Potential solar panel installation areas in NIU main campus

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1. Introduction:

In recent years, global warming due to excessive emissions of greenhouse gases has led to frequent extreme weather. Just one day before the recently concluded 2021 United Nations Climate Change Conference, the World Meteorological Organization released a report saying that 2015 to 2021 could be the hottest seven years on record, while warning that global warming caused by record atmospheric greenhouse gas concentrations threatens to have far-reaching consequences for current and future generations.[1]

The best way to control greenhouse gas emissions at this stage is to reduce the use of fossil fuels and replace them with clean energy. Although there are various types of clean energy, including wind, hydro, nuclear, and bioenergy. But for individuals and traditional business decision makers, solar energy is almost the only option, and the most convenient and least expensive option with the fastest return.

The purpose of this study is the following three points:

a. Investigate the feasibility of deploying solar panels at NIU.
b. Identify the most suitable buildings for deploying solar panels and the corresponding locations on their roofs.
c. Calculate the annual cumulative radiation intensity of these areas and the capital savings.

The results of the study show that the university could save millions of dollars annually in electricity costs just by installing solar panels on the south roofs of the

Human Resources Center, Milan Township School, and Chessick Practice Center buildings.

2. Data & Methods:

Data:

1. Illinois Height Modernization (ILHMP): LiDAR Data[2]

   Illinois Geospatial Data Clearinghouse

2. NIU's Building Polygon

   Phillip Young

Method:

i. **Preliminary research: Determine if the area where NIU is located meets the requirements for solar panel installation**

   An important task before discussing the installation of solar panels is to assess the feasibility of installing solar panels in the area, i.e., whether the solar panels will generate significant revenue in the area. One measure of an area's suitability for solar panel installation is to see if the area has an average of 4 hours of peak sun hours (PSH) per day. Illinois has a PSH of 3-4 hours, so it is assumed here that laying solar panels in NIU will create considerable benefits. See Table 1.[3]

ii. **Preliminary research: Overview the parameter settings of solar panel**

   Another preliminary task was to understand the parameters of the solar panels to determine the direction of the research and to ensure that the resulting solutions were more realistic. If the solution does not match the parameters of the solar panels, then the solution will not be implementable, or the cost estimate will be significantly different from the reality.

After studying the specifications of the solar panels, parameters such as panel size, photovoltaic conversion, maximum input power, service life and average annual performance loss are the main factors that affect the electrical energy calculation and cost estimation. The larger the panel, the smaller the volume ratio occupied by the frame and the smaller the total panel acquisition. For individual panels, the higher the photovoltaic conversion, the higher the maximum input power, and the lower the average annual performance loss, the more efficient the panels will be in utilizing solar energy, especially the peak radiation (if the maximum input power is low, then when the radiation intensity exceeds a certain threshold, the input power will no longer change i.e. the photovoltaic conversion rate decreases). In addition, the design life and the average annual performance loss represent the duration of return on a single investment. [3]

From Figure1, we can see that the maximum power of a typical commercial panel drops to 80% of the theoretical value after 25 years and decreases linearly. So it is reasonable to simplify the model to a 25-year lifetime with an average efficiency of 90% of the theoretical value in the subsequent calculations. Another information is that most commercial panels have a photovoltaic conversion rate between 15% and 20%, so we can simplify the model to the maximum input power divided by twenty percent when calculating the maximum light intensity of the panel (this calculation is more likely to underestimate the maximum light intensity when the panel is saturated with conversion, if the actual maximum light intensity is less than the maximum light intensity that can be received by the underestimated panel, then the panel can be selected. [4]

iii. **Mapping the solar map using data at winter solstice (Figure 2)**

Four tools need to be used in this section to complete:

- Create LAS Dataset

  Integrate the Lidar data downloaded from clearinghouse for each region to form a new overall layer;

- LAS Dataset To Raster

  This step is to change the point data of the Lidar into raster data, filling the gaps between the point data evenly with the values of the point data, so that there is no break between the data and the data.

- Extract by Mask

  This tool crops out portions of buildings from the raster data for the entire NIU main campus to create a new layer.

