Designing Rooftop Solar Arrays For WPI's Campus

An Interactive Qualifying Project submitted to
the Faculty of Worcester Polytechnic Institute as a partial
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Abstract

The objective of this research project is to create a plan to install solar arrays on WPI's campus. This is important because the Earth is being destroyed by carbon emissions from nonrenewable energy sources like natural gas. Also, Massachusetts has been restricting carbon emissions from private entities in recent years, so using solar panels is a way to reduce our carbon emissions. An IQP done in 2017 had a similar objective statement . They designed 12 arrays for different buildings, parking lots, and parking garages and those arrays could produce 7% of WPI's electricity consumption for FY16 (Brest et al. 2017).

My project designed two arrays, one for Olin Hall and one for the Recreation Center. They were designed using Helioscope, an online solar array design program owned and operated by Aurora Solar. After the arrays were designed in Helioscope, their total production of electricity over a 25 year lifetime was found with a 0.7% degradation in equipment each year. Their carbon offset was found using Hosenuzzman et al.'s report on the environmental impact of solar panels (Hosenuzzman et al. 2014). The cost of the arrays was found using NREL's report on the cost of building solar arrays for Q1: 2020. Figure 21 on page 34 was used mostly for finding the cost (Feldman et al. 2021).

The two arrays together would produce 514.84 MWh in their first year in operation and 11,845.69 MWh of electricity over 25 years. The arrays would offset 5.69×10^6 kg of CO_2 over 25 years and that's the equivalent of burning about 440,000 gallons of gasoline. The upfront cost of the Olin Hall array is estimated to be $117,249 and the Recreation Center would be $571,040. The savings on the electricity bill over the lifetime of the arrays would be $3,838,003.16 and the payback period would be less than 6 years.

The short payback period for the cost of the arrays, high ROI on the electricity savings, and the large amount of rooftop space to install the panels makes the designs appear to be feasible to implement. Installing solar arrays would benefit WPI by helping the school's progress towards goals set in the 2020-2025 Sustainability Plan and it can give people a more favorable view of WPI. Also, the reduction in carbon emissions will slow the impact of climate change worldwide. WPI's large network of connections could influence more people to invest in solar energy too.

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Abbreviations

Abbreviation:	Full Term:
AC	Alternating Current
CO_2	Carbon dioxide
DC	Direct Current
FY__	Fiscal year __
GDP	Gross Domestic Product
GHG	Greenhouse gas
KWh/FTE	Kilowatt hour per full-time equivalent
MWh	Megawatt-hour
ppm yr^{-1}	Part per million per year
ROI	Return-on-investment
SIMAP	Sustainability Indicator Management & Analysis Program
VFD	Variable frequency drive
WPI	Worcester Polytechnic Institute

1. Introduction

1.1 Objective

The objective of this research project is to create a plan to install solar arrays on WPI's campus.

1.2 Rationale

Since The Industrial Revolution in the 18th century, our usage of fossil fuels as a main power source has led to extreme environmental pollution. The acceleration of atmospheric pollution from this is frightening, as it has been one of the main contributors to the degradation of the ozone layer, exposing Earth to ultraviolet radiation. It's also heating up the planet, melting ice caps, creating droughts, and affecting the planet's wildlife (Liang et al. 2022). Millions of people and organizations have already started using solar arrays for their personal use. However, WPI does not use solar panels to produce electricity, instead getting energy mainly from burning fossil fuels (Luiz 2022). WPI is a STEM-based college, but its carbon footprint has stayed about the same for the past 12 years. Middlebury College is a liberal arts school in Vermont and it has been carbon-neutral since 2016 (Middlebury College Sustainability 2023). It's hypocritical that a liberal arts school can be better at reducing its carbon footprint than a college based around teaching engineering. This should not stave WPI away from investing though, because its effect on the planet can be reduced by installing solar panels and being more sustainable.

While it is important to consider the moral argument of saving the planet, another reason to install solar panels is to stay within guidelines set by the Massachusetts government. The government of Massachusetts released an environment protection plan in 2022 and it suggested that businesses and private entities "increase… development of renewable resources like… solar photovoltaics" (GWSA Implementation Advisory Committee 2022). Stricter guidelines for emissions will be coming soon in the state.

A way to reduce WPI's impact on the environment and to stay within government regulations is by investing in solar energy . Burning fossil fuels in place of renewable energy is destroying the planet and while WPI represents a small part of the world, it has a moral obligation to protect it.

1.3 State-of-the-art

1.3.1 2016-2017 IQP designing a solar array for campus

There was a previous IQP to create a solar panel array for WPI's campus. This IQP designed 12 separate designs of several different buildings and parking lots. The total design could have accounted for 7% of WPI's electricity consumption in fiscal year 2016 and could have offset an average of 1 million kg of carbon emissions per year, totaling 25 million kg with the assumption that the solar panels would last for 25 years. The group accounted for 0.5% equipment degradation each year as well.

The group used four different pricing models to estimate the price of the system. The first was a direct buying of all equipment. This had the steepest upfront cost but had the largest ROI. The next was leasing the panels, which would make WPI lose money for the first 7 years before a profit would be made. After another year, the total loss would be recovered from the profits. The third method was getting a loan to pay for the panels. The ROI is the highest of all payments for the first 10 years, but levels off after that. The final method was a Power Purchase Agreement (PPA). A PPA is an agreement between the installers of the panels and the school where the panels themselves are owned by the company, but WPI would purchase all the power generated by them. This would have no upfront cost for the installation, but it had the lowest ROI out of all the payment methods (Brest et al. 2017).

1.3.2 Cost analysis of solar arrays

The National Renewable Energy Laboratory (NREL) is a government-funded group whose purpose is to design, test, and study new and old renewable energy projects. In 2021, they published a report analyzing the cost of solar voltaic panels in the United States with several different power outputs, designs, and locations. For the sake of this paper, rooftop commercial arrays were researched.

The average cost of noncommercial rooftop arrays depends on the power output of the system, averaging to $1.72/W. This is an all-encompassing cost, including the cost of equipment, hired labor, profit for the company installing them, sales tax, permits, and more. The panels themselves cost $0.41/W and the inverters cost $0.12/W. Inverters convert the DC power that the panels generate into AC, which is what the power grid uses. All other parts used cost $0.65 - $0.88/W. The national average cost of hiring an electrician is $27.47/hour and laborers cost $18.17/hour.

