ASSESSING THE PHOTOVOLTAIC ROOFTOP POTENTIAL IN URBAN COMMUNITIES IN CITY OF SALZBURG, AUSTRIA

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Abstract

The advancement of mankind faces a great challenge in continuous rise in energy consumption, as current methods of energy production are seriously influencing the environment. To combat the climate change by reducing the release of harmful particles into the atmosphere whilst producing electric power for contemporary needs, society must shift towards renewable energy sources. One such indispensable resource is solar radiation that can be harnessed to generate electricity using photovoltaic panel installations. This paper explores the amount of electricity that can be harnessed from incoming solar radiation by photovoltaic panels for the course of the year of 2022 within the study area accounting the communities in Salzburg that border the hill Kapuzinerbeg. According to Area Solar Radiation calculation of solar irradiance the average for the study area amounts around 1055.7 kWh/m^2. Hence, the total amount of solar radiation for the study area amounts to 1,316.8 GWh, whereas the total photovoltaic potential amounts to 181.2 GWh. The obtained results are furtherly used to validate the accuracy of the measurements. Through sampling, the mean daily average is determined to be 3.26, while NASA's Data Access Viewer provides a value of 3.86 kWh/m^2.

Keywords: Solar radiation, photovoltaic potential, GIS

1. Introduction

Solar radiation is the ultimate precondition for making life possible on our planet and therefore is the main source of energy for all the physical and biological elements and processes to exist. More than a half of world's population is accommodated in urban environments and due to the rise of urban area migration, it is estimated to reach even 70% by 2050 (Fakhraian, Alier, Valls, Nameni, & Guerrero, 2021). Furthermore, on the one hand, the ongoing development of the society demands in constant and rapid increase of energy consumption while on the other hand the rise of energy crisis as well as environmental degradation concerns (Huang, Mendis, & Xu, 2019) make a renewable energy potential to be essential consideration in energy policies and regulation developments (Izquierdo, Rodrigues, & Fueyo, 2008).

The energy transmitted from the Sun is manifested as light and thermal energy and could be captured and transformed via photovoltaic (PV) solar panels into electricity for immediate or later use (Pavlović & Pesic-Georgiadis, 2019). Solar energy received differs across locations on Earth, necessitating the use of metrics to assess the affordability of the site for harnessing this energy. Aside from technical characteristics of PV cells, the characteristics of the terrain tracked by its elevation, inclination and orientation impact the length and amount of the solar regime, especially in terms of the level of shading playing a significant role in reducing the amount of solar irradiation received by the cells (Pavlović & Pesic-Georgiadis, 2019).

Taking the aforementioned factors into consideration, it is necessary to employ a specialized model that considers the complexity of the urban configuration when assessing the PV potential. Therefore, ESRI's Area Solar Radiation (ASR) tool is chosen as it considers these components for each cell. The aim of this seminar paper is to determine the amount of potential electric power that could be harnessed from PV from each rooftop within the communities bordering the Kapuzinerberg hill in Salzburg for the course of the year 2022. To achieve this, a 1m Digital Surface Model (DSM) serves as a baseline for representing the topography of an area from which the solar radiation is calculated. The output solar radiation cell values are further aggregated for each rooftop and converted to more adequate prefix multipliers such as kilo- and megawatts. Furthermore, to estimate the PV power gain from each rooftop, the solar radiation is converted to electric power. Lastly, results are validated by comparing the sample mean daily average against NASA's Data Access Viewer data.

2. Methods

2.1. Area Solar Radiation tool

The authors of the ASR tool point out that the analysis and mapping of solar irradiation by this tool are exceptionally useful for the places for which no direct measurement data of the solar radiation exist (Fu & Rich, 1999). The ASR calculation amounts the total solar radiation from direct and diffuse calculations over a specified time period for the selected geographical area and the result is returned as a raster with values expressed in Wh/m^2 (Pavlović & Pesic-Georgiadis, 2019).