- Area Solar Radiation

  In identifying the installable area, since it is only a rough assessment and does not involve calculations that require high-precision data such as cost calculations, we can improve data processing efficiency by appropriately reducing the estimation accuracy. Here, the sub-by-hour discrimination rate is set to 200 cells, the time interval is once every half hour, and other parameters also keep their default values.

iv. **Filtering out non-compliant data and use the rest to create a polygon layer**

Four tools need to be used in this section to complete:

- Con (Figure 3)

  The function of this tool is similar to the frequently used select by attribute, but this tool is used for raster data analysis. In this case, the purpose of this tool is to select raster pixels with matching values according to set criteria. Since the purpose of the study is to provide a significant amount of energy to the building where the solar panels are installed, this means that even in winter, on the winter solstice, when the sun receives the least amount of energy, a significant amount of power is provided. However, since the solar radiation on the winter solstice is converted to a PSH much lower than the average value for the whole year, using a value greater than 60% of the maximum value of radiation received on that day is a more reasonable criterion in this case. That is, a roof capable of reaching 815 watt-hours per square meter on the winter solstice was selected as a potential installation area.

- Clip Raster

  In the previous step, the tool Con is to determines whether the value of the pixels is greater than 60 percent of the maximum value and assigns a new Boolean value. In this step we use the clip tool with the same extend of NIU’s Buildings to cut out the area with a specific Boolean value, in this case, the tested value is 1, so cut out all the parts with a Boolean value of 1 and create a new raster layer.

- Raster To Polygon (Figure 4)

  After cutting out the raster layer for the required area, it needs to be converted into a polygon layer. It has two uses, one is that in the following step, the polygon layer of this area can be used as a mask to clip the solar data we want, another use is to get the shape area automatically.

v. Building selection (Figure 5)

Three tools need to be used in this section to complete：

- Raster To Point

  Besides to create the mask, the other thing is to calculate how much of the total building roof area can be installed, since it doesn't make any sense to select a building with only a small area where solar panels can be installed.

  Because there is no tool that can quickly calculate the area occupied by the raster data. This experiment uses Raster to Point to achieve this purpose. The principle is that the data of each pixel is pooled into a single point, and if a pixel represents 1 square meter, then a building with 100-pixel will have 100 points after this operation. After this operation, the problem of comparing the number of pixels in the installed area to the number of pixels in the total area of the building's roof is transformed into comparing the proportion of eligible points occupied by each building in a building layer to the total number of points owned by that building, which is equivalent to other ways to comparing the proportion of installable area to the total roof area of that building.

- Spatial Join

  After converting every pixel to a point, they have to be joined to every building polygon. In this case, the data of the whole building raster and the eligible area raster are both needed for the operation to get the joint count for whole buildings and eligible area. This step provides the original data for the subsequent calculations.

- Calculate Field, Select and Export

  This step is to calculate the proportion of eligible points occupied by each building in a building layer to the total number of points owned by that building. In this case, we want to find buildings with 50% or more installed area, so after calculating the Available Area Ratio, we select the area with a value greater than 0.5 for output. And there are only 3 buildings meet the criteria:

  1.Human Resources Center

  2.Milan Township School

  3.Chessick Practice Center

vi. Installation area projection on selected buildings (Figure 6)

Select the corresponding layer (the eligible building layer & the installation area of the corresponding building) to overlay for schematic output.

vii. Calculate the annual solar energy reception and hourly peak reception

After identifying the buildings and corresponding installation areas where solar panels are to be installed, more accurate solar radiation calculations are needed to prepare for the subsequent selection of solar panels.

For this step, the Area Solar Radiation tool is used again, but for the parameter settings, the hourly calculation interval is reduced, the Calculation Direction, Zenith divisions and Azimuth divisions are increased, and the Diffuse model type is set to standard overcast sky for the calculation of the annual data.

When calculating the peak radiation reception, 11:56 to 13:56 on the summer solstice is selected for calculation, and the final result is divided by two to obtain the peak radiation reception.

