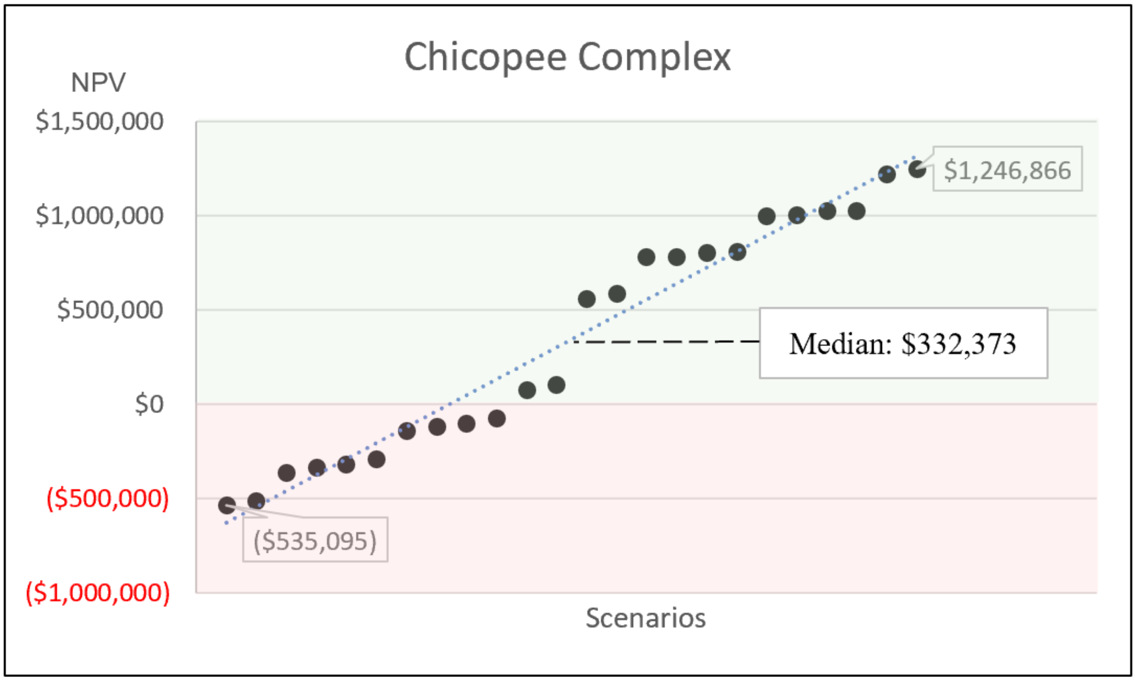
Our model has demonstrated that it would be a worthwhile investment for the University of Georgia to pursue independent verification and consultation regarding the implementation of solar panels on campus building.


Sanford Hall
NPV
$60,000
$40,000
$20,000
$0
($20,000)
($40,000)
($60,000)
($80,000)
$39,053
Median: -$18,786
($74,259)
Scenarios


Caldwell Hall
NPV
$80,000
$60,000
$40,000
$20,000
$0
($20,000)
($40,000)
($60,000)
($80,000)
($100,000)
$58,224
Median: -$13,212
($81,574)
Scenarios


Adderhold Hall
NPV
$150,000
$100,000
$50,000
$0
($50,000)
($100,000)
($150,000)
$121,288
Median: $5,123
($105,636)
Scenarios


Journalism Building
NPV
$400,000
$300,000
$200,000
$100,000
$0
($100,000)
($200,000)
($300,000)
$291,312
Median: $54,556
($170,507)
Scenarios


Chicopee Complex
NPV
$1,500,000
$1,000,000
$500,000
$0
($500,000)
($1,000,000)
$1,246,866
Median: $332,373
($535,095)
Scenarios

3. PPA Agreement

This report has been written on the premise that the University of Georgia will purchase the solar panels and assume complete ownership over the project. However, this is not the only ownership structure that exists and may also not be the most financially feasible. Now, we will be proposing an alternative arrangement that allows UGA to assume zero ownership in solar panels that are installed and pay zero upfront for their installation. UGA will only have the financial obligation to purchase electricity generated by the solar panels. Such an agreement is called a solar power purchase agreement (PPA). A 3rd party developer will assume the financial obligations to install and own the solar panels.

To examine the feasibility of such a structure, we have to look no further than Emory University which in 2019 entered into a 20-year PPA agreement with Cherry Street Energy that led to the installation of 5.5 MW of solar energy on 16 campus rooftops and parking garages.

As mentioned above, a PPA agreement leads to zero upfront costs to Emory. They are simply responsible for providing the space to install panels, and Cherry Street Energy is responsible for their installation and maintenance. Emory is then required to purchase all the energy that is produced by the solar panels.