As solar irradiation, weather factors and shadows from surrounding topography change drastically depending on the location and time, this model accounts the aforementioned factors and their variabilities in the solar radiation calculation (Kausika & van Sark, 2021). ASR calculates the amount and duration of incoming solar irradiance by computing an hemispherical viewshed for every pixel in the DSM based on a designated sky size and by using sun-maps, proportions of direct and diffuse radiation and topographic barriers (Fu & Rich, 1999).

The global solar radiation for the specified area is calculated for the year of 2022 by summing up cell values of resulting sun (direct) and sky (diffuse) map, while the tool excludes the reflected radiation from the calculation (Pavlović & Pesic-Georgiadis, 2019). Fu and Rich (1999) argue that the proportion of reflected radiation is rather small if the area is not high in albedo. Furthermore, without user intervention, the tool does not take into consideration the cloud cover over a monitored period of time (Carl, 2014).

To produce an accurate insolation map, the hemispherical viewsheds are provided to calculate the incoming radiation for each pixel. Figure 1. depicts its layout, providing a view of the surrounding topography that provides or prevents the direct solar radiation. White locations exhibit whether the sky directions are visible while the gray color demonstrates obstructed locations.

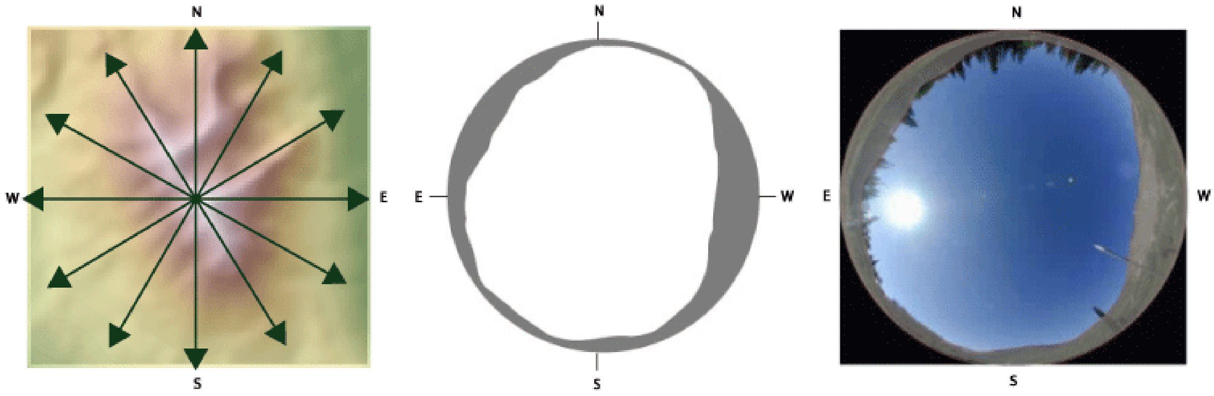

Figure 1. Illustration of the visible horizontal angles (left), resultant viewshes (centre) and viewshed mapped onto sky view (right) from a particular point (ESRI, 2023c)

The sun map is a representation of the sun over time and calculates the visibility or obstruction for each cell by identifying the solar constant, transmittivity, time duration, portion of visible sun and the angle of incidence (ESRI, 2023a). To estimate a direct radiation, each sky direction is calculated using a sun map in the same hemispherical projection, consisting of discrete sectors defined by the sun's position at particular time intervals (Pavlović & Pesic-Georgiadis, 2019). Depending on the latitude of the area under investigation and specified time interval, the map represents the Sun's trajectory by defining a corresponding unique value to each sector as presented in Figure 2. (ESRI, 2023c).