The specific results are shown in Table 2.

viii. Solar panels selection based on the data obtained

After estimation, every square meter of solar panels at a maximum input power greater than 160 watts meets the installation requirements at a theoretical level. The following is an example of a panel for subsequent cost estimation, which is a real panel and is named as the "panel" in this report. Please refer to Figure 7 for the specific parameters of the solar panel.

ix. Cost and saving estimation

The model is simplified in this experiment,

$$the\ number\ of\ panel = \frac{the\ total\ installion\ area}{the\ area\ of\ a\ single\ panel\ set}$$

$$the\ result\ will\ rounded\ up\ to\ an\ integer\ if\ it\ is\ a\ decimal$$

$$\begin{aligned} The\ price\ of\ the\ installation \\ &= \text{the unit price of the panel set} \times \text{tax} \\ &\times \text{the number of panels purchased} \end{aligned}$$

$$\begin{aligned} The\ power\ saving \\ &= the\ annual\ radiation\ received\ in\ the\ installed\ area \\ &\times the\ photoelectric\ conversion\ rate\ of\ the\ panel \\ &\times the\ 25 - year\ average\ work\ efficiency \end{aligned}$$

$$\begin{aligned} Electricity\ savings \\ &= the\ power\ saving\ \times Illinois\ industrial\ electricity\ rate \end{aligned}$$

$Using\ a\ low\ value\ (see\ Figure\ 5\ for\ specific\ data)\ as\ the\ Illinois\ industrial\ electricity\ rate\ to\ estimate\ the\ minimum\ annual\ electricity\ savings.$

See Table 3 for specific results.

3. Results:

The theoretical analysis of this study resulted in three buildings that are most suitable for the installation of solar panels: Human Resources Center, Milan Township School, and Chessick Practice Center. If solar panels are installed on these three buildings, not only will they pay for themselves in the first year, but they will also save NIU millions in electricity expenses over the next 25 years.

See Table 3 for specific results.

4. Discussion:

    1. At the time of conducting this study, data analysis was performed using only the winter solstice data for subsequent analysis. We assume that the installation recommendations derived from the winter solstice converge with those derived from the yearly data.
    2. For the budget estimation, I only took into account the material costs, not the labor installation and maintenance costs, and all calculations in this study are based on theoretical values, so the annual returns will be less than the calculated values in this study.
    3. At the end of the study, I found that the deployment of solar panels on these three buildings alone could generate significant benefits, and I believe that the selection criteria can be appropriately lowered in the building selection section: because there are many buildings that receive more solar radiation per unit area than the selected buildings, but are discarded because the available area is less than 50% of the total roof area, and if these buildings are also included in the alternative list where solar panels can be installed, a greater benefit can be obtained in the final cost estimation.

4. By the same token, in addition to roofs, I have found that many buildings in NIU's subdivision have unobstructed south walls all year round, which can also generate great benefits if solar panels are installed. If these buildings are included, not only can we save a lot of energy, but NIU can also invest the electricity purchase cost into research equipment, scholarship distribution, and poverty subsidies to provide more students with better education, which increases NIU's competitiveness and helps to form a virtuous cycle.
5. There is one extremely important parameter that is not taken into account during the calculation: the slope of the roof. The Shape_Area used in the study is actually the projected area of these installable areas, and the true area should be divided by the cosine of the slope. However, given that the experimental results of this study have been severely overestimated due to the use of all theoretical values, the inclusion of this parameter would continue to exacerbate the error between the results and the actual values. In addition, factors such as the load-bearing capacity of the roof, whether the roof structure supports the installation of solar panels, and if so, whether the installable area analyzed in the study can be completely covered, were not taken into account, so the study data are for reference only.

5. Conclusion:

With this study, we demonstrated the potential of solar energy with three buildings at NIU's main campus in DeKalb. Installing solar panels is really a good investment for most households, especially those living in detached houses rather than apartments, and for institutions such as large supermarkets, factories, and schools that can benefit from a single investment for several years. In the long run, the use of solar energy both helps to reduce greenhouse gas emissions and saves a large number of homes and institutions a lot of money on their electricity bills. As technology advances, the commercial solar industry will see even greater innovation, with more efficient, longer-lasting photovoltaic devices becoming available. The variables discussed in the study, as well as the factors mentioned in the discussion that have not been considered in the study, can be considered by decision makers in homes and institutions when considering the use of solar energy. The tools involved in the entire study are described in detail in the Data and Method, along with the entire process, so that readers can apply the method to their own area of residence (and save money on consulting fees, of course).

