Solar Energy and Boston College:

A Case Study on the Renewable Applicability at Boston College

Abby Host, Aidan Kilpatrick, & Carlos Tramonte

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Professor Tara Pisani Gareau

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Abstract

As implementation of solar energy has increased dramatically, coinciding with mass public support, improved financial returns, and unique practical benefit, Boston College still operates no renewable energy generation systems. Peer universities in New England and across the country have made renewable energy their marquee action in mitigating climate change. The following research investigates the viability of a photovoltaic (PV) solar system on Boston College's campus from operational, financial, and social perspectives. Included in this research is an analysis of the most viable on-campus rooftops for solar installations, with the ultimate determination that upper-campus dorms would be best suited for an initial installation. Financial analysis was then performed in order to assess the potential return on investment, including a selection of the most profitable method of financing the up-front costs of solar energy. Finally, a social analysis of student perception was conducted by surveying undergraduate students for their opinions on the appearance of solar panels. Our research culminates in a proposal for the consideration of Boston College administrators of a 470-kW solar system on the rooftops of dorms on upper campus, which would produce 85% of the area's average annual energy consumption, net the school over $3 million over 25 years, and receive the support of 89% of undergraduates.

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Introduction

Problem Statement

Boston College currently receives none of its electricity from solar energy (Energy & Engineering). The school has made efforts to reduce electric use in order to save money by "retrofitting buildings with efficient lights" as well as implementing computerized systems that operate heating, ventilation, and air conditioning (Energy & Engineering). However, all of Boston College's energy and heat comes from nonrenewables: fuel oils, natural gas, and the central heating plant that maintains three steam boilers. Boston College would benefit from transitioning to generating the electricity it needs from renewable energy, particularly from solar photovoltaic (PV) energy panels on certain campus buildings. Solar energy would help Boston College offset its sizable carbon emissions and move the university towards becoming a carbon neutral school, like other elite college campuses such as Colby College and Bowdoin College (Wise). Therefore, if Boston College wishes to remain competitive with these greener schools in order to attract environmentally-minded applicants, and move toward saving costs in helping combat climate change, it is imperative that BC pursues this investment in solar generation.

Questions

1. Where on campus can we put solar panels and how much electricity will they generate?
2. What is the time to break even for the return on investment (ROI) and what are the projected future savings?
3. How does the BC student population feel about installing roof top panels or other panels? How can other colleges and universities, such as those that exist in similar climates, serve as examples of solar energy applications for Boston College?

Background on Solar

The sun is the single greatest source of renewable energy available to humanity. In a single hour the sun hits the earth with more energy than mankind uses in a year (Harrington). Photovoltaic solar cells convert this energy into electricity and do so without emitting atmosphere-warming gases. Throughout the early history of PV solar panels their large-scale deployment has been obstructed by issues in efficiency, cost, and intermittency. The first PV cells, invented more than 50 years after the discovery of the photovoltaic effect, had efficiencies of 6% using selenium. However, through experimentation and investment in technological development, efficiency has increased so that the average rooftop panel on the market today is 20-30% efficient, using silicon as its conductive material. Researchers have reached up to 46% efficiency with new cell structures but the materials are prohibitively expensive. Costs were also a consistent burden for solar deployment for the past several decades. While popular support for installation was present, the economics were infeasible with a 6kW residential-scale system costing $50,000 even as recently as 2008. However, with significant investment and scaling up of manufacturing and sourcing, costs have steadily decreased 60% over the past decade with the same 6kW system costing only $15,000 to $20,000 (Sendy). This has been even more apparent for utility-scale PV installations with the price per watt (an important metric for solar installations) falling 82% from 2010 to 2019 (IRENA). The last obstacle is solar intermittency, referring to the inconsistent timing of electricity generation due to variable solar exposure. Since the United States grid is built to generate electricity at the same rate that society consumes it, the issue becomes one of real-time reliability. In order to control for the ebbs and flows of intermittency, battery storage serves as a reservoir, tapped when the sun does not shine, and filled when the appliances are turned off, rudimentarily speaking. This technology was, much like the photovoltaics themselves, behind the curve on cost and efficiency. However, battery storage costs have plummeted and have emerged as a cost-effective sustainable alternative in conjunction with solar energy.

Solar projects are financed in a variety of ways. Residential and commercial solar installers benefit from a sizable federal income tax credit of 20% of the total system cost, a serious break on corporate and private income tax burdens (Resnick). However, this does not help non-profit organizations such as churches, charities, and universities as they do not pay federal income tax. The remaining options for non-profits include Property Assessed Clean Energy (PACE), direct loans from a bank or other third party, a Power Purchase Agreement (PPA), and up-front payment. PACE financing is a great option for non-profits without the upfront capital to finance a solar installation. It covers energy efficiency and renewable energy improvements on properties, paid back progressively to the third party based on assessed value of the property (Pritchard). However, like other debt financing options, an interest rate is applied under PACE which extends the payback period and reduces the return on investment. Alternatively, many third parties offer PPAs to property owners that give ownership of the solar system to the third party in exchange for a discount on purchasing the energy it produces.

Therefore, the property owner pays no installation cost and gets an average of 25% of their electricity bill, but the third party benefits from the lion’s share of value produced by the solar system. Finally, an organization could choose to invest in the up-front costs of installation, which would net them a considerable profit over the warrantied-life of the system after a payback period (Resnick). Most systems have a 25-year warranty but often continue to produce energy and revenue for years after (Richardson). In conjunction with the up-front model, the Massachusetts Department of Energy offers a solar incentive through the Solar Massachusetts Renewable Target (SMART) program. This incentive raises the value of electricity produced by a solar system to set level based on the system size and the funds available in the program. This incentive would no longer apply once the utility rate crosses that price with an average annual price increase of 3.5% (EnergySage). However, it can serve as a helpful asset to increase early revenue, thereby decreasing the payback period and supplementing the ultimate return on investment.

Solar Panel Applications at other Universities

Since the introduction of solar power in the 1950s, solar energy has transformed into a valuable alternative to heat homes, power buildings, and reduce our impact on the planet. Additionally, solar photovoltaic (PV) energy panels have been widely used to provide energy as a cleaner, cheaper, and more renewable alternative than conventional fossil fuel energy systems within multiple universities across the country. These universities (Northwestern University, Georgetown University, and University of Washington, to name a few) have established ways to reduce their carbon footprint while also maintaining the aesthetic of their university buildings, allowing students and faculty to take pride in their clean energy missions. More specifically, Northwestern University’s solar energy transition was spear-headed by students in 2011, and now, in a similar climate to Boston, the Chicago university has a 16.8-kilowatt PV panel display that produces about 20,000 kWh each year. (Solar Power Authority). Therefore, Northwestern is just one example of student led initiatives for solar energy on college campuses, a transition that has become more common especially as the climate crisis worsens and the transition to renewable energy is necessary. In another example, University of Washington began a transition to solar energy in 2016, an initiative created by registered student organization UW Solar. This student organization installed three different arrays of solar panels to the roofs of university halls, and between 2016 and 2019, these arrays have saved University of Washington the equivalent of about 270 metric tons of carbon dioxide (Williamson). A similar student-led organization and initiative exists at Georgetown University where a group entitled Georgetown Energy developed a proposal for rooftop installation of solar panels in 2012. This club also proposed solar thermal heating on campus as well, in efforts to create a greener campus (Manger). As a result of this student initiative for solar energy, the University began its transition to renewable energy and in 2020, Georgetown University announced a 15-year Power Purchase Agreement that states that the University will begin to "source two-thirds of its energy needs through energy produced by solar panels" (McClean). These are a few examples of many universities and colleges with student-led solar energy initiatives. Boston College should be the next institution to add their name to this list.

When it comes to climate and weather, Boston College may initially seem like it is in a suboptimal geographic location for solar panels due to long winters and higher than average rates of annual snowfall. However, when compared to the previously mentioned universities, Boston is actually a similar, if not better climate, for solar panel implementation. This can be observed by comparison of annual days of full sun and annual days of snowfall in Boston, Chicago, Seattle, and Washington DC. According to *Current Results: Weather & Science Facts*, which gathers its climate data from National Climatic Data Center and World Data Center for Meteorology, Boston sees the most days of sun annually with 98 fully sunny days, while Chicago, Washington DC, and Seattle were less than that number, with 84 days, 96 days, and 71 days respectively. Additionally, Boston has the higher percentage of average annual sunshine (58%) than the other three cities. Finally, when looking at snowfall, Boston has, on average, 22.4 days with snowfall each year, while Chicago has 28.5 days. Both Seattle and Washington DC have less than 10 days with snowfall each year. However, this lower level snowfall in Seattle (only 3 days with snowfall) is overshadowed by the annual averages for total precipitation in the city. Boston's 126 days with precipitation annually is nearly identical to Chicago's 124 days, and more than 20 days higher than Seattle's 149 days (Current Results: Weather & Science Facts). Therefore, with higher average days of sunlight, and rainfall and snow statistics similar to that of Chicago, Seattle, and Washington DC, Boston boasts a similar, if not better climate suitable for the implementation of solar panels. Boston College must recognize these positive climate statistics and use the available sunlight to their advantage by transitioning to solar energy on campus.