The cost of installing these arrays have dropped recently and their performance has increased. In 2010, arrays used to cost $5.57/W, inverters were 95% efficient, and arrays degraded by 1% annually. In 2020, it cost $1.72/W for the array, inverters were 98% efficient, and arrays degraded by 0.7% annually. The cost to install arrays is projected to continue decreasing in the future (Feldman et al. 2021).

1.3.3 Solar array design software

Aurora Solar is a company that creates solar array design software. They own several different versions of this software, with one being Helioscope. This software uses information from patents of solar panels, batteries, and many other parts to set up arrays. The program takes into account the hours of sunlight, average cloud cover/rainfall, and many other factors to give the most accurate statistics about the performance of a given array.

After a model is created in Helioscope, a report is generated with pertinent statistics and figures. Some of these are the monthly production of electricity, the loss generated by system hardware, the optimal conditions for running the system, and more.

1.3.4 WPI focuses a lot on general sustainability

WPI has 149 sustainability-related courses (WPI Sustainability 2021). These are categorized between "sustainability-focused" and "sustainability-inclusive." Sustainability-focused courses "are those for which the primary focus is on sustainability and(or) understanding one or more major sustainability challenges" (Mathisen 2023). Some examples of these are Resilient Infrastructure for a Changing Climate, Energy Challenges in the 21st Century, and Adventures in Sustainable Urbanism. Sustainability-inclusive classes are not devoted to sustainability, but have units or material related to it. Some courses like this are Fuel Cell Technology, Global Planning and Logistics, and Fermentation Biology (WPI Sustainability 2021).

Also, WPI pushes a message for sustainable living and creating a better future. The front page of WPI's website says "At WPI you'll use an education built around science, engineering, and the humanities to create solutions to problems faced by real people—both here at home and around the world." Using this statement as a guideline, it shows the school's interest in solving a lot of the wasteful practices of the world (WPI 2023).

Additionally, WPI released a Sustainability Plan for 2020-2025. This included a 25% increase in renewable energy used on campus in place of burning fossil fuels. Right now, WPI claims that 20% of the electricity used is sourced from renewable energy, so they're planning to increase that to 25%. Also, it called for a 10% reduction of energy use in KWh/FTE. Dozens of other tasks had been listed as well, ranging from additional spending on sustainable food sources to more diverse sustainability teaching for the students (WPI Sustainability 2019).

1.3.5 Other schools' carbon-neutrality efforts and progress

Several other schools in New England have set forth plans to cut their carbon footprint and have been acting on them since their release. In order to make sure WPI's attempts at carbon-neutrality are not ill-advised, it is a good idea to see what other schools nearby have done and what has been working for them. Three schools that are important to investigate are Middlebury College, The College of the Holy Cross, and Clark University.

Middlebury College is a liberal arts school in Middlebury, VT that started reducing its carbon footprint in 2001. The most substantial contribution to its reduction efforts comes from the establishment of an on-campus biomass gasification plant in 2009. The plant provides most of the school's heating and about 20% of the electricity for the school now, and is completely carbon neutral. This completely replaced the burning of oil to heat the buildings for campus. The biggest contributors for the school's carbon footprint in FY21 was natural gas burning and travel by students and employees. Middlebury College counts all travel towards their footprint;

employees commute to work, student's commute and plane tickets to the school, and any travel done by the campus' vehicles (Middlebury College Sustainability 2023).

They reached carbon-neutrality in 2016 by quantifying carbon-credits from the land owned by the school. Since 2010, Middlebury College has cut their total carbon footprint down by about 60% when the carbon credits aren't involved, going from about 19,000 tons of CO_2 in FY10 to about 7,000 tons in FY21. In that same time period, WPI has reduced their emissions by about 6% and is nowhere near carbon-neutrality (Middlebury College Sustainability 2023).

The College of the Holy Cross is a Catholic college in Worcester, MA, located about 3 miles away from WPI. In 2009, the college released a Carbon Neutrality Plan that outlines how they will reduce their carbon footprint. Some of the efforts made in the years since the plan were upgrading the lighting and temperature controls in buildings, repairing leaks in the steam pipes that heat the school, and encouraging the reduction of energy use to students and staff. All buildings constructed on campus are required to be at least LEED Silver certified as well (Merrill et al. 2009).

SIMAP, a campus-aimed sustainability-oriented monitoring tool for carbon and nitrogen emissions, continuously updates with the ecological footprint of Holy Cross. Holy Cross has been exceeding their yearly goals of reducing their footprint every year since 2007. They have cut their emissions by 51% in that time (SIMAP 2015) and plan to be completely carbon neutral by 2040 (Merrill et al. 2009).

Clark University is a private college also in Worcester, MA. The school plans on being carbon neutral by 2030. Some things they have implemented and are planning to bring in are changing all lights and outlets to high efficiency ones, there are plans to renovate the central boilers of the school, and rerouting all cooling for the school to a central chiller (Bort et al. 2014). The college is also installing VFDs for buildings, changing the amount of energy put into the building depending on how many people are occupying it. The average fuel economy of university-owned vehicles was 35.5 mpg in 2015. Many other initiatives have been started or finished as well. The school hit their goal for emissions reduction for 2015 four years early, showing that their efforts towards carbon-neutrality are working significantly better than expected (Brooks et al. 2012). Sierra Club is a sustainability-focused and advocacy organization that ranked Clark as the 17th "greenest" college in America.

In all, WPI is lagging greatly behind other schools in the area and around New England. All of the schools listed above have smaller student populations and less funds that could be dedicated to reducing their carbon footprint. It should be easier for WPI to implement changes like those above since they can base their plans off those other schools have done.

1.3.6 Carbon dioxide emissions are at an all-time high

In 2021, the planet emitted 37.12 billion tonnes of CO_2 into the atmosphere and The United States accounted for 5.01 billion of that. Per capita, America is one of the worst polluters of the atmosphere and has continuously increased its impact on the planet. Since 1950, the country's emissions have increased six-fold and the only year where there was a decrease in CO_2 emissions was in 2020 (Ritchie et al. 2020).