6. References:

[1]: Anon (2021), State of climate in 2021: Extreme events and major impacts, World Meteorological Organization. Available from: https://public.wmo.int/en/media/press-release/state-of-climate-2021-extreme-events-and-major-impacts (Accessed 11 December 2021)

[2]: Illinois Height Modernization (ILHMP): LiDAR Data, Available from: https://clearinghouse.isgs.illinois.edu/data/elevation/illinois-height-modernization-ilhmp(Accessed 10 December 2021)

[3]: Hyder, Z. (2019), What is a peak Sun hour? what are Peak sun hour numbers for your state?, Solar Reviews. Available from: https://www.solarreviews.com/blog/peak-sun-hours-explained (Accessed 10 December 2021)

[4]: Q.PEAK duo L-G6 - Iconicnrg.com, Available from: https://iconicnrg.com/wp-content/uploads/2021/01/Q_CELLS_Data_sheet_Q.PEAK_DUO_L-G6.pdf (Accessed 10 December 2021)

[5]: Photovoltaic energy factsheet, Photovoltaic Energy Factsheet | Center for Sustainable Systems. Available from: https://css.umich.edu/factsheets/photovoltaic-energy-factsheet (Accessed 10 December 2021)

7. Tables:

Table 1: Average peak sun hours by state

Location	Peak Sun Hours (PSH)
Alabama	3.5 – 4
Alaska	2 – 3
Arizona	7 – 8
Arkansas	3.5 – 4
California	5 - 7.5
Colorado	5 – 6.5
Connecticut	3
Florida	4
Georgia	4 – 4.5
Idaho	4 – 4.5
Illinois	3 – 4
Indiana	2.5 – 4
Iowa	4
Kansas	4 – 5.5
Kentucky	3 – 4
Louisiana	4 – 4.5
Maine	3 – 3.5
Maryland	3 – 4
Massachusetts	3
Michigan	2.5 – 3.5
Minnesota	4
Mississippi	4 – 4.5
Missouri	4 – 4.5
Montana	4 – 5
Nebraska	4.5 – 5
Nevada	6 – 7.5
New Hampshire	3 – 3.5
New Jersey	3.5 – 4
New Mexico	6 – 7
New York	3 – 3.5
North Carolina	4 – 4.5
North Dakota	4 – 4.5
Ohio	2.5 – 3.5
Oklahoma	4.5 – 5.5
Oregon	3 – 5
Pennsylvania	3
Rhode Island	3.5
South Carolina	4 – 4.5
South Dakota	4.5 – 5
Tennessee	4
Texas	4.5 – 6
Utah	6 – 7
Vermont	3 – 3.5
Virginia	3.5 – 4
Washington	2.5 – 5
West Virginia	3
Wisconsin	3.5
Wyoming	5.5 – 6

Table 2: Solar Calculation Result

Name	Area(m²)	AvgRadiation (WH/m²)	Total Energy (kWH)	Hourly peak(WH)	Available(kWH)
Human resources center	876.602002	1246792.5	1092940.802	787.175659	218588.1603
Milan Township school	45.002357	1180154	53109.71162	675.08844	10621.94232
Chessick practice center	3861.68165	1263884.25	4880718.616	791.621887	976143.7232
sum	**4783.286009**		**6026769.129**		**1205353.826**

Table 3: Cost Estimate

Number of purchases	4,020.00
Cost per Unit	$582.11
Costs required (USD)	$2,340,082.20
Cost per kWH	6.73
Total Energy reception	2,344,108.93
Average conversion efficiency	20%
Available(kWH)	**1,205,353.83**
Electricity Expense	$8,112,031.25
First Year Saving	$5,771,949.05