Solar at Boston College

With nearly 9,000 undergraduate and graduate students, 20 student dormitories, 3 dining hall locations, and 2 full sized stadiums, Boston College's energy consumption is high (Dixon, Sustainability and Energy Specialist). Currently, Boston College currently receives none of its electricity from solar energy (Energy & Engineering) or any renewable energy source, and although the school has made efforts to reduce electric use in order to save money, it has mostly done so by "retrofitting buildings with efficient lights" as well as implementing computerized systems that operate heating, ventilation, and air conditioning (Energy & Engineering). However, even though this has contributed to a smaller energy bill, all of Boston College's electricity and heating comes from nonrenewables: fuel oils, and natural gas. Due to the nonrenewable nature of Boston College's energy system, the transition towards electricity generation from renewable energy, particularly from solar photovoltaic (PV) energy panels, would be a cost effective and practical way at reducing the universities carbon footprint. Therefore, this report will serve to outline potential locations for solar panel implementation and the financial feasibility of solar generation to provide a comprehensive plan for Boston College moving forward. Through this implementation, Boston College would be able to offset its sizable carbon emissions and move the university towards becoming a carbon-neutral school, like other elite college campuses stated above. Additionally, investing in solar PV will provide a myriad of benefits, which include: protecting the university from rising energy costs, allowing the university to remain competitive against greener schools by increasing their sustainability initiatives, attracting environmentally-minded applicants and donors, and reducing their energy costs. As such, our objective is to provide Boston College administrators with a realistic and tangible plan for the first implementation of renewable energy on campus with the aim of portraying the Jesuit values of "Men and Women for Others" within the 21st century.

Methods

Choosing a Location

In combination with talks with BC's Sustainability and Energy Specialist, Bruce Dixon, and the previous study on the application of solar panels on Boston College's Brighton Campus in 2014 (Meyer, 2014), we had many different perspectives to take into consideration when establishing solar energy on campus. Through the previous literature and talks with specialists, the determination of where to establish our solar panels was based on a series of criteria, which included 1. Aesthetics and location, 2. BC's Institutional Development Master Plan (Fig. 1), and 3. The overall financial feasibility and potential profitability. Our first variable, aesthetics and location, was integral to the overall viability of solar implementation was location. Sánchez-Pantoja, a researcher at the University of Jaume in Spain, concluded that the visibility, size, and degree of integration are extremely important when looking at the aesthetic impact of solar panels (Sánchez-Pantoja et al, 2018). As such, it was important to be able to emphasize these criteria, and provide a qualitative framework that can be used in the process of integrating solar energy on campus. Through the analysis of BC's architectural cohesion, we knew that any solar panel integration on Boston College's campus would also have to go through the framework presented (which looks at rooftop use, system energy, glare, size, color, and shape).

This was determined by examining the different areas on campus, which include Main campus, Newton campus, Brighton campus, and the Weston Observatory. In addition to the different campuses, it's important to denote what constitutes Main Campus, as it is broken up into different sections given its size. **Lower Campus**, is all of the buildings east of and including Merkert, Conte, Maloney, Comm. Ave. Garage, Hillside dorms, 90-Thomas More, and St. Ignatius including T-More Apartments. **Middle Campus** is all of the buildings west of the aforementioned buildings. **Upper Campus** is all of the dorms within the Tudor Rd., Hammond St., and Beacon St. triangle, including Roncalli, Welch, and Williams Hall (Dixon, Sustainability and Energy Specialist). We understood that BC's administration would not like to see solar panels, as it would reduce the aesthetic they've tried to curate, so much of middle campus within Main Campus would have to be ruled out, since the buildings consist of gothic architecture, which is the dominant appearance of campus; an aesthetic that BC administration has previously stated is "dedicated to maintaining." This group includes buildings such as Bapst, St. Mary's

Gasson, Lyons, Stokes North and South, Devlin, and Fulton as well as buildings in close proximity to the gothic architecture, which includes McGuinn, Merkert, Maloney O'Neill, Conte Forum, Higgins, Carney, and dormitory buildings on Lower Campus. This left us with a reduced amount of buildings to choose from, leading us to focus our attention to upper campus's dormitories (Medieros (Fig 2A), CLFX (Fig 2B), Fitzaga (Fig 2C), Williams, Welsh, Roncalli, Kostka (Fig 2E), and Cheverus (Fig 2F)), which are tucked away from BC's administration; compromising with both the visual continuity within the Gothic architecture of BC and the renewable energy vision of the 21st century.

The second criterion, BC's Institutional Development Master Plan, was important to take into consideration as it would be nearly impossible to get approval for solar generation if a building would be torn down within the next 30 years. This is because solar PV panels have a natural lifespan of 25-30 years (Richardson). As such, buildings like Carney, McElroy, McGuinn and the College Road houses were not viable options for the placement of solar PV panels, further strengthening our reasoning for choosing the upper campus dormitories. Additionally, following BC's Master Plan, three new undergraduate dormitories will be built in the upper campus dormitory section, future proofing our renewable energy plan since the infrastructure will already exist and new solar panels on these buildings will be able to connect to the system with ease. The final criterion, and possibly the most important to consider for Boston College, is the financial feasibility and profitability of the buildings. Because we wanted to choose buildings with relatively large surface areas that would not detract from the aforementioned aesthetic, upper campus dormitories are the best fit for the criteria we have to consider. Additionally, Given the upfront costs associated with installing solar panels, we wanted to make sure that the return on investment would be reached within a reasonable amount of time. This resulted in a cutoff point of 4,000 square feet of usable space for our solar PV panels, and since all upper dormitories fit this description (with the exception of the Shaw House and O'Connell House Student Union Building), the feasibility for these buildings to provide an adequate amount of solar energy is manageable and will provide a return on investment in a reasonable timeframe.

It is also important to bring up potential arguments against this project, one being that the upper campus dormitories do not use energy year-round (i.e., drastically reduced energy costs during the summer), reducing the effectiveness of the project and thus should not be considered for solar PV panel placements. Although it is true that those buildings do not account for high energy usage during the summer months (Mid May - Late August) and winter months (Mid December - Mid January) due to breaks within the semesters, our project considers that to reduce the costs of future maintenance, it would be much more cost effective in the long term to attach the electricity generation by solar panels to the existing energy meter instead of having closed systems for each individual building.. This would allow the energy offset from the panels to come out of the total campus energy use rather than just out of the building it is installed on, allowing high consuming buildings such as Higgins and Conte to have more of the total energy expenditure come from renewable energy sources.