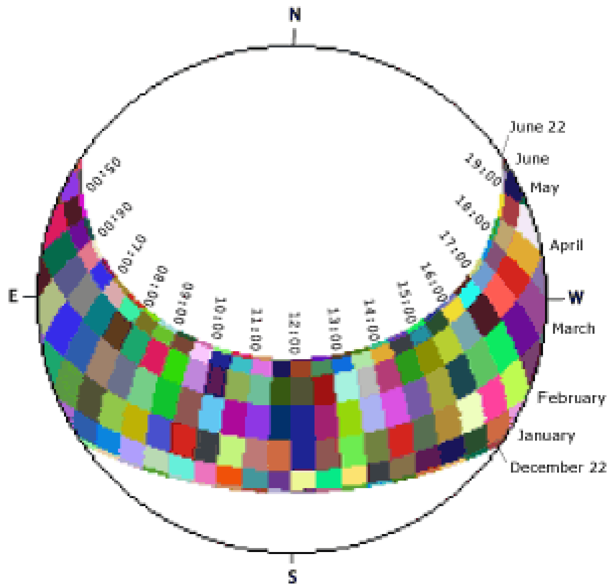

Figure 2. Map of direct solar radiation (ESRI, 2023c)

Sky maps are diffused proportion of the global radiation, and the ratio varies for clear sky and cloudy sky conditions (ESRI, 2023a). Hence, unlike direct one, diffuse solar radiation can originate from any direction and is received from various directions to the observed point (Pavlović & Pesic-Georgiadis, 2019). Because of this, as presented in Figure 3., it exhibits a hemispherical view of the entire sky divided into sectors with unique, differing values and number of sectors depends on the required accuracy (ESRI, 2023c). Sky sectors in the figure are divided with 8 zenith and 16 azimuth divisions.

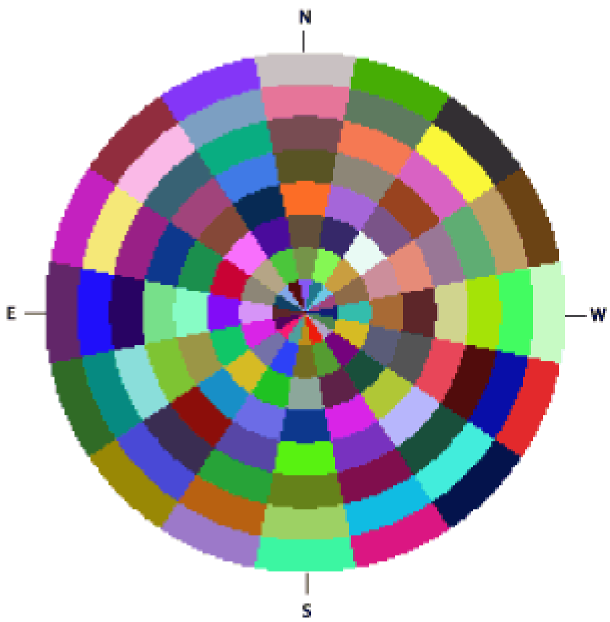

Figure 3. Map of diffuse solar radiation (ESRI, 2023c)

The result of the ASR calculation is a raster for which the viewshed raster is overlaid with sun and sky maps to calculate and aggregate the final value. Visible sky area in each viewshed sector is computed by performing a division of the number of unobstructed cells by their total number (ESRI, 2023c). Overall, the global solar radiation is the sum of the direct and diffuse radiation for each cell.

2.2.Data for model input

Here, the ASR tool is conducted over building rooftops in communities bordering the Kapuzinerberg hill in the middle of the Salzburg city. The boundary of these communities as a polygon shapefile was used to determine the computing extent for all considered processes. Main reason for considering several communities opposed to the whole city lies in the experimental nature of assessing the influence of the morphological features such as Kapuzinerberg over the insolation on buildings in the middle of the city. Furthermore, the modeling tool is computationally intensive (Kausika & van Sark, 2021) and decreasing the computational area can vastly improve the time needed to receive the results. The processing time for the area with the hardware used takes around one hour. The dataset was acquired via OpenStreetMap, offering free access to geospatial data but the accuracy of the data may not be perfect, as the building footprints do not perfectly reflect with the real-world structures.

For representing the topographic surface of the analyzed area, a Digital Surface Model (DSM) with resolution of 1m is used. Unlike Digital Elevation Model (DEM) and Digital Terrain Model (DTM), DSM provides the additional information on obstacles that exist between the Sun and location points. With this resolution, it is possible to capture and consider multiple surface values for each building rooftop, overall providing more adequate calculations. Furthermore, other morphological aspects derived from DSM such as slope and aspect orientations are considered within the Area Solar Radiation tool when performing calculations.