8. Figures:

Figure 1: Efficiency of Solar Panel

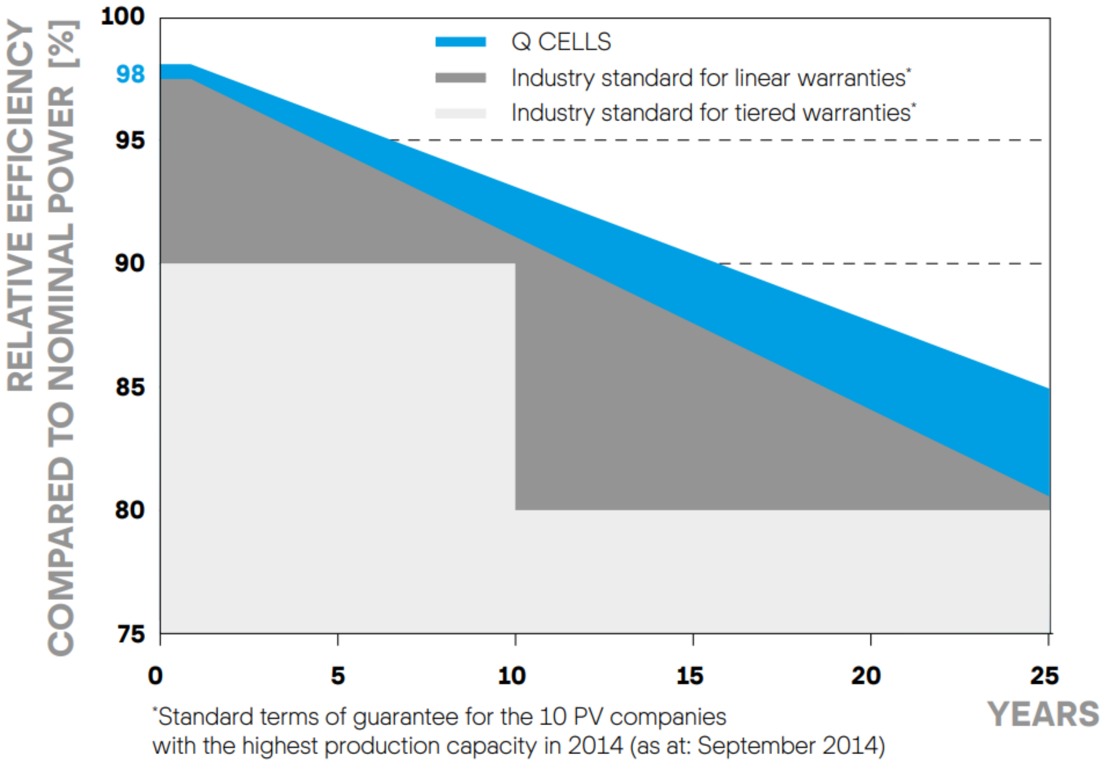

Figure 2: Solar map in winter solstice

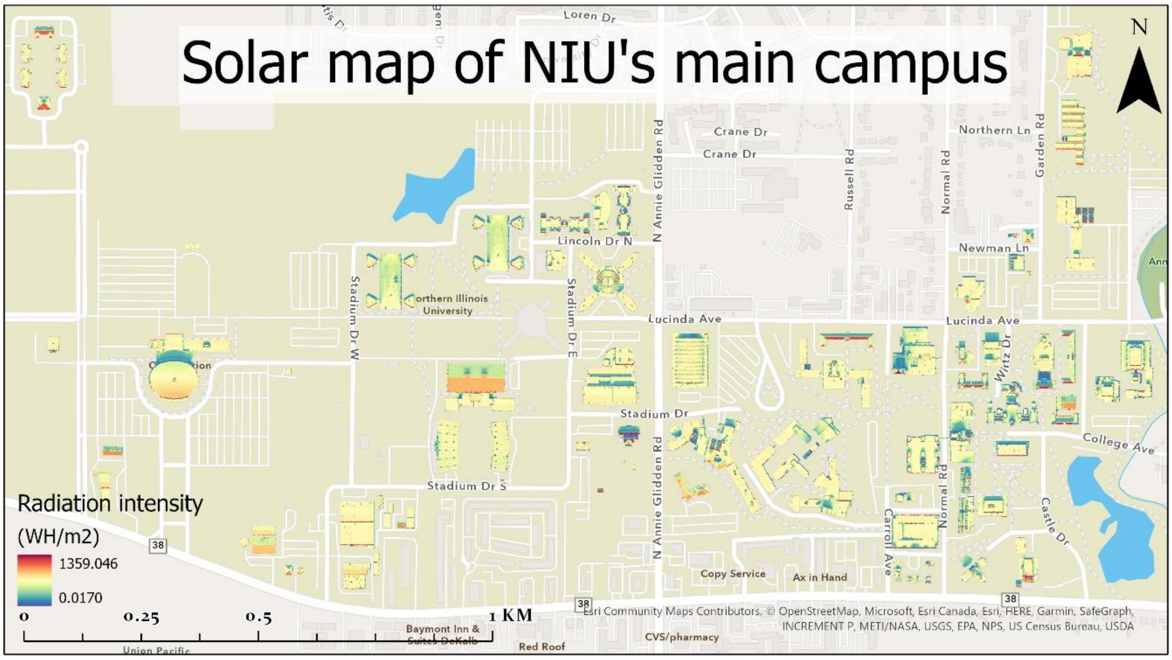

Figure 3: Test using Con tool