Another study was released analyzing the rate of emissions using the 2021 statistics and it found that there is a 67% chance that the global temperature will increase by 1.5℃ within the next decade. The production of electricity by burning oil, coal, and natural gas contributed 657 megatonnes of CO_2 in 2021 and it is projected to continue to climb. This is because of the lack of large-scale investment into renewable energy. The study estimates that in order for the global temperature to increase by 1.5 ℃, 400 gigatonnes of CO_2 needs to be emitted and for an increase of 2 ℃, 1,150 gigatonnes of CO_2 is required. Even with the dramatic drop in emissions for 2020, that year still consumed 8.3% of the carbon budget for a 1.5 ℃ increase (Liu et al. 2022).

1.4 Approach

Using the state-of-the-art, the student will design a solar panel array, but make the array more adaptable for the future than what was made in the 2016-2017 IQP. This way, the school can use the plan to create a modified version with whatever specifications that they would like. This will also open the opportunity to move the arrays onto different buildings, add more to what was planned, or even integrate the design into new buildings that will be constructed in the future.

We can also use the data to determine what the construction of the plan would do to offset WPI's emissions and the global emissions. Doing this can shed light on how much of an impact WPI has on the Earth. The information collected about the other schools can also be used to suggest other improvements to WPI's carbon-neutrality efforts beyond just solar panels.

The average price of electricity for Massachusetts has risen since the report in 2017. The average cost of electricity in New England for 2017 was $.195/KWh but in January 2023, it was $.324/KWh (Bureau of Labor Statistics 2020). This report will use the new cost of electricity for cost analysis and give a more accurate view on how it could save WPI money.

2. Methods

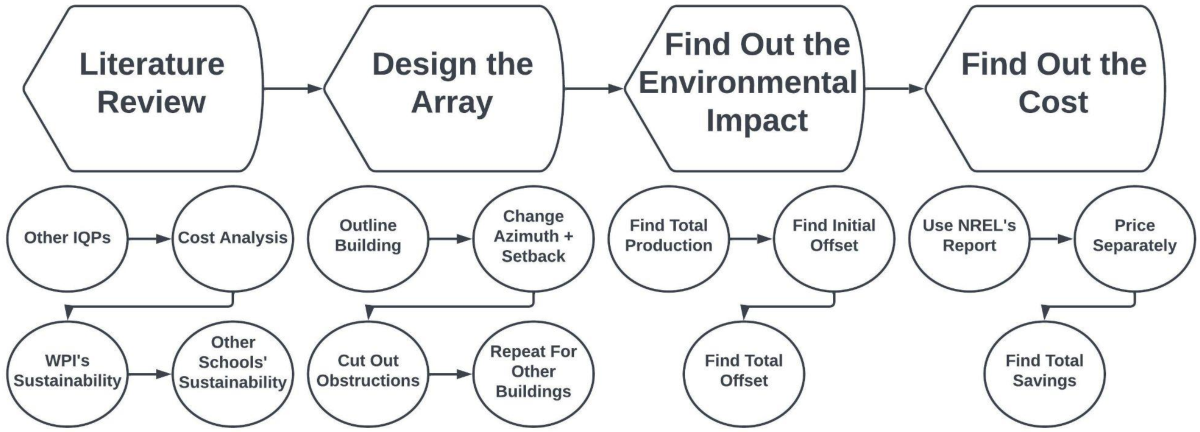

Figure 2.1: This is a flowchart condensing the Methods section into a smaller format. All bubbles in this chart are explained below. This was created using Lucidchart's online flowchart creator.

The first step I took was to conduct a literature review of the subject and any important information, starting with previous IQPs designing solar arrays for WPI. The objective of researching these was to see what has already been done specifically about designing solar arrays at WPI and possibly improve on their designs. There were two recently, one in 2017 (Brest et al. 2017) and another in 2019 (Bernier et al. 2019) and both can be accessed through the WPI Library website.

I researched the cost involved in installing a solar array. Since prices of solar arrays have gone down and the cost of electricity has gone up, it was important to get updated statistics on this. I used NREL's U.S. Solar PV System Cost Benchmark: Q1 2020 which can be accessed through their website or by searching the title of the report on Google.

I researched WPI and its sustainability efforts. This is to gauge whether WPI would be interested in installing solar panels. I read the 2020-2021 Sustainability Report and 2020-2025 Sustainability Plan published by the Office of Sustainability at WPI, both reports can be accessed through their website, wpi.edu/offices/sustainability.

I researched current carbon emissions for the world. The purpose of this is to see how much of an effect WPI has on the rest of the planet. The articles cited in this report can be found by searching "Current Carbon Emissions" in Google Scholar, adjust the search criteria to "Since 2019", and all sources used were in the first 3 pages of the search results.

I researched other colleges in New England and their sustainability efforts focusing on Middlebury College, The College of the Holy Cross, and Clark University. The purpose of this is to see what other schools have done for sustainability and whether WPI could emulate their actions. For Middlebury College, I searched "Middlebury College Sustainability" in Google and looked through their website. All the data used in this report about the school was from there.

For Holy Cross, I searched "Holy Cross Carbon Commitment" and read their "2009 Carbon Neutral Plan" and their SIMAP Report on emissions. For Clark, I searched "Clark University sustainability" and read through their Sustainability Benchmark for FY 12 and their 2014 Climate Action Plan. Both pages cannot be found through Google or on their Sustainability website anymore, but they can be accessed through the links in this report's references.

I used Helioscope to design the solar arrays for Olin Hall and the Recreation Center at WPI. These two were chosen because Olin Hall has a slanted roof and the Recreation Center has a flat roof. This gives an example of each roof type if this report were to ever be used or expanded on. Helioscope was chosen to design the arrays because the program is easy to use and it generates a lot of data on the arrays. The first step is to create an account or use a previously created account. I started a new design and outlined the top of the roof for the Recreation Center. I adjusted the azimuth of the design to 180° and set a 4 ft setback from the edge of the roof. I made cutouts around the solar thermal panels and the AC units on the roof. I saved the design and generated a report for it. I created a new design and started at Olin Hall. Olin has slanted roofs, so each side needed to be outlined separately. Also, the azimuth for each of the sections were adjusted to make the panels parallel to the edge of the roof.