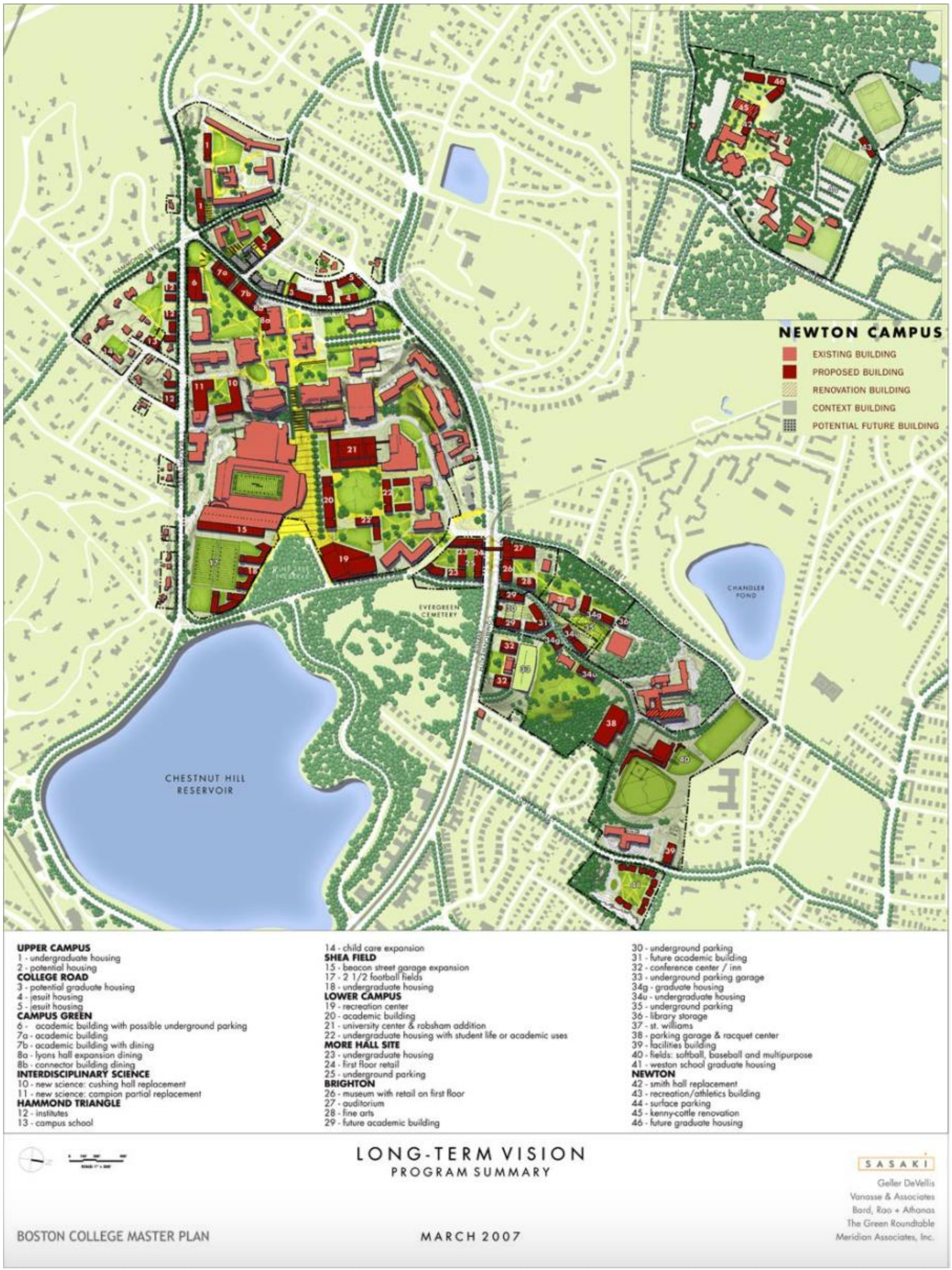


Figure 1: 30-50-year vision for Boston College's Master Plan Program Summary.

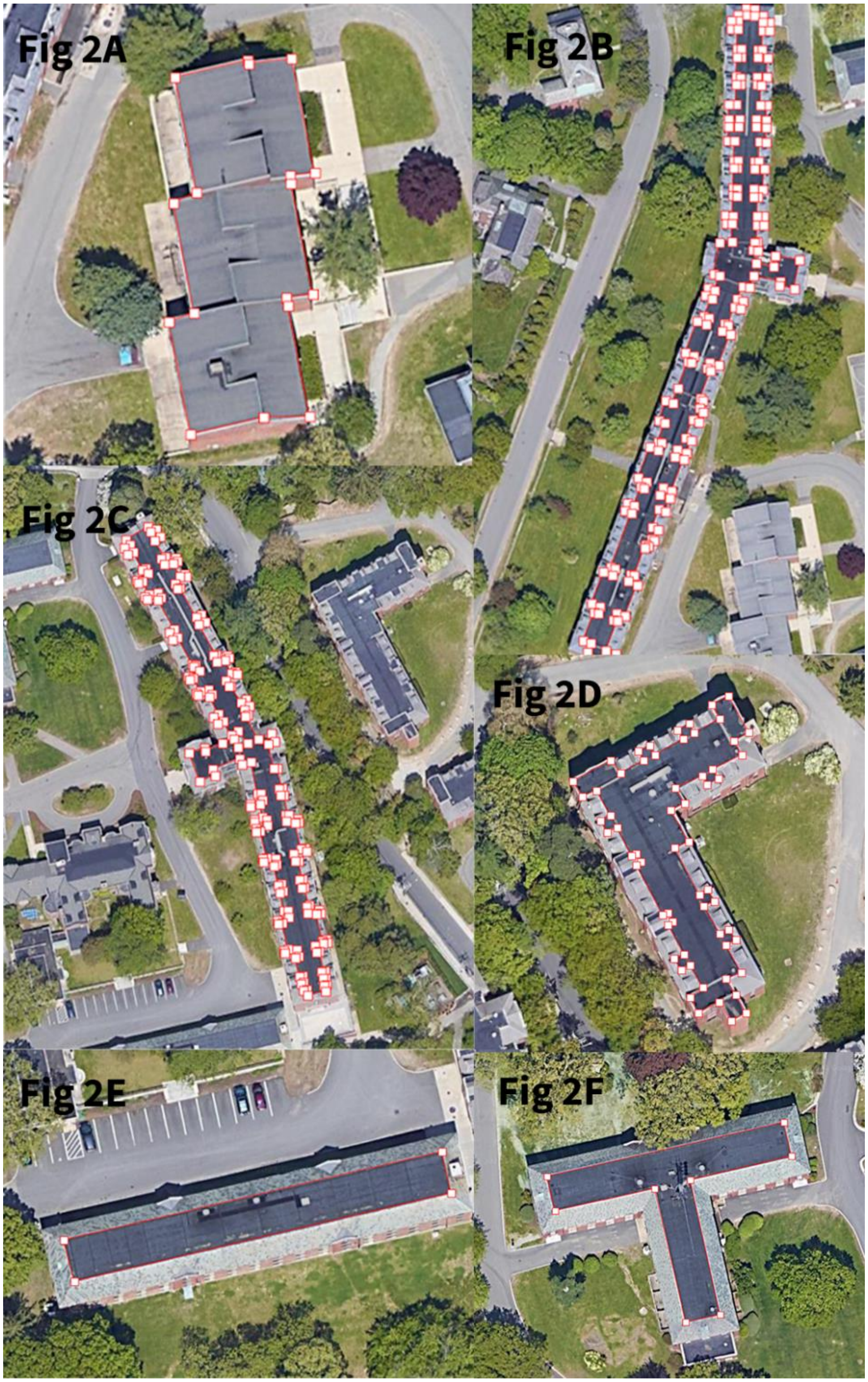


Figure 2: **Medieros**, Figure 2A. **CLFX**, Figure 2B. **Fitzaga**, Figure 2C. **Williams**, **Welsh**, **Roncalli**, Figure 2D. **Kostka**, Figure 2E. And **Cheverus**, Figure 2F. All surface area calculations and energy estimates were done on the PV Watts database.

Energy Estimates & Analysis

Using data pulled from the National Weather Service and PVWatts Database, along with the DaftLogic Google Maps Area Calculator Tool, a concrete amount of data was obtained which helped in answering how much energy would be produced and how much money would BC save per year. As seen in Table 1, the "Surface Area", which was calculated with the DaftLogic software, was used to determine the number of panels possible based on the size of the panels (given by the column under "Square Footage per Panel"). Once this was determined, the surface area was imported into the PVWatts Database, which uses the national laboratory from the Department of Energy's Office of Energy Efficiency and Renewable Energy (NREL) to determine the size of the system (given in kWh) depending on variables such as: Tilt (30 degrees), Direction (south), System Loss (20.5%), Array Type (Fixed), Rate (.165 USD/kWh) and the subsequent output of the system (given in kWh/year). This data was then used to determine an estimated annual value in USD that the university would save by implementing solar panels. Once the Annual System Output was calculated for, the top three buildings were chosen for financial analysis.

Financial Estimates & Analysis

To provide a full financial analysis of the viability of installing solar on upper campus dorms at Boston College, data was collected from Bruce Dixon in the Office of Sustainability, the National Renewable Energy Laboratory (NREL), and EnergySage. Boston College's current electricity rate and projected consumption data were then used to calculate the electricity costs for BC in a single year. Then the cost savings were calculated by subtracting the value of projected energy production from a proposed installation from the university's annual cost of electricity on the upper and middle campus. In order to extrapolate these savings over the warranted period for solar systems, an electricity cost growth rate was used in a future value formula to estimate the compounded savings the university could amass after 25 years. The SMART solar incentive was then added to the price calculations in Excel, which then produced the cost savings projections of the solar system proposal. Total installation cost was calculated by applying the assessed price per watt of a system between 100 and 500 kW to the proposed system size. This was then applied to the cost savings to establish an expected ROI. The most viable (non-debt) financing options were then analyzed for their payback period and long-term value by extrapolating when accumulated cost savings would break even with initial installation cost. These included PPA and outright ownership.

Social Aspect

The social aspect of this study is largely important in determining student opinion on solar panels on Boston College's campus. Therefore, two final questions were posed in this study: Do students have significant opinions on solar panels on campus and, pending the answer determined from the first question, why should Boston College listen to students and implement solar panels on campus?