2.3. Estimating solar radiation

To derive the total solar radiation most accurately over a selected period over the selected communities in city of Salzburg, it is needed to adjust the ASR tool parameters that best represents the temporal, topographical and radiation state of the area under concern. Therefore, the input parameters are explained and set accordingly (ESRI, 2023a):

- **Input raster**: DSM;
- Latitude: the mean latitude which is automatically calculated for spatially referenced raster;
- **Sky size/resolution**: representing the output resolution of the viewshed, sky and sun map. Default is 200 x 200 and is kept that way as Fu and Rich (1999) in their testing have come to similar results from both default and 400 x 400 viewshed resolutions.
- **Time configuration**: can be set to within one, multiple or specific days or for the course of the whole year. In this case, the calculations were performed for the complete year of 2022. In the case of this selection, an hour interval must be chosen. It is the time

interval by which the sky sectors for the sun map are to be calculated. The default value was chosen.

- Topography parameters:
    - **Z factor**: multiplies the z values of the input raster. Used when z units are different from the x, y units. By inspecting the DSM, the linear unit and scale factors indicate that the coordinate system uses meters as the unit of measure. Therefore, the input value is kept as default.
    - **Slope and aspect input type**: to derive the slope and aspect information to be used within the analysis. It is kept as default in order to calculate the information from the input raster dataset.
    - **Calculation directions**: how many directions are used when calculating the viewshed. The default value of 32 is considered sufficient for complex topography and kept as input value.
- Radiation parameters:
    - **Zenith and azimuth divisions**: zenith and azimuth sky sectors in the sky map. They are kept as default values.
    - **Diffuse model type**: “uniform overcast sky” for calculating the incoming diffuse radiation as uniform from all directions, while “standard overcast sky” depends on the zenith incidence. Here, the first model was chosen.
    - **Diffuse proportion**: represents the fraction of diffuse radiation in total radiation. Default value for mostly clear sky conditions is 0.3. By investigating and interpreting the cloud coverage in Salzburg on Spark (2023), the value was set as 0.5, meaning the middle ground between clear and cloudy sky conditions.
    - **Transmittivity**: an inverse relationship from diffuse proportion. Defines the amount of radiation that passes through atmosphere. Therefore, default value is kept as 0.5.

Figure 4. exhibits the final output of the annual solar radiation calculated for 2022. The incoming solar radiation displays a minimum of 0.265 kWh/m^2 and a maximum of 1,573.06 kWh/m^2 on a yearly basis.