Like UGA, Emory currently purchases its energy from the grid at a discounted price from an energy provider. They collaborated with Cherry Street Energy to select enough installation space so that the cost at which they are now purchasing the solar energy is on par with the price at which they pay for conventional grid energy. Essentially, using economies of scale they spread the fixed costs of the agreement across enough buildings to drive down the cost per Watt of purchasing the electricity that will be produced.

Entering into this agreement has yielded 4,300 metric tons of Co2 reduction per year for Emory University. And they can do so at zero cost[3] with their only obligation being to provide a space for installation, purchase the energy that is produced, and keep the solar panels clear of shade. They do this while being able to retain exogenous benefits such as promoting their stance as a university pursuing sustainability initiatives.

UGA should follow the footsteps of Emory University and explore options of entering into a PPA agreement. At a **bare minimum**, the university should let the market know that they are exploring PPA agreements and field inquiries and estimates from interested parties. This can be done at little to no cost given that the estimates are being provided for free. (Zero risk all benefits).

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[3] The zero costs references costs related to purchasing, installing, and maintaining the solar panels. There are costs such as having a project manager, putting buildings out of service for the installation, and opportunity cost.

4. Conclusion

This report outlines the motivations, value, and concerns of pursuing solar panel investments at the University of Georgia. We have made several conservative assumptions in our calculations, including selecting a discount rate for our cash flows that we consider to be on the upper end of the University's potential discount rate. This reduces the value of future cash flows and makes the initial up-front installation and purchase costs become a larger component of the net present financial value. Additionally, we selected a lower bound efficiency rating that is lower than the average efficiency rating range. This will result in lower electricity generation, therefore lower revenues, and thus a lower average net present value of this project.

For each building, we calculated 24 scenarios, each with a distinct net present value which represents the financial returns to such an investment. For each building, we found several scenarios in which investing in installing solar panels would yield a positive return on investment project.

We have also explored power purchase agreements (PPA) in discussion with individuals at Emory University. PPA are a low-cost way that the University of Georgia would be able to reap the benefits of solar installations without significant upfront or ongoing costs.

We strongly urge the University of Georgia to pursue third party consultation regarding the financial viability of solar panel installation on campus buildings either through self-financing or PPA agreements and report the findings of such consultations to the University community.

This is the end of the main portion of the report. The following pages include additional considerations, images of our financial model, and references.

5. Additional Considerations

5.1 Environmental Impact

Solar cells are typically known for having zero-emissions, but solar cells do produce toxic chemicals and heavy metals in the production process. Solar cells are produced with hazardous chemicals such as hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, 1,1,1-trichloroethane and acetone.[xv] U.S. environmental laws regulate these fluids and control the methods of their disposal.[xvi] However, if these chemicals aren't disposed of properly they could introduce health problems for workers manufacturing the solar cells and can introduce risks to surrounding environments. Solar cells are also manufactured with dangerous heavy metals such as gallium arsenide, copper-indium-gallium-diselenide, and cadmium-telluride.[xvii]

The transportation of materials, installation, and maintenance of solar cells are all factors that require transportation in vehicles that most likely emit carbon dioxide, which is a greenhouse gas.[xviii] An excess of carbon dioxide in the atmosphere can contribute to global warming; these solar cells require ongoing maintenance that will require emissions to get to the solar cells.

At the end of their useful lifetime, solar cells must be properly dismantled and disposed of or recycled in order to prevent the leaching of toxic chemicals into the soil. Solar cells typically have a lifetime between 25 to 35 years, eventually having to be replaced.[xix] Solar cell recycling is not widely available in the U.S. for all components of the solar cells and not every solar cell manufacturer will accept used solar cells.[xx] This is due to the complexity and expense of the material separation process.

5.2 Safety Considerations

5.2.a Electrical Hazard

Solar energy workers are exposed to electrical hazards when installing, repairing, or testing solar panel systems.[xxi] It is crucial only trained technicians enter the electrical cabinets. Electrical shocks and burns can occur when connecting solar panels to an electric circuit.[xxii]

Additionally, arc flashes may occur if a solar panel system short circuits. An arc flash is an electrical explosion which causes a flash of heat and a shockwave.[xxiii] Electrocution is another potential electrical hazard that needs to be considered. In 2015, of 134 work-related electrocution fatalities, 82 occurred in construction.[xxiv]

5.2.b Fire Hazard

Fires that occur due to solar panels are rare, only being linked to 1.5% of residential fires in Australia.[xxv] However, they are still likely to occur if solar panel systems are not properly connected or certain safety codes are not met prior to energizing.[xxvi] The few flammable components of solar panels cannot support a significant fire, but large fires from other situations may cause a solar panel to burn up as well.[xxvii]

Solar panels can also affect the way firefighters combat a fire. Firefighters typically ventilate a building's roof to fight a fire because this allows toxic gases to escape the building quicker. The presence of solar panels may limit the access to ventilation points on a rooftop.