I found out the environmental impact of installing the arrays. The objective of this is to find out whether or not a monetary investment will be worth it. The first step of this is to see how much electricity the arrays would produce. The NREL's report states that the average lifetime of a solar array is 25 years and the arrays' efficiency reduces by 0.70% per year (Feldman et al. 2021). Using these numbers, the total production over the lifetime of the array is:

$$Total\ Production = \int_{1}^{25} (Initial\ Production * e^{-.007x}) dx$$

The average solar panel array mitigates 1 kg of CO_2 being emitted for every 2 KWh of electricity produced (Hosenuzzman et al., 2014). The first year's electricity production of the array can be used to calculate the initial CO_2 offset, represented by C_1. The total CO_2 offset can be found using:

$$Total\ CO_2\ Offset = \int_{1}^{25} C_1 * .993^{t-1} dt$$

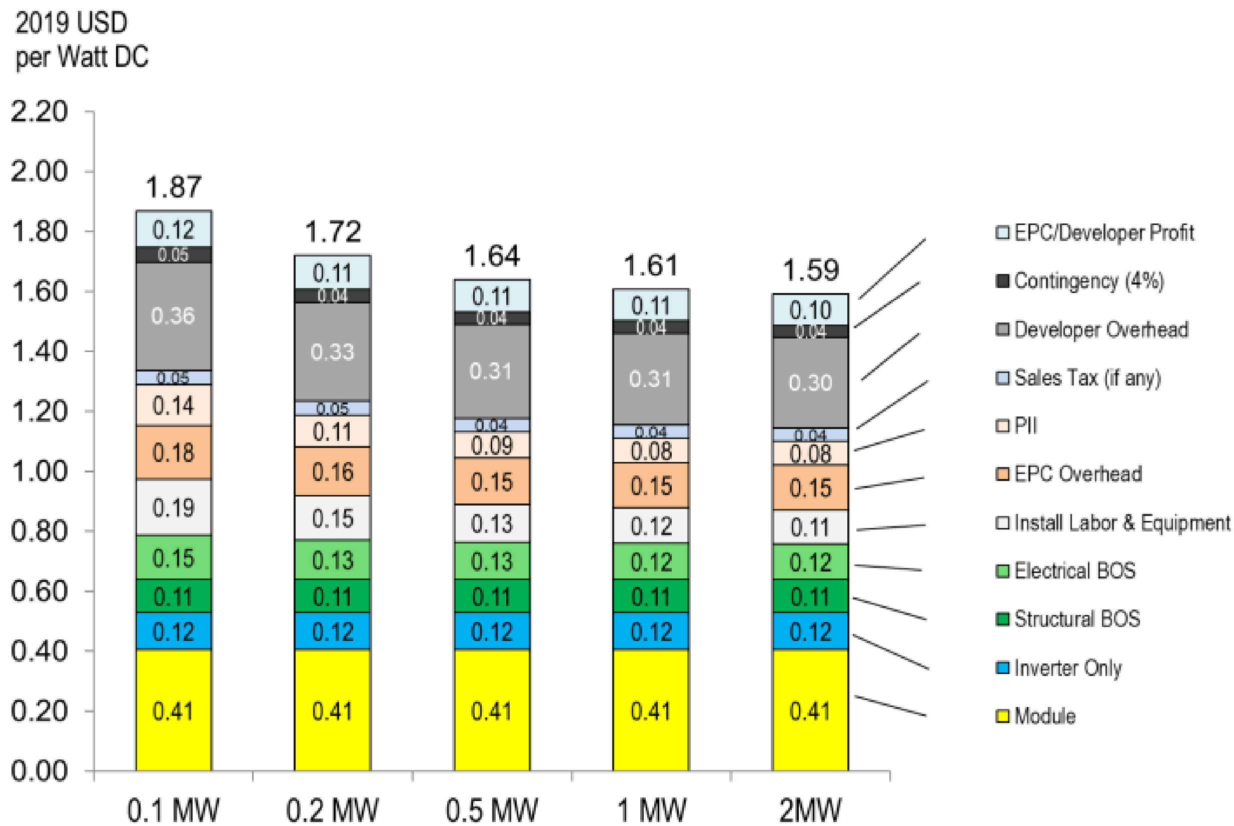

Figure 2.2: This is a bar graph from NREL's U.S. PV System and Energy Storage Cost Benchmark showing the prices for different power outputs of rooftop solar arrays. This was used for the cost analysis of the solar arrays (Feldman et al. 2021).

Finding the price of the arrays was done to see if installing the arrays makes sense financially. I assumed that the buildings would need to be separate in cost. They are too far apart for the two systems to be connected and connecting them would reduce efficiency and drive up the cost. The two systems would have different prices per watt because they are separate. The Olin Hall array was estimated to cost $1.87/W and the Recreation Center array was estimated to cost $1.72/W. These are not exact values found from the NREL's report, but it was estimated from Figure 21. After the price was found, I used the average cost of electricity per KWh in New England and the amount of electricity generated by the array to see how much money would be saved on the electricity bill if the array was installed.

3. Results

The design made for Olin Hall has the capacity to produce 71.24 MWh of electricity in its first year. Over the lifetime of the panels, the Olin Hall will produce 1,639.12 MWh of electricity, when accounting for a 0.7% degradation of equipment. The design for the Recreation Center can generate 443.6 MWh of electricity in its first year and 10,206.56 MWh over its lifetime as well. The total production of both plots is 11,845.69 MWh over 25 years.