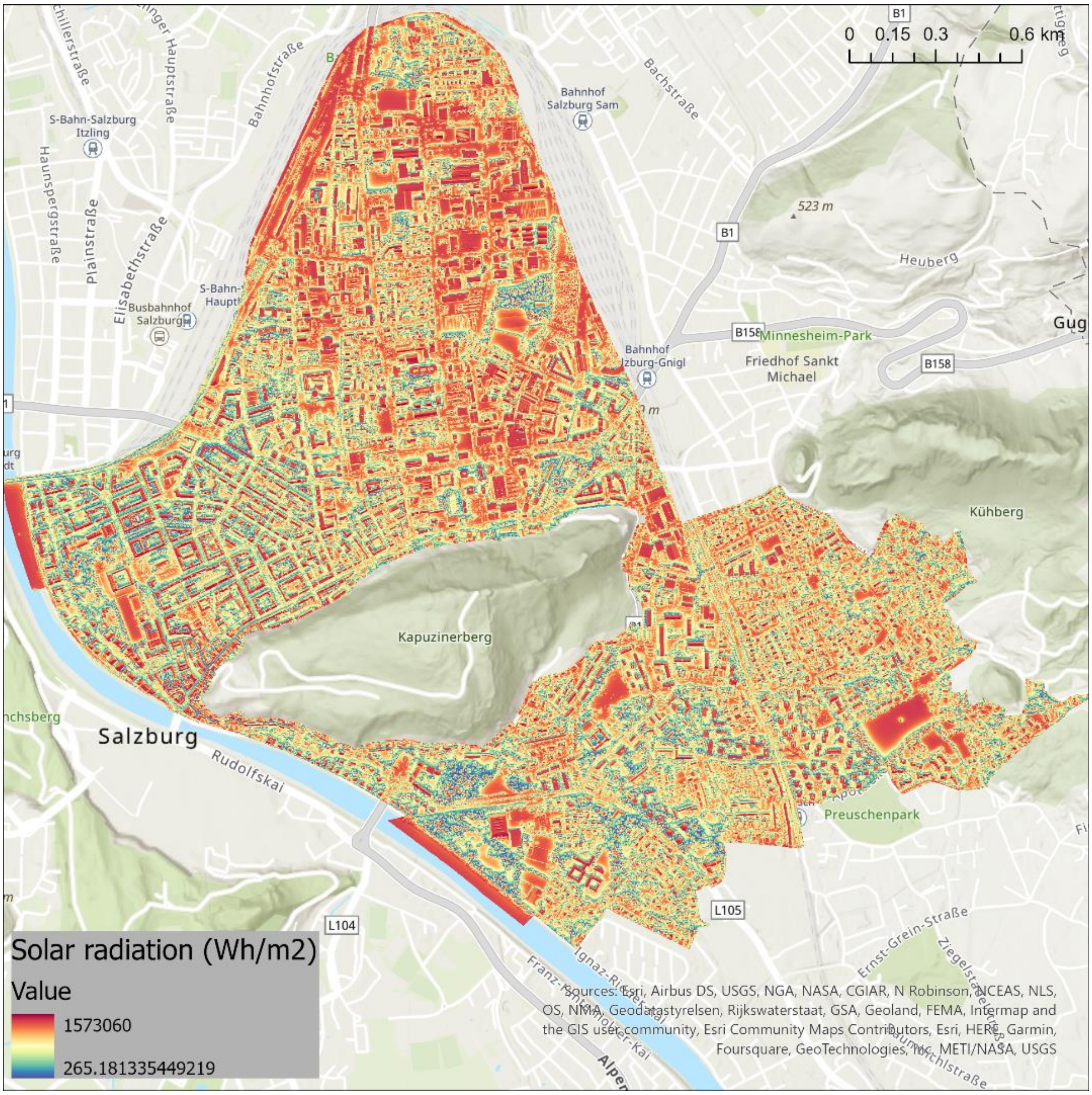

Figure 4. Map of incoming solar radiation

2.4. Calculating the PV potential for total study area

After calculating the amount of solar radiation each cell within the study area receives, further steps are taken to determine the electric power production if each square meter of the rooftops under investigation was covered by PV installations:

- First, to narrow down the amount of solar radiation and therefore the PV output for the buildings, the output raster is clipped to the extent of the building footprints.
- Since the representations are by default expressed in watt-hours, the values were expressed to kilowatt-hours by using the *Raster Calculator*.
- Calculated the area and average solar radiation per square meter for each building by using the *Zonal Statistics as Table* and transferred the attributes by performing the *Join Field* to each building by using their unique ID.

- Generated the field "*SR_MWh*" that represents solar radiation expressed in megawatt-hours and used *Calculate field* to receive the total amount of solar radiation received by each rooftop with following expression in the calculator: *(!AREA! * !MEAN!) / 1000*, where *!AREA!* represents the total area of the rooftop, *!MEAN!* is the average solar radiation per square meter performed in the previous step and division by 1000 converts the kWh to MWh.
- To convert the solar radiation to electric power production, an "*EleP_MWh"* field is created and populated by the following expression: *!SR_MWh! * 0.16 * 0.86*. To assess the electric power production potential from a PV system, as proposed by The United States Environmental Protection Agency (EPA) the solar radiation is converted by the equation: E = A * r * H * PR, where (ESRI, 2023b; Pavlović & Pesic-Georgiadis, 2019):
  - **E** = Energy (MWh);
  - **A** = Total solar panel area (m^2);
  - **r** = Solar panel efficiency (%);
  - **H** = Annual average solar radiation on tilted panels;
  - **PR** = performance ratio, coefficient for losses.

