Evaluation of photovoltaic potential application in urban environments using GIS-based method: the particular case of Baghdad /Iraq

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Abstract: This paper aims to develop a multi-criteria technique that originated in Geo-Information Systems (GIS), horizontal radiation data and Light Detection and Ranging (LIDAR) to discover the installation potential of photovoltaic systems in an urban area and assess the output of yearly generation of electricity. In a small area in the center of Baghdad (Iraq), data that were obtained from LIDAR provide a precise representation of the urban environments through the development of a Digital Surface Model (DSM) that was utilized for computing the degree of the roofs of building local inclination and orientation using the impact of shadow for the different elements (other construction and trees). The paper introduces the possibility of distinguishing two forms of roof: for the first one, PV panels were situated parallel with the roofs, while for the second, the optimum position was obtained through the utilization of the structures to mount them. For the second case, the self-shading was considered. Incident radiation on the surface of panels is computed using a geometric technique that depends on horizontal radiation per hour, including direct and diffuse components. Finally, the evaluation of the effective production also includes panels efficiency and various sources of waste, particularly temperature.

Keywords: GIS; LIDAR; Photovoltaic; Solar potential.

1. Introduction
Photovoltaic systems implementation for power production and supply in urban environments become more crucial. The energy resource of the region relies on its characteristics, such as weather conditions, geographic position, so Geo-Information Systems (GIS) are considered an ideal tool for such type of analysis. The shape and location of buildings are essential data required to properly manage the city itself. Today, modern geomatics provide highly precise, effective methods for collecting data on a larger scale [1]. The assessment of solar radiation of the useful surface is the main problem. The best way to deal with this problem is by computing the irradiation from the position of the sun in addition to a three-dimension model of the area [2]. This simply takes the actual elevation of the roof surface into consideration and accurately defines various urban elements with the related shadows. But the downside is it doesn’t consider the weather situations of the region during the year. This issue was partially solved [3] through the use of a monthly scale for Solar Analyst, so some variance in the atmosphere would be incorporated in the model. In addition, a Daysim backward-ray tracing daylight simulation engine was developed by Jakubiec and Reinhart (2013), which can
describe accurately the building surfaces as well as their reflections [4]. During a typical meteorological year, an alternative route is to begin with irradiation per hour on a horizontal surface and irradiation derived on an arbitrary surface using a geometric model. An accurate view of the urban environment obtained from (LIDAR) data that can obtain the height for the entire element in a work area, so it becomes the cornerstone of all these new models. Utilizing geometric processes to quantify the irradiance in addition to a multiple-criterion approach for classifying acceptable locations, this paper attempted to proceed in this approach. A primary approach which developed for leveled roofs, that determines PV panel optimum orientation and inclination, together with the shading of the inter-panel. The amount of power is determined from the incident radiation, considering the various types of losses, in particular temperature and shadow data. This creative and more accurate explanation of rooftop PV Syst. makes the total occupancy factor as well as yearly production of the area being studied estimated more accurately.

2. Methodology
This paper aims to build a GIS-based model to examine the ability of PV solar systems to generate power in urban environments and assess their yearly output of electricity. In Figure 1, a suggested model diagram. This model needs two types of inputs, the position, in this situation a section of Baghdad city (Baghdad, Iraq), and the solar data (the position of the Sun and the horizontal irradiation). The model is capable of dealing with these data and evaluates the roof PV potential automatically.

So to determine the location and shape of the buildings, the first phase was constructing the 3D model for the selected part of the city and simultaneously individualizes the existence of the barriers which could shade PV panels, and this is crucial to the accuracy of the information utilized for a 3D model. So to develop the digital surface model (DSM), the data will be first categorized and analyzed with VRMeshV 8.5 Studio processing software and then transfer to ArcGIS10.3. Then a map with and roof’s orientation and inclination are produced. Based on this data, the roofs have been categorized into two typologies: the first one is the sloped roofs, in which the panels have been mounted at a plain structure that is parallel with the roof, while the second one is flat roofs, and the panels have been mounted on these structures and then directed and inclined as required. These are a requisite aspect of the model since it is a currently familiar application that utilizes structures to maximize the angle and direction of the solar panel.

This panels positioning flexibility substantially alters the projected generation of electricity. There are various ways of optimizing the location of the panel. In this paper, the maximum yearly output per meter square of the grid is used to determine the best inclination and orientation for the panels. The way used for measuring solar irradiation is the second essential property. Hourly irradiation data on a horizontal surface have been used by a geometric method to measure it. Data obtained from Meteosat measurements for the period from January 2000 to December 2003 were used with a (2km×2km) spatial resolution and time resolution of 30-min [5]. This allows the effect of weather changes to be recorded. In addition, this procedure can be used for panels which not parallel to the roof to measure radiation. The yearly generation of AC electricity is then computed by the equation:

\[ E_{\text{annual}} = \text{APV} \cdot e \sum_h (1) \cdot \text{PRh} \cdot I_g^h \]  

Where: \( \text{APV} \) (m²) PV panels determined area from the preceding section, \( e \) the efficiency, \( I_g^h \) (kW/m²) represent the irradiation per hour, \(( e )\) the efficiency, and \( \text{PRh} \) the ratio of performance.