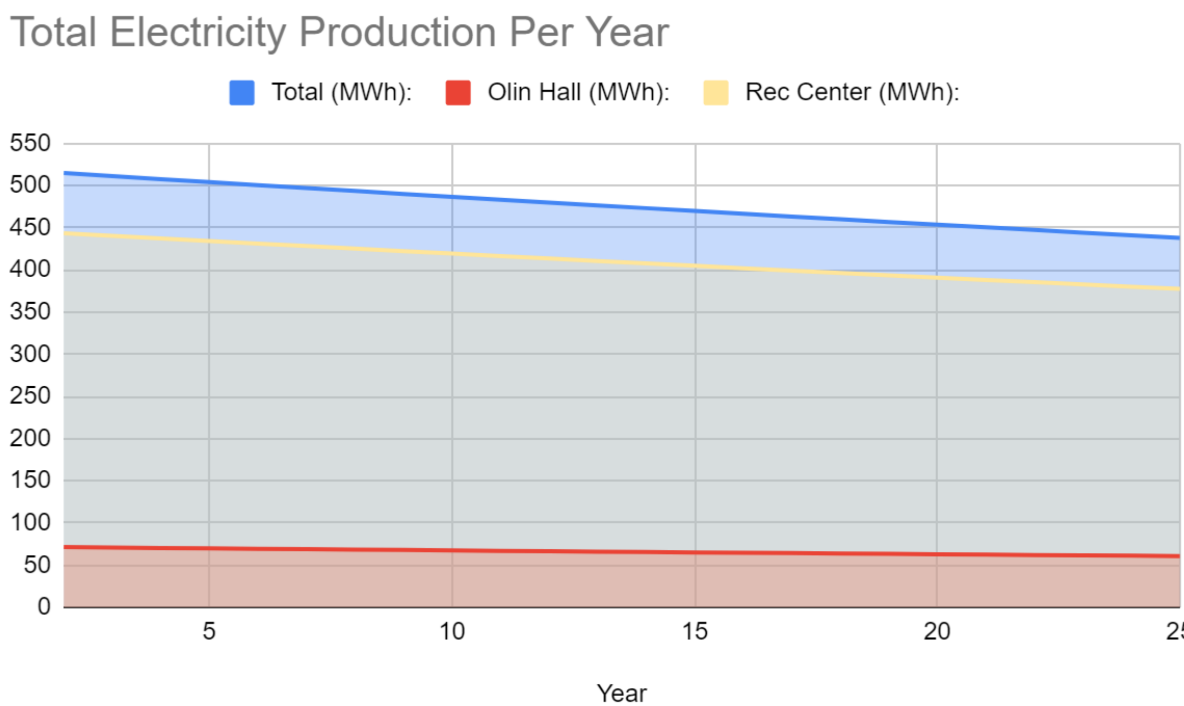

Figure 3.1: This is a graph created to show the production of electricity each year for each design and also for the system as a whole.

The total emissions offset where C_1 is the carbon offset for the first year of use, the array offsets 5.69×10^6 kg of CO_2. This is the equivalent of burning about 439,000 gallons of gasoline (Yu et al. 2018). That much gasoline could power a 2022 Toyota Corolla for 16.26 million miles of driving. A graph of the carbon emissions offset would look similar to Figure 3.1, with the Recreation Center array offsetting most of the CO_2 emissions.

The upfront cost of the Olin Hall array is estimated to be $117,249. The upfront cost of the Recreation Center array is estimated to be $571,040. Both of the arrays would cost $688,289. The two arrays being separate increases the overall cost because the Olin Hall array was estimated to cost $1.87/W instead of the Recreation Center array's cost of $1.72/W. The increased cost is because of the Olin Hall array's lower power output and adjusted costs based on the NREL's report.

The Olin Hall array would save WPI $23,081.76 on its electricity bill in its first year in operation and $531,076.34 over 25 years. The Recreation Center array would save $143,726.40 in its first year and $3,306,926.82 over 25 years. The total savings on electricity would be $3,838,003.16 if the two systems were installed. These numbers account for the 0.7% degradation of equipment each year. The payback period for the arrays is less than 6 years.

4. Discussion

The 2017 IQP designed 12 arrays which could produce 1.97 million KWh of electricity every year. This was 7% of WPI's electricity use in FY16. The 12 arrays were on top of buildings, canopies over parking lots, and canopies over East Hall Garage and Gateway Garage. The array over Boynton Lot produced the most electricity and had the highest ROI out of all the arrays.

The Boynton Lot array's price was given at $927,371. This array is no longer possible to build in its 2017 design because Unity Hall was built on the southern portion of the parking lot. It would need to be modified to the parking lot's new shape before installation. The Boynton Lot would have produced over $2 million in profits from its electricity cost savings. If all 12 arrays were installed, the report claimed to offset 25 million kg of CO_2 over the lifetime of the arrays as well (Brest et al. 2017).

Installing solar arrays on campus appears to be feasible for WPI, based on this study. WPI has 70,000 m^2 of rooftop, parking lot, and parking garage roof spaces. Not all of it is suitable for solar panels, but a large portion of it is suitable (Brest et al. 2017). Rooftop appliances, walking paths for Facilities work, and other things take away from the space available for solar arrays. The solar arrays designed in this report have a high ROI and a short payback period. The arrays designed in this report can also be expanded on. Using Helioscope and NREL's report makes it easy to build on the two designs presented here. Additional arrays can be designed as well for other buildings.

Installing these solar arrays would help WPI in a lot of ways. It can show the school's commitment to become carbon-neutral. WPI has released two separate sustainability plans in the past 10 years with the 2020-2025 Sustainability Plan building off the goals set in the previous one. All the progress made in the years before were built on, setting new and ambitious goals for the next five years (WPI Sustainability 2019). If these arrays were installed, they could greatly reduce WPI's carbon footprint and could set more ambitious goals by the time the next sustainability plan comes out. Objective O1.2, Tasks 1-3 in the 2020 Sustainability Plan are directly related to solar energy, wanting to reduce energy consumption per person on campus and invest in more renewable energy One of Middlebury College's biggest points for incoming students and investors is that they are carbon-neutral. If WPI was carbon-neutral, they could push this same point and bring in more students.

The arrays would save WPI money as well, saving millions on the electricity bill over the lifetime of the arrays. If the upfront cost of the panels is too much for the school, they could look into taking out a loan to pay for them. The payments on a loan could be less than the amount of money saved on electricity purchasing too. WPI could look into installing heated solar panels, which would save money on the labor of clearing off the panels after a snow storm. They could save from damage as well, if a heavy snow storm would have broken the panels. This could make the cost of installing the panels more expensive because of the additional labor and equipment required to put them in.

Installing the arrays would help the world's climate. WPI is home to thousands of people for eight months every year. Solar panels could reduce these people's environmental impact. Also, WPI has a large outreach potential. Its thousands of alumni, network of employers, and reputation could influence other people and groups to invest in solar energy.

5. Conclusion

How feasible is it to install a solar array at WPI?

- The payback period is 6 years.
- There is plenty of roof space that the arrays can be installed on.

What would a solar array do for WPI?

- They could save WPI almost $4 million over 25 years.
- Increase WPI's progress in their Sustainability Plan for Objective O1.2, Tasks 1-3
- Give people a more favorable view of WPI

How would a solar array at WPI impact the world?