  The agency provides a best estimate with 16% efficiency (how much the solar panels can convert of incoming solar energy into electricity) and 86% performance ratio (how much of the left electricity is preserved after running through the installations) (EPA, 2023). Since the rooftop area and average solar radiation were merged in the previous steps, the area was left out from the equation. The amount of potential electric power that could be harnessed from PV systems from each rooftop within the study area can be summed up by inspecting the attributes statistics within the software.

- Last step is for visualization purposes, as shown in Figure 5., to provide a map representation of how much each building provides PV energy production on average MWh/m^2. The field named "*EleP_MWHm2*" was calculated by performing the expression: *(!MEAN! * 0.16 * 0.86) / 1000*.

3. Results

The PV energy potential for all 3.884 buildings within the study area is derived from solar radiation layer by aggregating, merging, and converting the solar radiation estimations with the use of formula suggested by EPA. The total amount of electricity expressed in MWh that is received by each building depends on the size i.e., the amount of PV panels to be installed on them.

As previously stated, the minimum amount of solar radiation a cell within the study area for 2022 receives is 0.265 kWh/m^2, while maximum being 1,573.06 kWh/m^2 and average for all the features is 1,055.7 kWh/m^2. Overall, the total amount of the solar radiation received for all the buildings equals to 1,316.8 GWh. When converted to PV energy output, if ideally each square meter of the buildings under investigation was covered with a panel, the total amount of potential energy production would be 181.2 GWh.

Figure 5. illustrates the average PV output in MWh/m^2 for each building. The minimum average amount of electricity produced from PV systems 0.016 MWh/m^2 while the maximum can be

reached up to 0.196 MWh/m^2. This visual representation allows for the identification of buildings that are more favorable for PV installations compared to others.

The validation of the results is carried on by extracting a single point from the NASA's Data Access Viewer presented in kWh on a daily prediction (Thinley, 2022). The mean daily average radiation at the validated point from NASA's data is 3.28 kWh/m^2, while the output from the Area Solar Radiation is 3.86 kWh/m^2.