In order to answer these questions, the methods are twofold. First, a survey (Appendix A) was conducted on campus. This survey consisted of 4 questions in total about opinions on solar panels and their potential implementation on campus. In order to maintain a random sample of surveyed students, researchers stood outside of O'Neill Library for 2 hours and asked students if they would be willing to fill out a quick survey regarding renewable energy on Boston College's campus. If the students agreed to the survey, they scanned a QR code (Appendix A) and were redirected to the Google Form Survey Page entitled "Solar Energy at Boston College". Therefore, the survey was voluntary and as random as possible on Middle Campus during the day. The results from the survey were exported into a google spreadsheet and then converted into a .csv file. In order to analyze the data collected with the survey, it was imported into R Studio and analyzed graphically. Statistical analyses were conducted using R (Version 1.2.1225, R Core Team, 2019) and representative data graphs were created using packages: RColorBrewer (Neuwirth, 2014), ggplot2 (Wickham, 2016), ggpubr (Kassambara, 2019), and emmeans (Lenth, 2019). The results and figures are featured in the results section of this report and data analysis is recorded in the discussion.

The second part of the methods consists primarily of research using online databases and other university solar reports or articles. This research served as the way to compare energy and sustainability efforts at Boston College to other institutions in similar, or worse, climates as Massachusetts. Both quantitative and qualitative data was gathered from University of Washington, Georgetown University, and Northwestern University, in addition to data gathered from Boston College and the Greater Boston area. This research was analyzed in a largely qualitative manner, as a multifaceted comparative study that compares climate, overall solar energy potential, and administration and student opinions on the implementation of solar energy on these different university campuses. This analysis is located primarily in the discussion section of this report.

Results

Building and System

Based on Table 1 and 2, BC's solar applicability is possible. The three largest Dorms by surface area, CLXF, Fitzaga, and Medieros (all boasting over 6000ft^2 of usable roof space) have an annual system output of 281,836 kWh/year, 215,061kWh/year, and 127,709 kWh/year, respectively. They also have an estimated value of over 100,000 USD in savings per year when the annual system output is multiplied by the electricity rate that Boston College pays for currently for its electricity. The next biggest Dorms, Williams, Welch, and Roncalli, which are all identical floor plans and building design, have over 5000 ft^2 in surface area, creating an annual system output of 97,707 kWh/year and savings of nearly 50,000 USD per year. The final two dorms, Cheverus and Kostka, have surface areas of 5115 ft^2 and 4320 ft^2, respectively, with Cheverus having a potential output of 96,379 kWh/year and an estimated savings of 15,902 USD and Kosta having a potential output of 80,581 kWh/year and annual savings of 13297 USD.

Dorm	Surface Area (ft^2)	Square Footage per Panel	Angle + Direction	# of Panels	System Size (kWh)	Annual System Output (kWh/year)	Electricity Rate ($/kWh)	Estimated Savings per Year (USD)
CLXF	15510	19.25	30 + South	806	212.3	281836	.165	46502
Fitzaga	11820	19.25	30 + South	614	162	215061	.165	35486
Medieros	6840	19.25	30 + South	355	96.2	127709	.165	21071
Williams	5250	19.25	30 + South	273	73.6	97707	.165	16122
Welch	5250	19.25	30 + South	273	73.6	97707	.165	16122
Roncalli	5250	19.25	30 + South	273	73.6	97707	.165	16122
Cheverus	5115	19.25	30 + South	266	72.6	96379	.165	15902
Kostka	4320	19.25	30 + South	224	60.7	80581	.165	13297

Table 1: Upper campus undergraduate residential dormitories with flat roof surface areas (ft²) and optimal angles and direction for maximum solar capture throughout the day. Includes the number of solar panels that would fit on a given surface area, the system size in kWh, its output dependent on solar radiation and size, and the potential value of solar generation given in USD. Calculated using the PV Watts database.

Month	Open Sky (%)	Solar Radiation (kWh/ft^2/day)
January	0.31	0.320
February	0.32	0.415
March	0.43	0.457
April	0.45	0.514
May	0.47	0.530
June	0.42	0.539
July	0.51	0.574
August	0.51	0.562
September	0.47	0.510
October	0.4	0.385
November	0.44	0.300
December	0.33	0.278

Table 2: 12-month cycle of the percentage of **Open Sky** (defined by how much cloud cover on average for the month) determined from the National Weather Forecast System's 5-year record of Boston, MA. **Solar Radiation** levels were compiled based on the PVWatt Database which uses the NREL Department of Energy database to determine radiative levels. Records the amount of kWh energy per square foot per day.

Financial Viability

Considering average solar variability, sky cover, and a fixed angle setting as discussed in the prior section, the projected energy production would be approximately 624,606 kWh per year. The upper campus's yearly consumption was 732,845.88 kWh in net energy in the past year. At the university's current electricity rate of $0.165 per kW, the proposed system would generate $103,059.99 worth of electricity per year (Dixon). If the up-front investment and ownership approach is taken, each year the school would save $103,059 on its electricity bill, which would extend over the warrantied lifetime of the solar system for the next 25 years. After

25 years, the cost savings would total $2,576,499.75. However, given that electricity rates rise at an average annual rate of 3.5%, this can be extrapolated to the projected cost savings (EnergySage). Also, adding the SMART incentive increases the value of electricity produced to $0.18 per kWh for a 470-kW system in 2020, saving a total of $112,735.14 for each of the first three years (EnergySage). At a 3.5% growth rate, the value of the electricity produced by the solar system then compounds annually, saving the university a total of $4,223,104.99 over 25 years. The cost of installation based on $2.44 per watt would be $1,148,020 up-front (NREL). When subtracted from the cost savings over the system warranty, the school would accumulate $3,075,084.99 in profit. Figure 3 shows that after a payback period of 9.6 years, ROI would begin to accumulate.

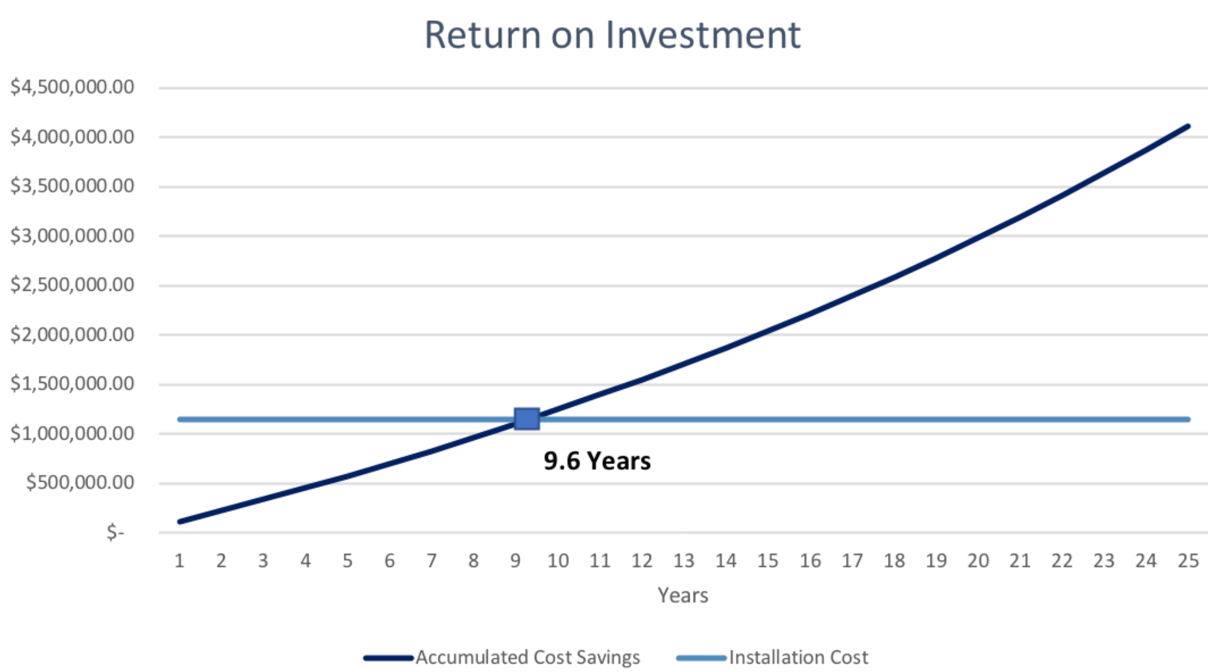


Figure 3: Line graph depicting the cost savings meeting the up-front installation cost threshold at 9.6 years, after which profit is accumulated.

Under a PPA model, the university would pay zero up-front but purchase the energy at 75% of the market value at first, with a 3% growth rate applied to the price over the contract period (EnergySage). This would save the university 25% off the initial market price, accumulating over 25 years with the growth rate included to save $964,625.34 total. Below,

Figure 4 shows a comparison of the two financing options over 25 years and the annual cost savings they would return.