- Would reduce the school's emissions by 5.78×10^6 kg of CO_2, slowing climate change
- Could motivate others to invest in solar energy

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7. Appendix

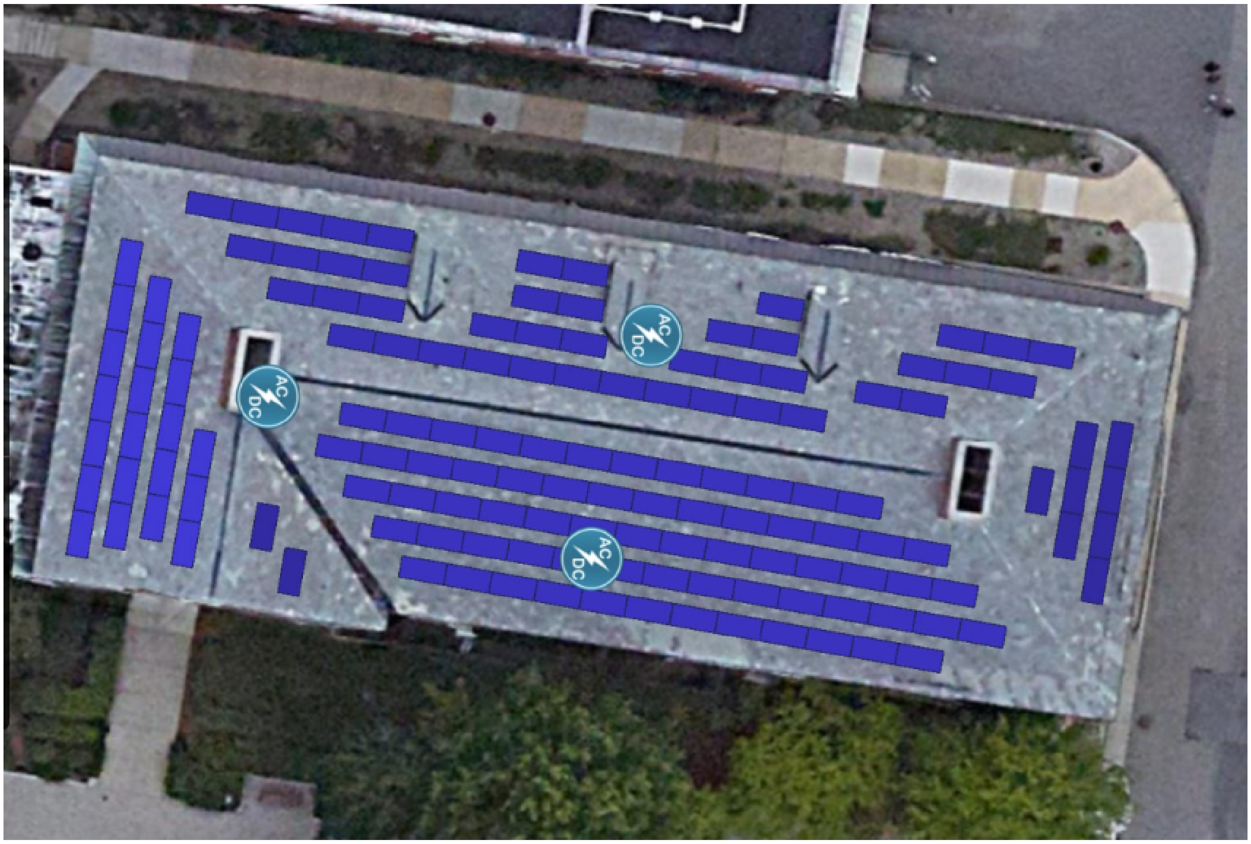

Figure 7.1: Design of the solar array on Olin Hall created in Helioscope. This includes a buffer-zone of 4 feet from the side of the building and 2 feet around the obstacles on the roof. This also accounts for the areas of the roof that get the most shade.

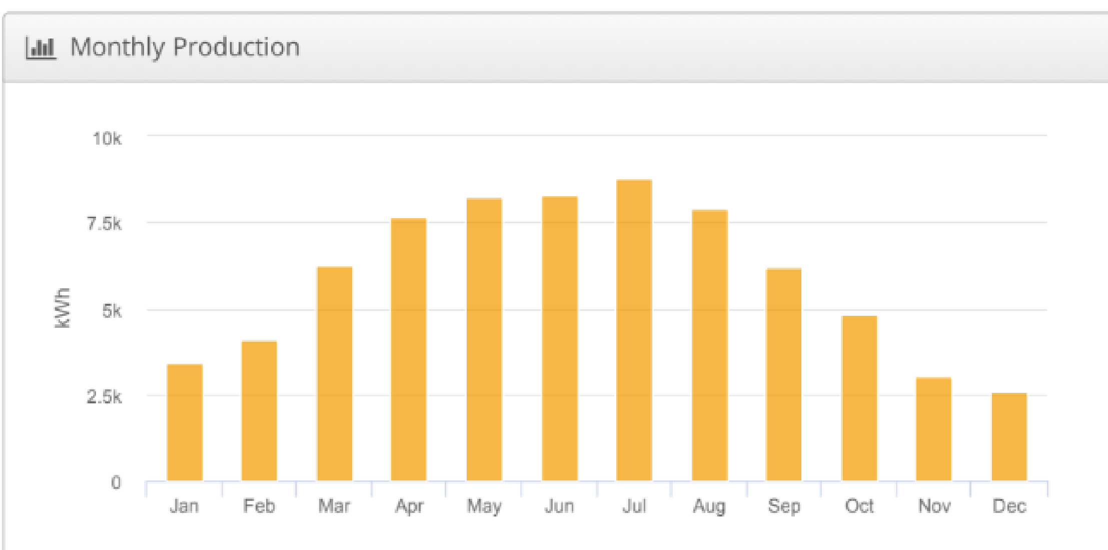

Figure 7.2: This shows the monthly production of electricity from the Olin Hall array. Higher amounts of energy can be generated in the summer because of longer sunlight hours and higher amounts of energy from the sun. This was generated by Helioscope.