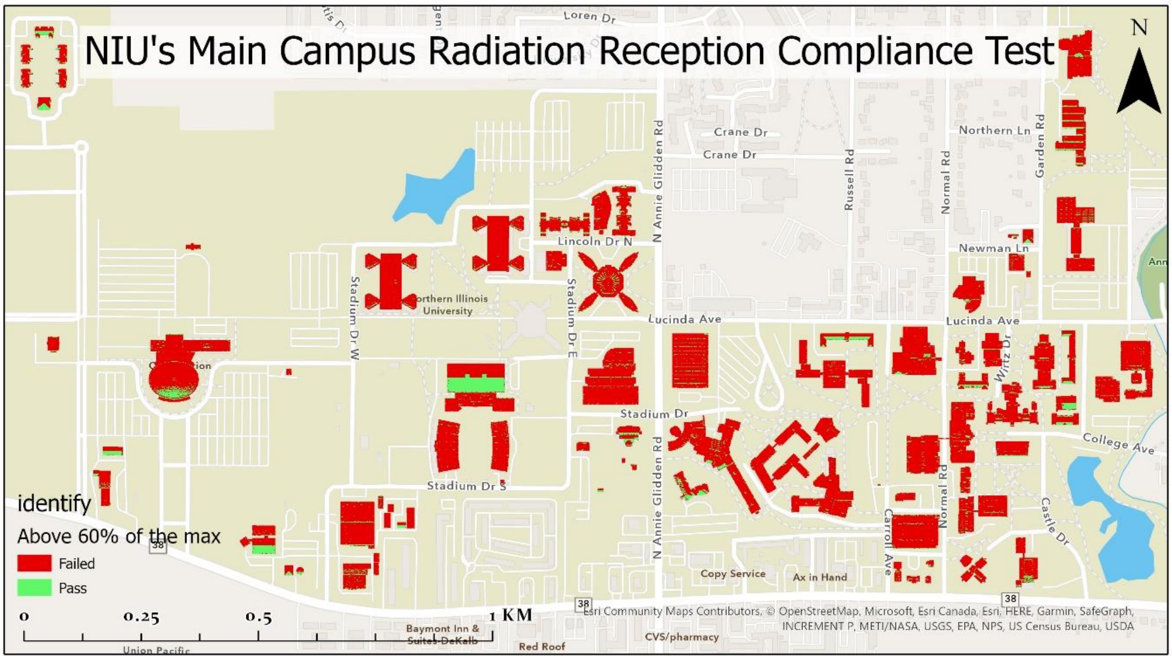

Figure 4: Eligible Area

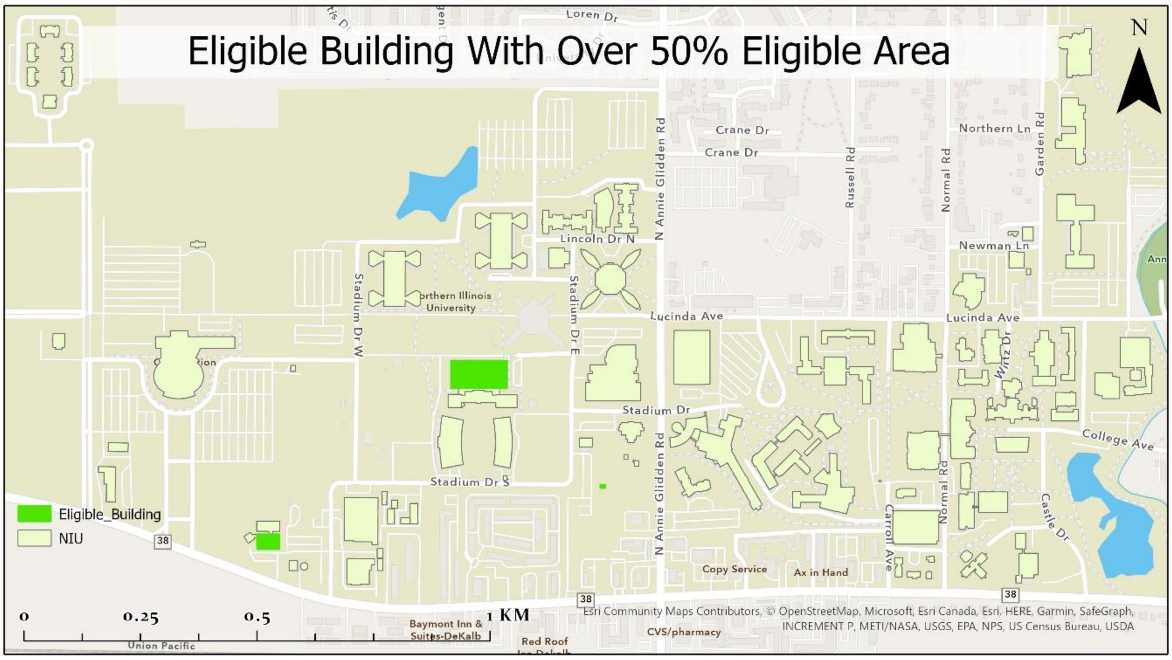

Figure 5: Eligible Building

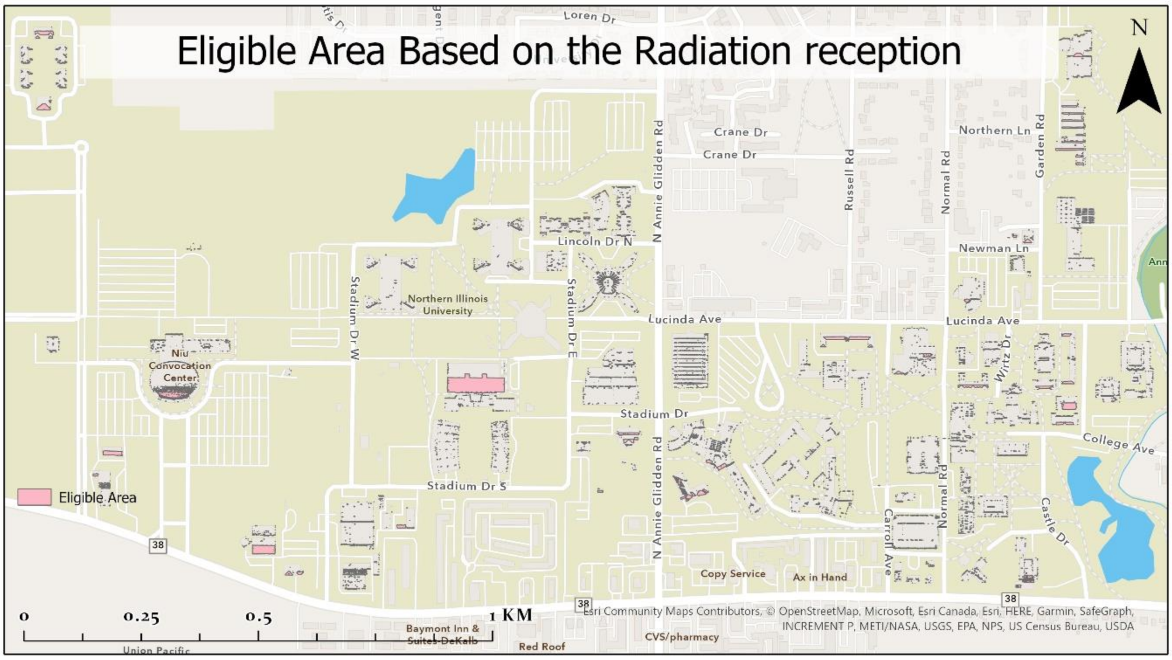

Figure 6: Result Illustration