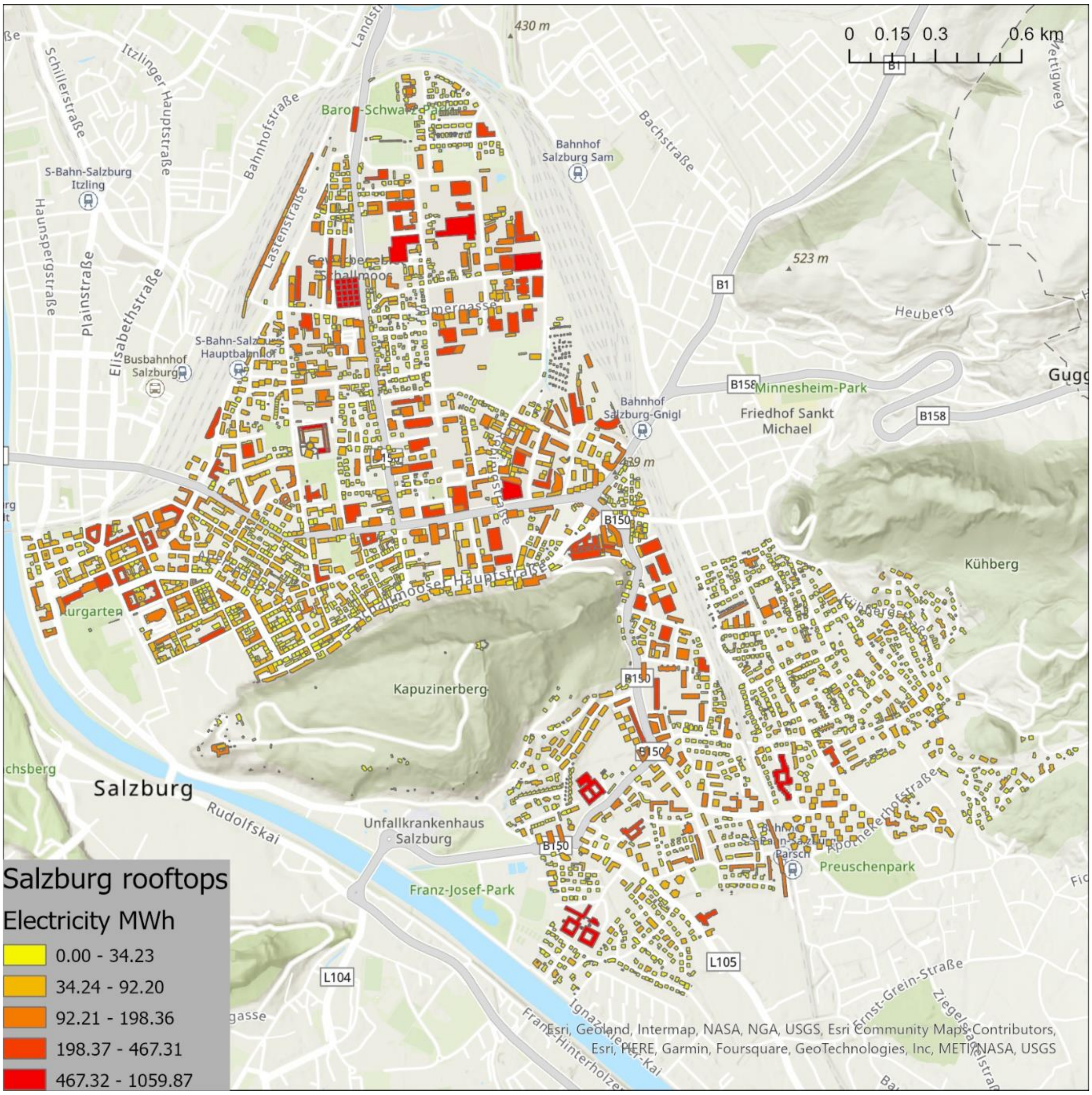

Figure 5. Average PV output per square meter for each building within the study area

4. Discussion

The study provides a valuable insight into the assessment of electricity generation from solar radiation with the Area Solar Radiation tool and therefore serves as a foundation for further research to obtain more accurate results in this endeavor. To accomplish this, it is important to overcome several challenges encountered during the analysis.

One of the main difficulties is related to the initial misalignment of the DSM dataset. The attempt to mitigate this issue by reprojecting the raster model resulted in the dataset with cells containing no data. As a temporary solution, this alignment challenge was overcome with a manual georeferencing approach. Additionally, the building footprints retrieved from OpenStreetMap have shown the imperfect alignment with the real-world structures. Some features were either too narrow or too large compared to the expected dimensions of the structures. Finally, the inconsistencies between the validated points are probably to large degree due to ASR tool not accounting for the reflected radiation. Another factor contributing to this results in the limitations of the NASA's tool providing latitude and longitude values up to four decimal places. This limitation results in near but not perfect alignment between the validation points, yielding slight variations.

5. Conclusion

In this study, for possibilities of harnessing clean energy and leverage its numerous beneficious aspects, the photovoltaic rooftop potential in communities bordering the Kapuzinerberg was assessed. The aim was to evaluate the total amount of electricity that could be generated from incoming solar radiation by PV panels within the study area for 2022, resulting in 181.2 GWh.

The analysis was conducted by using the Area Solar Radiation tool within the ArcGIS Pro software. The benefit of using tool lies within its consideration of meteorological and topographical factors as well as incorporation of 3D modeling by accounting for surface steepness and orientation factors. By overcoming the challenges such as the initial misalignment of the raster dataset, imperfect building footprint data representations, and limitations of the tool used for validation, the method used could obtain more accurate results in future research endeavors.

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