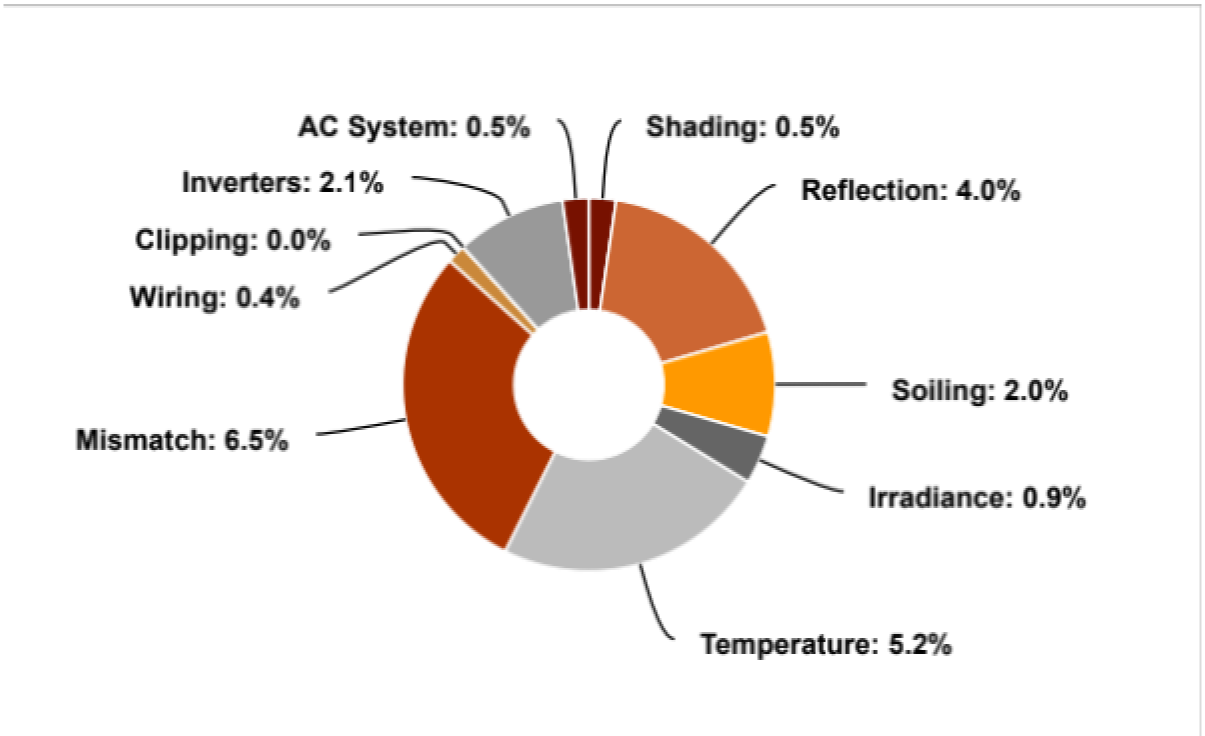

Figure 7.3: This is a pie chart showing the sources of loss for the Recreation Center's array. In total, 22.1% of the power generated will be lost for various reasons. This was generated by Helioscope.

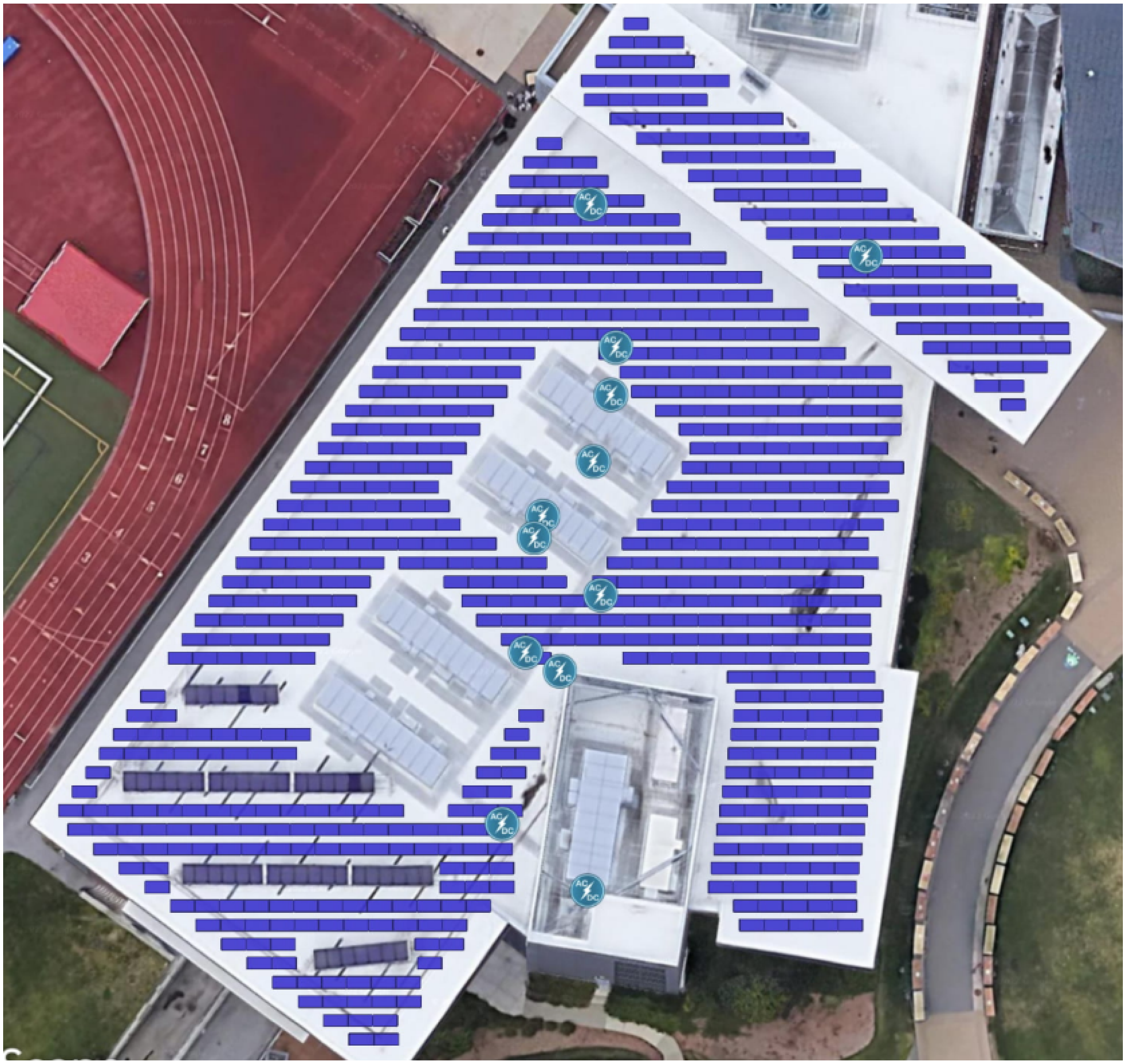

Figure 7.4: This is a picture of the solar array on the Recreation Center created in Helioscope. This covers almost the whole roof, except for the air conditioning units and the solar-thermal panels on the roof.