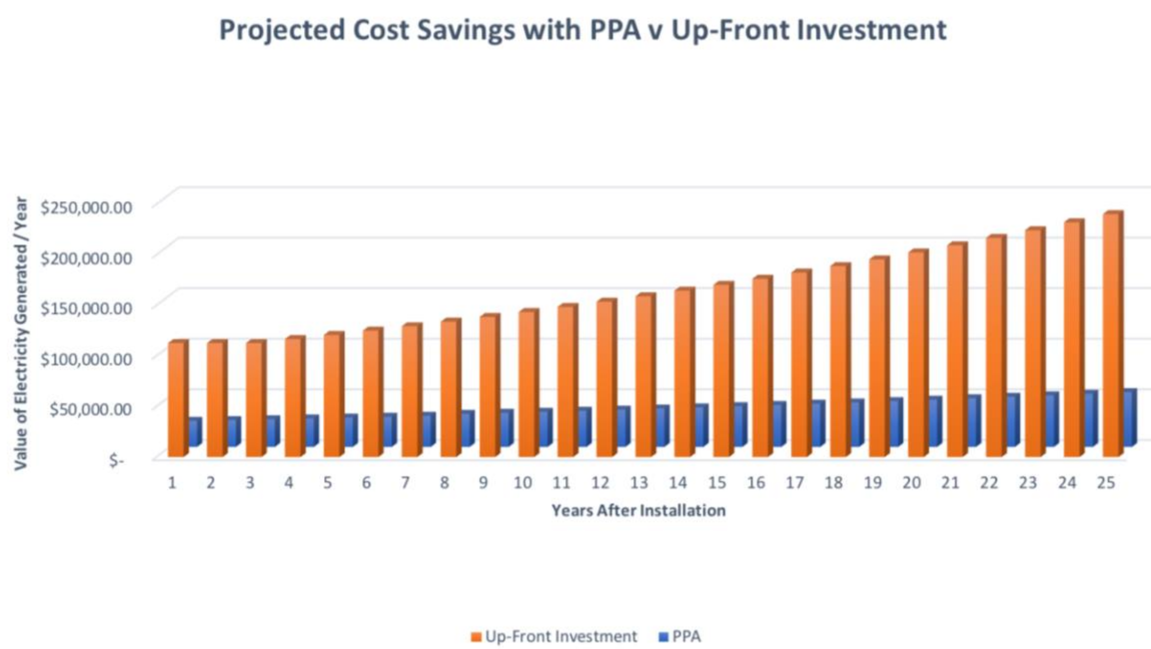


Figure 4: Bar graph depicting the compared annual cost savings projection of a Power Purchase Agreement (PPA) and Up-Front Investment over 25 years.

Survey Questions

The "Solar Energy at Boston College" survey received 103 responses, in which a random array of Boston College students answered the 4 survey questions, listed in Appendix A. Each of these questions was answered on a scale of 1 to 5. The details of the 1 to 5 scale is listed in each figure for reference. The final results of the survey are listed in figures 5-8, shown as histograms in which the # of surveyors that chose each option, 1 through 5, are listed on the top of each column. These 4 histograms of the survey question results serve as results for student opinions on solar panels. The randomized group of student surveyees from middle campus ensures unbiased answers on these survey questions.

Figure 5 is the histogram of survey responses for Question 1, how aesthetically pleasing are rooftop solar panels, on a scale of 1, not at all, to 5, extremely pleasing? This distribution was left-skewed such that 5, extremely pleasing, had 39 responses, the most of the question, followed by rankings 3 and 4. The mode was the rank of 5, while the median and the mean lie somewhere within the ranks of 3, 4, and 5. Therefore, of the 103 surveyed students at Boston College, the highest percentage of them thought that solar panels were at least a little bit aesthetically pleasing, hence the left-skewness of this histogram.

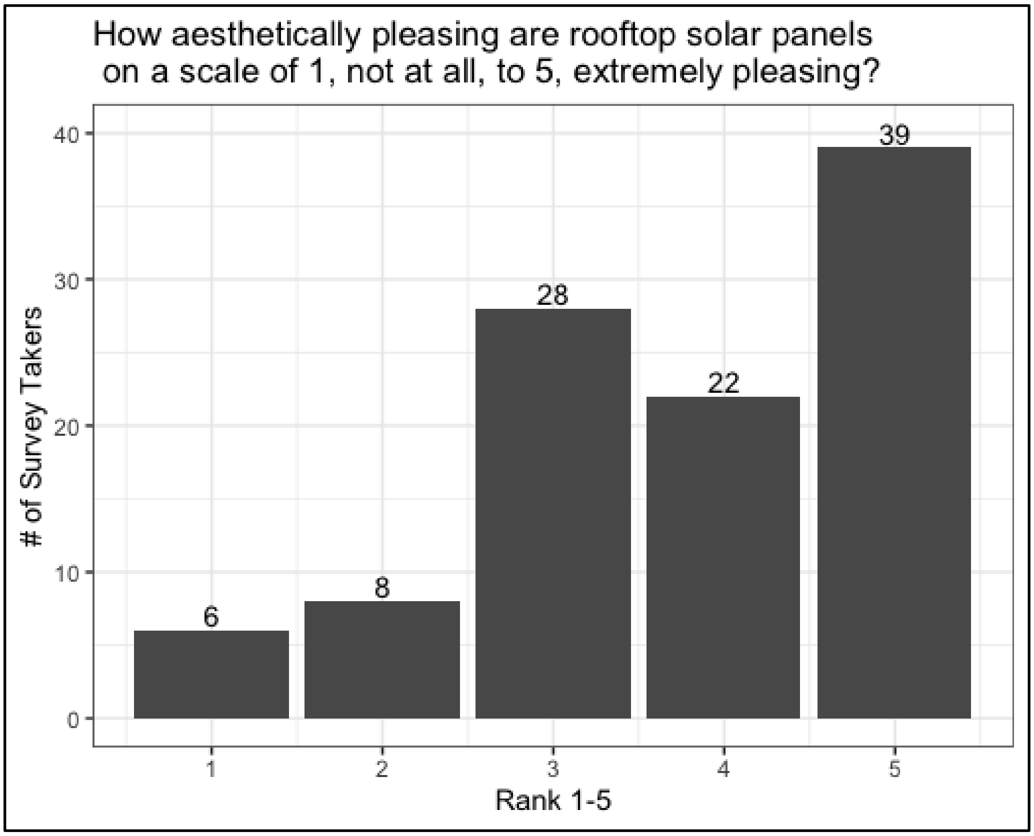


Figure 5: **Histogram for responses of 103 Boston College students to Question 1 of Survey** (Appendix A): How aesthetically pleasing are rooftop solar panels? (where 1 is not at all, and 5 is extremely pleasing).

Figure 6 is the histogram of the survey responses for Question 2, would you like to see solar panels at Boston College? In this question, 1 was not at all and 5 was yes, definitely. The distribution of this histogram is completely left-skewing such that 92 surveyed students, of the 103 overall respondents, said that they would yes, definitely (rank 5) want to see solar panels at Boston College. A simple calculation notes that this means that 89.3% of survey respondents want to see solar panels on campus at Boston College. Therefore, the student body opinion on solar panels on campus is clear.

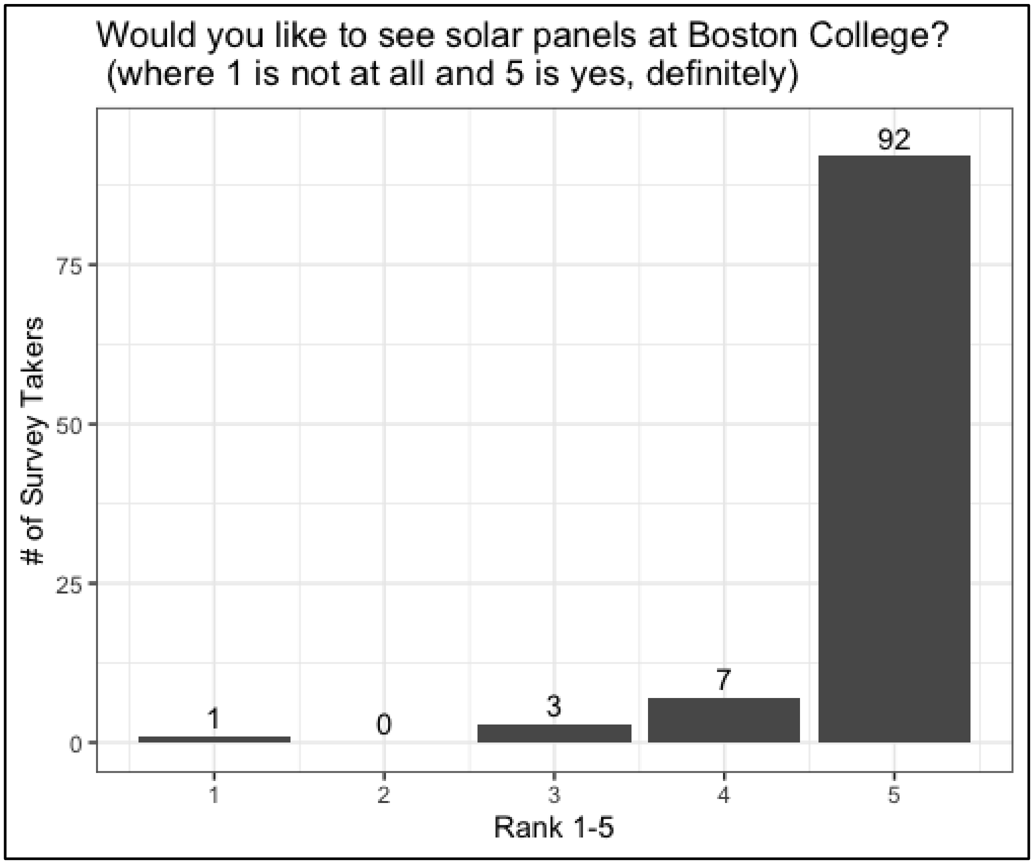


Figure 6: **Histogram for responses of 103 Boston College students to Question 2 of Survey** (Appendix A): Would you like to see solar panels at Boston College? (where 1 is not at all, and 5 is yes, definitely)