5.2.c Occupational Hazard

Solar energy workers face the risk of falling off of roofs, especially as installation of each solar panel reduces the walking space. In many cases, workers must walk close to roof hatches and skylights when repairing or testing solar panels.[xxviii]

Workers may also be exposed to extreme hot or cold weather conditions. Heat stroke, dehydration, and heat exhaustion are some of hazards associated with hot weather that must be monitored.[xxix]

6. Sample Financial Model

Below is a sample portion of our financial model. Note: the sample goes to year three, while the actual model goes until year 20. The actual processes used to build this model are covered in the report. We will not be reviewing the individual cell calculations in detail in this paper, however, for any inquiries please reach out to terrystudentresearchers@gmail.com and we will provide you with the spreadsheet.

		Year	0	1	2	3
Electricity Production (kW)						
		Total Solar Sum		3,309,626	3,309,626	3,309,626
	Electricity Produced	Panel Efficiency (L)		496,444	496,444	496,444
	Electricity Produced	Panel Efficiency (H)		628,829	628,829	628,829
		Deflating Multiple		0.90	0.90	0.90
	Electricity Produced	w/Deflating Mult. (L)		446799	446799	446799
	Electricity Produced	w/Deflating Mult. (H)		565946	565946	565946
Efficiency Loss						
		Effic. Loss (L)		0.0%	0.5%	1.0%
		Effic. Loss (H)		0.0%	1.0%	2.0%
Electricity Prod. Cases (kW)						
		(L) Efficiency, (H) Efficiency Loss		446799	442331	437864
		(L) Efficiency, (L) Efficiency Loss		446799	444565	442331
		(H) Efficiency, (H) Efficiency Loss		565946	560287	554627
		(H) Efficiency, (L) Efficiency Loss		565946	563116	560287
Revenue ($)						
A		(L) Efficiency, (H) Efficiency Loss		$23,412	$23,178	$22,944
B		(L) Efficiency, (L) Efficiency Loss		$23,412	$23,295	$23,178
C		(H) Efficiency, (H) Efficiency Loss		$29,656	$29,359	$29,062
D		(H) Efficiency, (L) Efficiency Loss		$29,656	$29,507	$29,359
Maintenance Cost						
AA		Maintenance Cost (L)		$2,000.00	$2,000.00	$2,000.00
BB		Maintenance Cost (H)		$4,000.00	$4,000.00	$4,000.00

		Year	0	1	2	3
Yearly Profit						
AAA		A - AA		$21,412	$21,178	$20,944
BBB		A - BB		$19,412	$19,178	$18,944
CCC		B - AA		$21,412	$21,295	$21,178
DDD		B - BB		$19,412	$19,295	$19,178
EEE		C - AA		$27,656	$27,359	$27,062
FFF		C - BB		$25,656	$25,359	$25,062
GGG		D - AA		$27,656	$27,507	$27,359
HHH		D - BB		$25,656	$25,507	$25,359
Discounted Cash Flows						
		PV of CFs SUM				
AAA		$243,786		$20,393	$19,209	$18,092
BBB		$218,862		$18,488	$17,395	$16,365
CCC		$255,315		$20,393	$19,315	$18,294
DDD		$230,391		$18,488	$17,501	$16,567
EEE		$315,442		$26,339	$24,815	$23,378
FFF		$290,518		$24,434	$23,001	$21,650
GGG		$330,046		$26,339	$24,950	$23,634
HHH		$305,121		$24,434	$23,136	$21,906
Installation Cost						
AAAA		Installation Cost (L)	$271,822			
BBBB		Installation Cost (B)	$286,129			
CCCC		Installation Cost (H)	$300,435			

Net Present Value

	AAAA	BBBB	CCCC
AAA	-$28,036	-$42,343	-$56,649
BBB	-$52,961	-$67,267	-$81,574
CCC	-$16,507	-$30,814	-$45,120
DDD	-$41,431	-$55,738	-$70,044
EEE	$43,620	$29,313	$15,007
FFF	$18,695	$4,389	-$9,917
GGG	$58,224	$43,917	$29,611
HHH	$33,299	$18,993	$4,686

How to interpret the Net Present Value table: AAAA and AAA produces a net present value of -$28,036. The AAAA indicates the total installation cost of $271,822.38 which is the low installation cost scenario and AAA indicates the total present value of the cash flows of $243,786. The $271,822.38 (AAAA) is subtracted from $243,786 (AA) to produce a total net present value of -$28,036.

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