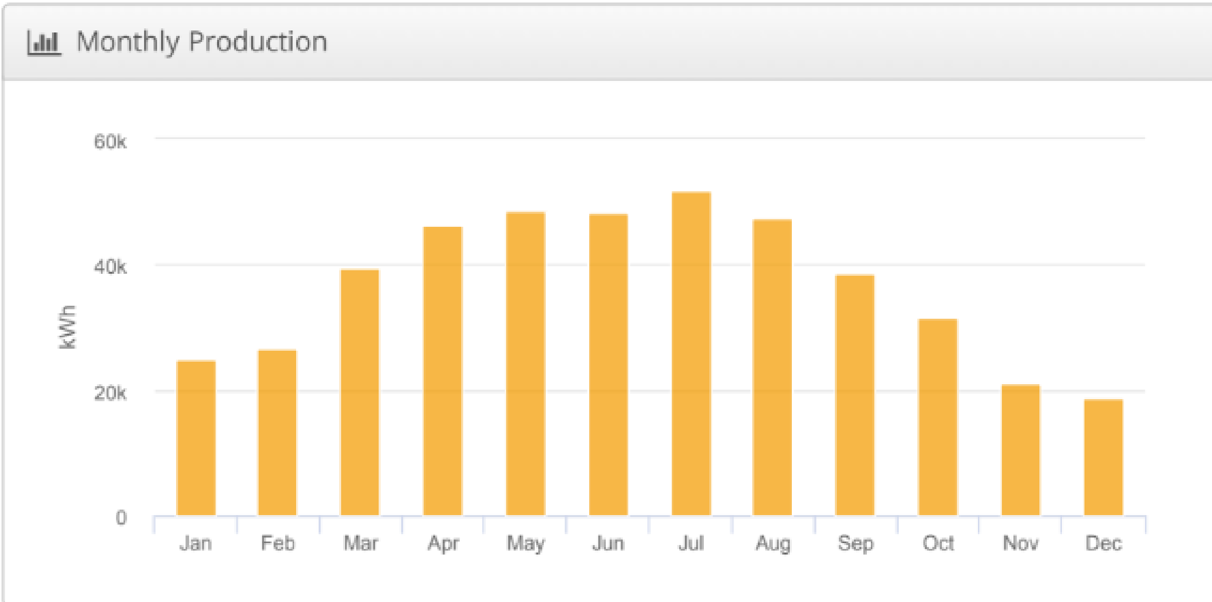

Figure 7.5: This is the monthly electricity production of the Recreation Center's solar array. This has similar trends to Olin Hall's system. This was generated by Helioscope.

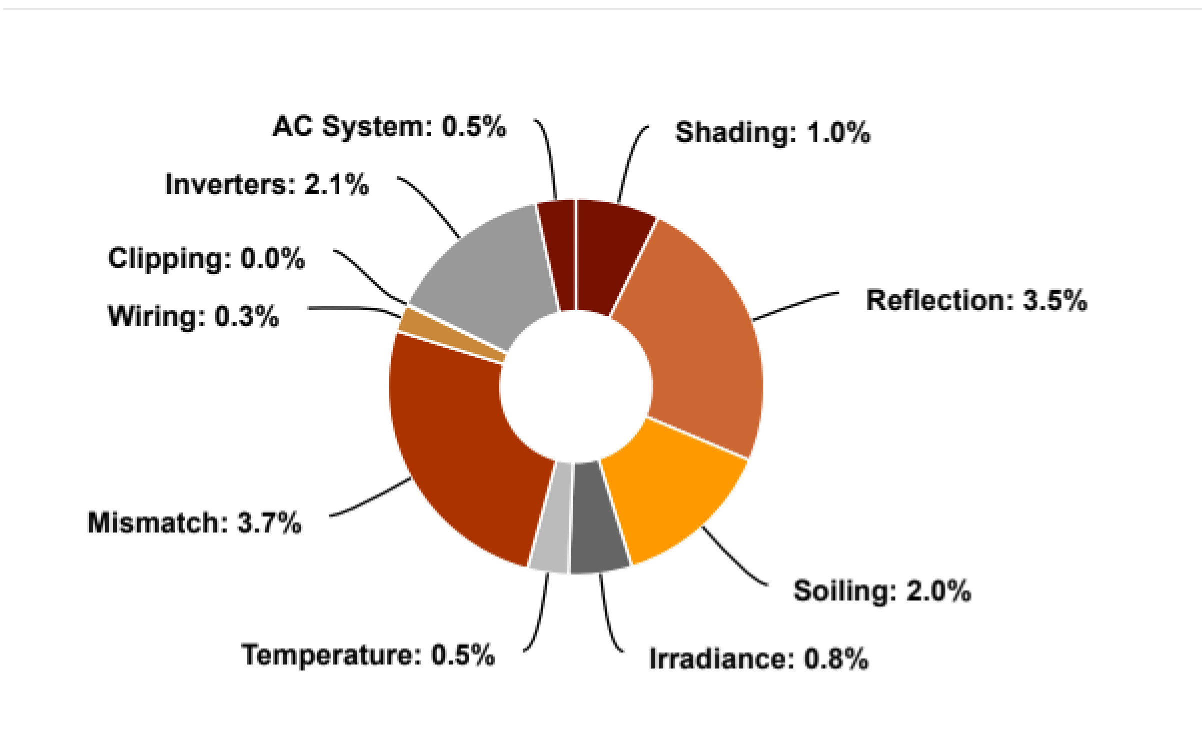

Figure 7.6: This is a pie chart showing the sources of loss for the Recreation Center's array. In total, 13.4% of the power generated will be lost for various reasons. This was generated by Helioscope.