Figure 7 is a histogram of survey responses from Question 3, how important is it for you to physically see these solar panels? In this question, the rank of 1 meant not important and 5 was very important. As seen in this histogram, answers varied across the board. The mode is rank 1, so most survey respondents believe that it is not important to physically see solar panels on campus. However, the next highest group of answers is rank 5, very important to see these solar panels. Therefore, while the mode is located at rank 1, the median and mean are likely somewhere closer to the rank of 3, showing that it is neither truly important or not important to see solar panels on Boston College's campus. This means that visually students do not mind if they see them or not; instead, it is more important that students know that they are there and being used for energy (as seen in the results of Figure 6), whether or not students can physically see them or not.

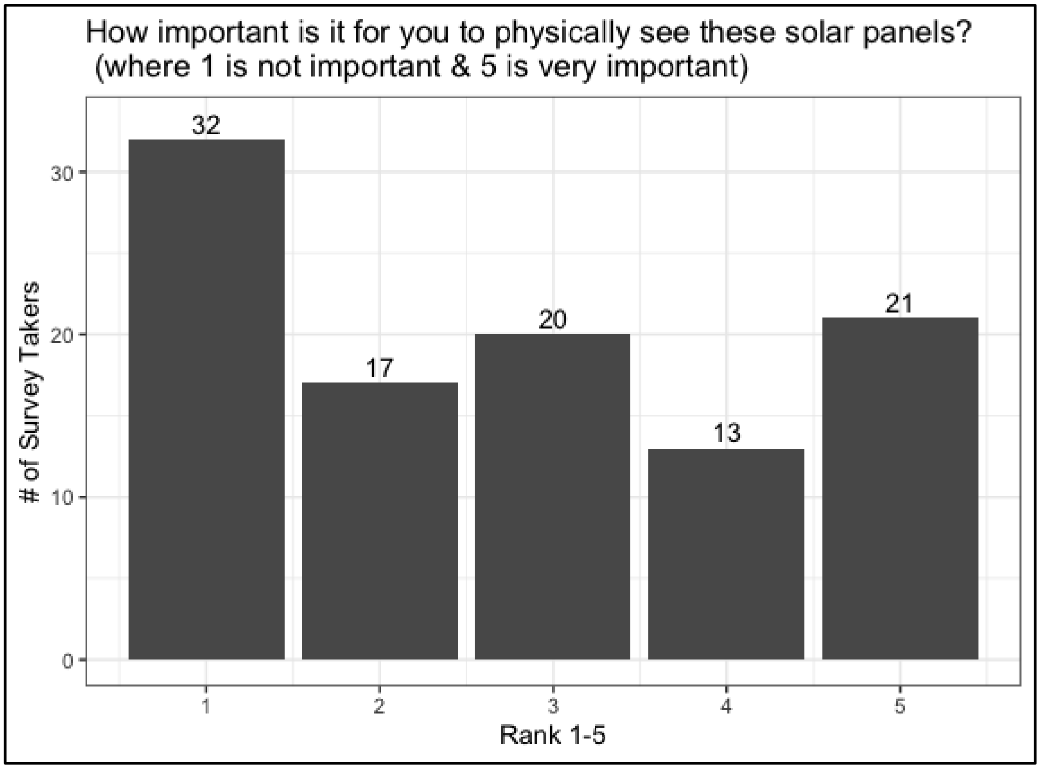


Figure 7: **Histogram for responses of 103 Boston College students to Question 3 of Survey** (Appendix A): How important is it for you to physically see these solar panels? (where 1 is not important, and 5 is very important)

Figure 8 is a histogram of the survey responses for question 4, do you think the use of solar panels to decarbonize energy on campus would attract more potential students? In this question, 1 is not at all and 5 is yes, definitely. The survey results, as shown by the histogram, are skewed to the left, such that 5 has 64 responses, and this number decreases linearly from the rank of 5 to 1. In this histogram, 1 (not at all) only has 1 response. A simple percentage calculation shows that 62.1% of survey respondents believe that yes, solar panels will definitely attract more students, and 95.1% of survey respondents are at least neutral to the idea that the implementation of solar panels will attract more potential students for Boston College.

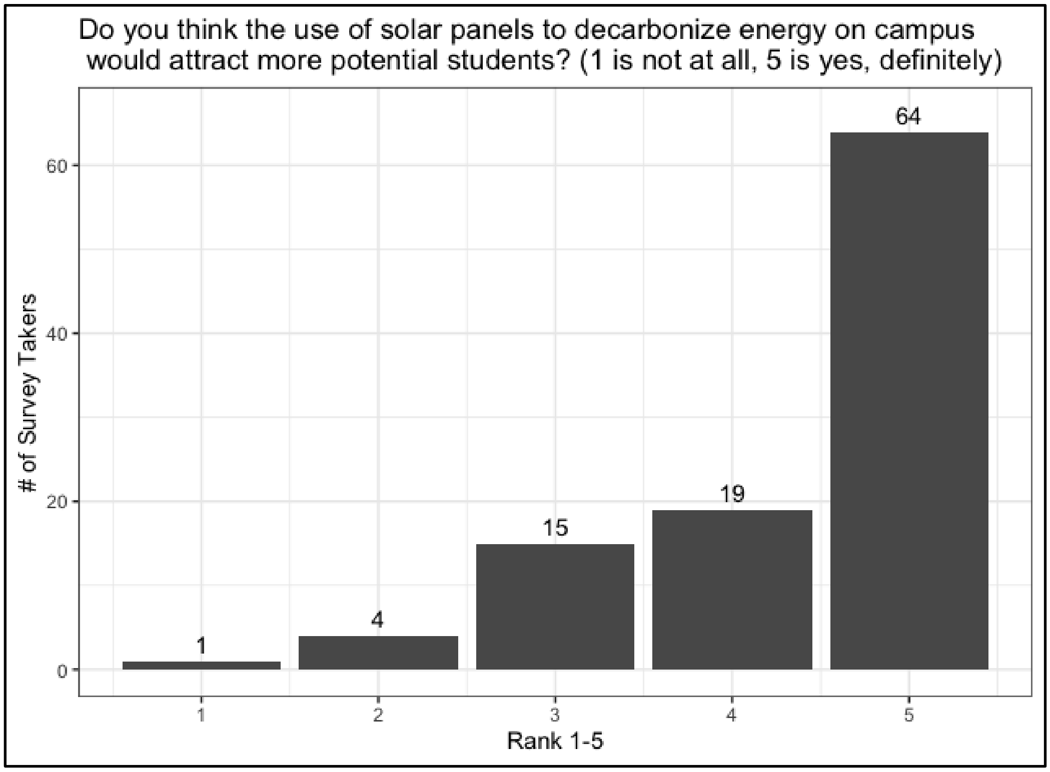


Figure 8. **Histogram for responses of 103 Boston College students to Question 4 of Survey** (Appendix A): Do you think the use of solar panels to decarbonize energy on campus would attract more potential students? (where 1 is not at all, and 5 is yes, definitely).

Discussion

Anthropogenic climate change, caused by the release of carbon into the atmosphere as a result of nonrenewable energy usage, has increasingly had an impact on the planet (NASA). This has brought about stronger storms, bigger fires, and long droughts, bringing more and more attention to the need to solve this issue. Because of this, it is imperative that our society shifts from using nonrenewable resources as our main energy source, and instead use renewables such as wind, geothermal, hydroelectric, and solar. As stated in the Solar at Boston College section of the introduction, BC does not have any renewable energy systems powering its campus; instead focusing its energy consumption on fossil fuels to meet its energy needs. This not only reduces the universities ability to lower their carbon footprint, but also creates more long-term costs for the university and increases the already severe disconnect between the student body and the administration.