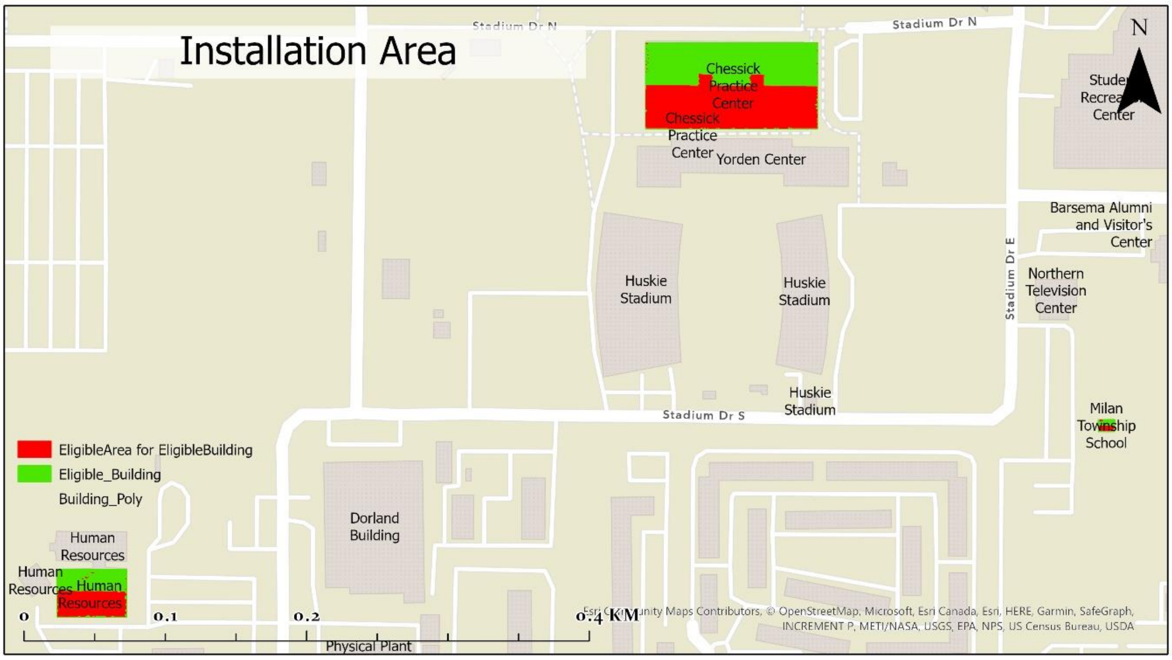

Figure 7: “The Panel”

Specifications:

Dimensions: 42 x 11 x 0.1 inch

Solar Cell: Monocrystalline

Cell Efficiency: ≥23.5%

Maximum Power(Pmax): 200W

Maximum Power Voltage(Vmp): 18V

Maximum Power Current(Imp): 8A

Open Circuit Voltage(Voc): 24.3V

Short Circuit Current(Isc): 11A

Maximum System Voltage(Vmax): 1000V DC

Operating Temperature: (- 10℃ – +65℃)

Module temperature: 25℃

Weight: 16 lbs