Looking at the data collected in Table's 1 and 2, it is clear that the amount of kWh energy produced is significant enough to provide enough of an incentive for Boston College. The amount of energy produced is able to power over 60 homes for an entire year (the average home American home requires 10,524 kWh of electricity per year (US Energy Information Administration)). The results also show that the surface area directly correlates to the amount of energy that the system outputs, as increased rooftop area allows for greater radiative absorption by more solar panels. Additionally, when compared to the amount of oil needed to produce one kWh of electricity on Boston College's campus, which ranges between .08 gallons and .10 gallons of oil, solar is much efficient in the long run, especially considering its relatively infinite source. This is because it takes over 100,000 gallons of oil per year to power middle campus alone, and when you look at Boston College as a whole, that amount jumps to nearly 250,000 gallons of oil a year; adding 4.2 - 4.7 million pounds of carbon dioxide into the atmosphere each year (US Energy Information Administration).

Our results also show that although there may be better areas to place solar panels due to larger surface areas (Higgins, Conte, Lower dorms, etc.) due to the larger surface areas on their roofs, the ability to compromise with administrators on the best location that satisfies both the needs of society and BC decision makers is a solid start in BC's shift to adopting renewable energy sources around the entire campus. However, that is not to say that the buildings chosen do not provide ample electricity, quite the opposite actually, with the buildings able to generate roughly 85% of the energy needed to power upper campus. Furthermore, due to the relatively small scale of the project in relation to the campus as a whole, the decision to place panels on upper campus dormitories is thus used as a proving ground for the benefits to solar, both financially and environmentally, so that it can then be implemented at a scale large enough to diminish our dependence on fossil fuels entirely.

In addition to the environmental benefits of installing a substantial 470 kW solar system, there are considerable financial profits available as well. The administration would have several options for financing such a project, each with their own pros and cons. PACE financing and direct bank loans would both reduce the strain of the initial system cost, but would also incur debt interest that would cut into cost savings potential. A PPA would provide financial convenience that may be attractive to university administrators being that all installation costs and liability would fall to the third party that is supplying the PPA. However, this involves forgoing ownership of the infrastructure itself, and forgoing most of the savings by purchasing the electricity from the third-party for a discount. Ultimately, up-front investment and ownership would be the most efficient and profitable option for Boston College. They would maintain control and operation of the system in the event that needs change. Additionally, the profits would be approximately $3,075,085 over 25 years, which is $2,110,460 or 319% more than if through a PPA.

It is true that ownership would mean saddling the school with the entire installation cost of $1,148,020. The full payback period would be 9.6 years before seeing a return on investment. At the same time, fundraising has been used as an effective tool by other non-profit organizations looking to go solar (Resnick). Using the fundraising infrastructure BC has to its advantage, a "Sponsor a Panel" campaign could be launched to cover a portion or, depending on the success, a majority of the up-front costs. This would significantly reduce the payback period by shrinking the up-front capital BC would have to source from its budget or endowment. As the survey results (Appendix A) from this report show, many students in the Boston College community already feel strongly about climate change, and as they graduate, these new Alumni could begin a wave of donations towards the renewable energy system on campus.

It is clear from the survey results (Appendix A) that a majority of Boston College students are in favor of adding solar panels to campus in order to move the university away from fossil fuels and towards a more renewable and sustainable energy source. This is especially true when looking at Figure 6, which shows that 89.3% of the surveyed students want to see solar panels on campus, and 99.0% of surveyed students are at least neutral (rank 3) wanting solar panels on campus. Therefore, the student body is on board with the transition to solar PV energy on campus, and in the case of this paper, on upper campus. If current students are invested in solar energy on campus, they will likely continue to support this initiative as alumni. Alumni support is extremely important for institutions, such as Boston College. Support from Boston College Alumni is what allows the institution to continue to invest in their athletic teams, fund research grants and opportunities, and continue awarding financial support to students. Without alumni support, Boston College would be a very different place (Alumni Giving). Therefore, administration would do well to listen to current Boston College students, and future alumni, in their opinions of solar energy on campus in efforts to divest from fossil fuels. It is also worth noting that in a liberal, urban city like Boston, renewable energy is becoming more attractive, and an institution like Boston College could gain a great deal of leverage in the community by labeling itself as a environmentally conscious university.

The survey figures are also key findings when it comes to student opinions on the effects of solar panels on building aesthetics. In Figure 5, 37.8% of surveyed students answered that rooftop solar panels were extremely aesthetically pleasing, and 86.4% of respondents were at least neutral to the idea of solar panels being aesthetically pleasing. Therefore, implementing solar panels on the upper campus of Boston College is an excellent opportunity for the administration to begin the transition to renewable energy on campus. Majority of students were at least neutral to liking the aesthetics of these rooftop solar panels. Additionally, according to Figure 7, students were largely neutral to the idea of physically seeing solar panels. To be more specific, 67% of respondents were at least neutral with not physically seeing these solar panels while 52.4% of respondents were at least neutral to being able to physically see solar panels. In conclusion, Figure 6 and 7 prove that students want solar panels on campus and are quite neutral about whether or not they can see them or not, and Figure 5 draws the conclusion that the majority of students on Boston College's campus think that rooftop solar panels are aesthetically pleasing. Upper campus of Boston College offers a location with high roofs that are rarely seen from the aerial view. In videos and promotional content from Boston College, upper campus dormitories are rarely featured, a trend that can be seen in a simple google search of "Boston College". In the top 10 results, those dormitories are not featured once, whereas the more "aesthetically pleasing" buildings of middle campus are featured prominently. Therefore, by placing solar panels on upper campus dormitories, Boston College administration can both listen to its student's voices and work to decarbonize campus while also making sure not to disrupt the aesthetics of popular campus buildings on middle campus.

The final important analysis from the survey pertains to Figure 8, which shows that 62.1% of student respondents believe that solar panels to decarbonize campus will definitely attract potential students. In further analysis, the histogram shows that 95.1% of student respondents are at least neutral to the implementation of solar panels attracting more potential students to Boston College. Therefore, it is clear that a majority of students, as displayed by this random selection of survey respondents, that solar panels have the potential to attract prospective students to campus, which is something that the Administration should take into consideration. As institutions around the country become more and more competitive, Boston College needs to up the ante and continue to improve. Solar energy may offer a way to do just that. Solar energy is important, not only to students, but also teachers and other stakeholders at institutions of higher education, and in making choices about who they will partner with, students and teachers often consider the level of accountability and sustainability an organization possesses (Jevahirian). Additionally, by choosing to install solar panels, Boston College will improve its sustainable brand image. In a liberal, urban environment like Boston, this would make Boston College highly competitive against other universities in this area and other institutions around the country in other urban areas, such as Chicago, Washington DC, and San Francisco. In these liberal environments, prospective students may see eco-conscious and sustainable behavior such as solar panel implementation as a distinguishing factor. These solar panels could be the element that helps a prospective student decide on Boston College over another university. As noted by EnergySage, universities are increasingly interested in showcasing innovation, and therefore, divestment from fossil fuels towards more renewable energy such as rooftop solar arrays will affirm the credibility of a university as a progressive, innovative institution (Richardson).

Recommendations

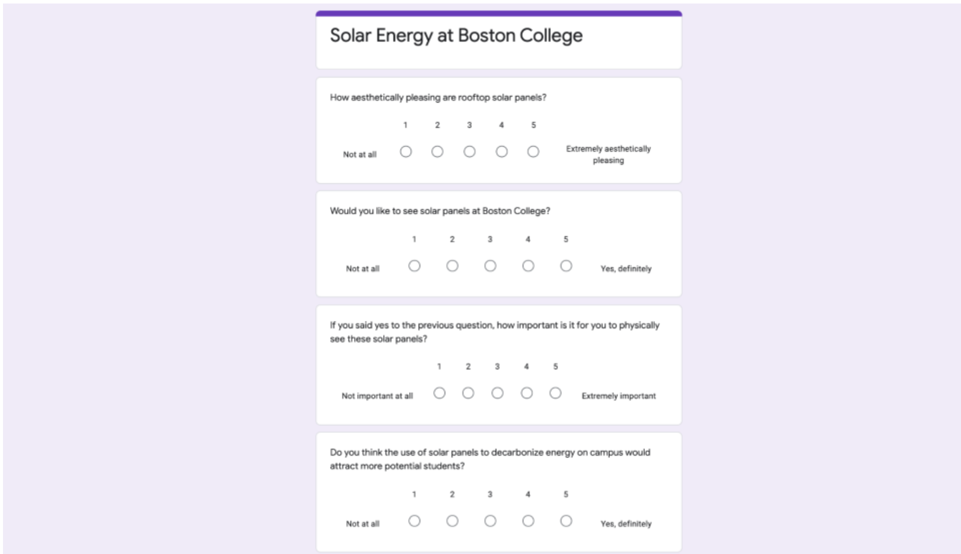
Although we are confident that our proposal to include solar power on campus will help provide financial and environmental benefits based on our findings, there are still some recommendations for future studies that are important to take into consideration for Boston College and future students. There are a number of ways in which the results of this study could be further developed. First of all, future research could focus on the impact of snow, as well as other weather conditions, on Boston College's campus. As a coastal city in the Northeast, Boston receives a significant amount of snow and rain each year, making it crucial to place solar panels in locations that will continue to optimize energy output even during days with snow and rain. While heavy snow can impact the support structure of panels, snow has actually been shown to help clean panels as it melts away (Gay). Additionally, snow has strong reflective properties which may help to enhance the energy output of solar panels in days after snowfall. Therefore, research on the impacts of snow and other inclement weather would provide a stronger framework for the potential application of rooftop solar panels on Boston College's campus. Another recommendation that can be looked into is the cost benefit analysis of having solar panels on buildings near gothic architecture. From the study above, it is clear that Boston College's administration does not want to have solar panels installed near buildings that have gothic architecture, as it would reduce the aesthetic of the university. However, if a study is made that takes a look at the potential solar power generation as well as the financial benefits to installing a system, maybe the administration would not be as hesitant to include solar panels on buildings like McGuinn, Merkert, Maloney O'Neill, Conte Forum, Higgins, Carney, and dormitory buildings on Lower Campus.

More investigatory research on the relationship between people and renewable energy may expose a number of sociological findings about human opinions on solar energy. For example, in this study, researchers conducted only one overarching survey with a random selection of Boston College students. In order to further develop the conclusions made about campus opinions about solar energy, survey groups could be narrowed down to more niche groups, such as students, administrators, professors, or general staff. These groups have different interests in mind, are different ages, and may all have different backgrounds and educations as well. Therefore, exploring opinions of these niche groups could lead to very different results than those found in Figures 4 through 7. Various surveys would determine if and how opinions vary on installing solar panels around Boston College's campus, and if opinions do vary, different plans of approach could be implemented to convince different Boston College groups why solar energy is a positive project for administration to invest in as soon as possible.

When considering the aesthetic value of solar energy in conjunction with the gothic architecture and pristine landscaping at Boston College, a major factor that the administration has to prioritize is the how the architecture and visual appearance of the campus appeals to prospective undergraduate students. A high application rate and a corresponding low acceptance rate is a marquee feature of a prestigious university. Therefore, it could provide additional richness to supplement this research with a study of how application rates change among comparable universities that have installed solar panels on campus. This may include an analysis of application records in addition to qualitative interviews with undergraduate students as to the impact renewable energy on campus had on their college decision. Whether the result is that solar panels have a negative, positive, or neutral effect on applicants, such information would be useful to administrators to include when performing a cost-benefit analysis of a potential solar system. A positive or even neutral correlation may provide evidence against the assumption that photovoltaics would ruin the visual appeal of the Chestnut Hill campus. Instead, administrators could turn their attention to the environmental, financial, and public perception benefits that our research details.

Appendix A

Solar Energy at Boston College: Survey Picture & Survey Link



Survey Questions

1. How aesthetically pleasing are rooftop solar panels
    a. 1 - not at all ; 5 - extremely aesthetically pleasing
2. Would you like to see solar panels at Boston College
    a. 1 - not at all ; 5 - yes, definitely
3. If you said yes to the previous question, how important is it for you to physically see these solar panels?
    a. 1 - not important at all ; 5 - extremely important
4. Do you think the use of solar panels to decarbonize energy on campus would attract more potential students?
    a. 1 - not at all ; 5 - yes, definitely

QR Code for Survey

SCAN ME

References

Alumni Giving. "Giving." *Boston College: Alumni*, Boston College, www.bc.edu/bc-web/offices/alumni/giving.html.

BC. Boston College Institutional Development Master Plan. Retrieved from https://www.bc.edu/content/bc-web/sites/institutional-master-plan/maps---drawings.html.

Wise. (2020). Carbon Neutral Universities in the United States" *Second Nature.* Retrieved from https://secondnature.org/media/carbon-neutral-universities-in-the-united-states/.

BC. Energy & engineering. Retrieved from https://www.bc.edu/content/bc-web/offices/facilities/services/energy-engineering.html#utilities_management.

Current Results. "Annual Average Snowfall for Cities in the United States." *Current Results: Weather and Science Facts*, 2021, www.currentresults.com/Weather/US/annual-snowfall-by-city.php.

Current Results. "Average Annual Sunshine in American Cities." *Current Results: Weather and Science Facts*, 2021, www.currentresults.com/Weather/US/average-annual-sunshine-by-city.php.

Dixon, B. 2021. "Sustainability and Energy Specialist - Energy Usage on Campus". Email Interview.

Gay, Charlie. "Let It Snow: How Solar Panels Can Thrive in Winter Weather." *Energy*, Office of Energy Efficiency & Renewable Energy, 5 Jan. 2017, www.energy.gov/eere/articles/let-it-snow-how-solar-panels-can-thrive-winter-weather#:~:text=A%20dusting%20of%20snow%20has,the%20panel%20to%20produce%20electricity.&text=Once%20the%20snow%20starts%20to,is%20able%20to%20occur%20again.

Harrington, Rebecca. "This Incredible Fact Should Get You Psyched about Solar Power." Business Insider, Business Insider, 29 Sept. 2015, www.businessinsider.com/this-is-the-potential-of-solar-power-2015-9.

Jevahirian, J. "Benefits of Solar Power for Schools and Universities." *Michigan Solar Solutions*, Michigan Solar Solutions, 20 Nov. 2019, www.michigansolarsolutions.com/news/benefits-of-solar-power-for-schools-and-universities.

Manger, Morgan. "Student-Led Sustainability Projects Expanding." *The Georgetown Voice*, 2 Feb. 2012, georgetownvoice.com/2012/02/02/student-led-sustainability-projects-expanding/.

McLean, Caitlin. "GU to Power Over Half of Campus With Energy Sourced from Solar Plants." *The Hoya*, 13 Nov. 2020, thehoya.com/gu-to-power-over-half-of-campus-with-solar/.

Meyer, 2014. "A Case Study: Solar Panels at Boston College." *Boston College's GE Environmental Studies Senior Seminar.* https://www.bc.edu/content/dam/files/schools/cas_sites/envstudies/pdf/Student%20Research/8_Solar_Panels_at_Boston%20College_paper.pdf.

NASA. (2020). A degree of concern: Why global temperatures matter - climate change: Vital signs of the planet. Retrieved fromhttps://climate.nasa.gov/news/2865/a-degree-of-concern-why-global-temperatures-matter/#:~:text=Polar%20Ice%20Sheets%20%E2%80%94%20The%20report,over%20a%20time%20scale%20of.

NREL. (2021). National renewable energy laboratory (nrel). Retrieved from https://www.nrel.gov/.

Pritchard, Justin. "Borrow for Green Improvements and Repay on Your Tax Bill With PACE." The Balance, 1 Oct. 2020, www.thebalance.com/pace-loans-financing-for-upgrades-4124071.

PV Watts. PVWatts Database. Retrieved from https://pvwatts.nrel.gov/.

Resnick, Maya. "How to Fund Your Solar Project as a Nonprofit." Independent Power Systems, 16 Mar. 2020, www.solarips.com/about/blog/2020/march/how-to-fund-your-solar-project-as-a-nonprofit/.

Richardson, L. (2019) "Solar Options for Schools." *EnergySage*, US Department of Energy https://news.energysage.com/solar-panels-for-schools-how-k-12s-and-universities-can-benefit-from-solar/.

Richardson, L. (2021). How long do solar panels last?: Energysage. Retrieved from https://news.energysage.com/how-long-do-solar-panels-last/.

RStudio Team (2021). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com/

Solar Power Authority Staff. "Top 10 US Solar-Powered Universities." *Solar Power Authority*, www.solarpowerauthority.com/top-10-u-s-solar-powered-universities-and-how-theyre-doing-it/.

EnergySage "Types of Solar Leases and Power Purchase Agreements.", 8 Oct. 2020, www.energysage.com/solar/financing/types-of-solar-leases-and-ppas/.

U.S. Energy Information Administration (EIA). (2021). Frequently asked Questions (faqs). Retrieved from https://www.eia.gov/tools/faqs/faq.php?id=97&t=3#:~:text=How%20much%20electricity%20does%20an,about%20877%20kWh%20per%20month.

Williamson, Isobel. "UW Solar Illuminates Student-Led Sustainability Initiatives." *The Daily of the University of Washington*, 22 Feb. 2019, www.dailyuw.com/science/article_2ebf858c-358f-11e9-a7fb-dfd7f2c09225.html.