2.1. Optimization of layout of the panel
Determining the layout for solar panels is a difficult activity based on several factors, so no rule is appropriate at all times. In general, PV panels could be directly mounted on a leveled roof or on specific structures that permit for the required inclination and orientation to be arranged. The second approach is obviously the most workable solution. It is also more costly. So at the beginning decision should be taken if the improvement in panel efficiency is offset by the higher installation cost through the effective contribution of the responsible manager and the executive sponsor using their awareness and creativity [6]. If so, it is necessary to determine the optimum orientation and inclination for the panel.
This relies strongly on upon if output for the surface of the panel or roof should be maximized. In each particular situation, the choice of the best solution is outside the context of this study, so roofs have been classified into two main types. The first type involves all roofs in any orientation with a slope less than 5°, while the second type involves roofs facing the equator with a slope of 5° to 15° (90° < α < 90°). The two groups of the roofs are named "flat," and at an optimal location, panels are angled and oriented. It is not appropriate to install additional structures on sloped roofs because the panels and the roof orientation and inclination are the same. For the first type, the optimal case found where the output of the PV panel area is greatest. The perfect direction is toward the equator line, where α = 0 (Figure 2).

The irradiation equation is maximized to compute the inclination. At β = 32°, irradiation has a flat limit (Figure 3). It is necessary to note that only panels not influenced by shading are eligible for this result. The optimal inclination and orientation may differ from the found here if there is shading. But it would be too time-consuming to precisely determine the optimal layout for each rooftop and would not substantially affect the outcome, so in any case, highly shaded rooftops are neglected. Therefore, for any rooftop, this outcome could be considered a suitable estimation. In addition, it is essential for the flat roofs to evaluate the space between panel rows. Thus wider the space among the rows, then the less hours panels would be shaded by the row located in front of them in a year.

Figure 1. The proposed model Basic diagram
Figure 2. The relation between yearly irradiation and orientation (α). diverse lines were related to diverse inclination (β) value. Horizontal line represent the horizontal surface while the remain were for value of( β ) from (10° - 90°) at interval of (10°).

Figure 3. The total radiance with relation to β when α=0.

When the spacing Increase, however, this reduces the row numbers in a given area that can be arranged. Using the general rule to prevent winter noon time shading, the spacing among panel rows is:

$$d_f = L \frac{\sin(\beta_\theta - \beta)}{\tan(\delta_1 - \delta + \beta)} \ldots \ldots \ldots (2)$$
Where L is panel length, β is the roof inclination, and \( \beta_0 \) is the panel inclination. Occupancy factor, which is the proportion between roofs available domain that is needed for panel installation to the surface of the PV panel is:

\[
k_d = \frac{i+\delta_f}{L} \ldots \ldots \nonumber \]

\[
= (\cos(\beta_0 - \beta) + \sin(\beta_0 - \beta)/\tan(61 - \delta + \beta)) \ldots \ldots (3) \nonumber
\]

This element takes into account the roof's current use. PV panel shading is the last aspect that would be examined. Such various factors like topography surrounding neighboring houses and other rooftops, trees, walls, and so on must be included in the shading study. "As outlined following, to determine if the area is shaded or not as well as shadows size at any time given, the Esri" Hillshade "feature is used. The row may cast its shadow onto some other lines on flat roofs covered by panels grouped in many lines. The Hillshade tool is dependent on DSM in case the tilted panel structures do not exist. Thus, it is essential to develop another way of measuring the panel's additional shading. Shadow factor is the surface fraction in the shade, assuming an infinite series of parallel rows of panels:

\[
S_f = \max \left[ 0,1 - \frac{\cos \beta + \delta_f}{\cos \beta + \frac{\gamma_s}{Z_s} \sin \beta} \right] \ldots \ldots (4) \nonumber
\]

Where

\[
\begin{pmatrix}
X_s \\
Y_s \\
Z_s
\end{pmatrix} = \begin{pmatrix}
1 & 0 & 0 \\
0 & \cos \beta & -\sin \beta \\
0 & \sin \beta & \cos \beta
\end{pmatrix} \begin{pmatrix}
X_s \\
Y_s \\
Z_s
\end{pmatrix} \ldots \ldots \ldots (5) \nonumber
\]

and \( X_s; Y_s; \) and \( Z_s \) are the sun unitary vector in Cartesian coordinates that could be given as zenith and azimuth functions:

\[
X_s = \cos \theta_z \sin \phi_s, \quad Y_s = \cos \theta_z \cos \phi_s, \quad Z_s = \sin \theta_z \nonumber
\]

Eq. (4) is not valid if \( \gamma_s < 0 \)

\( s < 0 \) the factor of shadow could be assumed (1) at the time when the sun enlightens the panels back, or when the sun is hideaway by the surface of the roof \( (Z_s < 0) \). As aforementioned, this equation may not appropriate for rows that are infinitely longy. It is possible to compute a correction K factor to take this into consideration.

\[
S_{SN} = S_f \cdot K : K = \max \left[ 0,1 - \frac{\delta_f/X_s^2}{\gamma Y_s} \right] \nonumber
\]

As the correction factor value is less than 1 (7), thus; not considering it, overestimating shadow impact, and the received irradiation from the panels or the generated energy.

2.2. Solar potential

The DSM and Hillshade can be used to create a shadow map that shows roofs orientation and inclination. The roofs are categorized into two types utilizing this data, as mentioned in the previous section. The output is an orientation and inclination map of the panel that is different from the roof orientation and inclination map. In the irradiation equations, this map, in addition to the shadow map, will be the input. The geometric method that Hay and Davis (8) developed is used to measure the irradiation on a virtual surface successfully.

On an arbitrary surface, global irradiation \( I_h = (\alpha, \beta) \) is given by direct irradiation, \( B_{ih} = (\alpha, \beta) \), diffuse irradiation (the sum of the isotropic and circumsolar components) \( D_h(\alpha, \beta) = D_{ih}(\alpha, \beta) + D_{ih}(\alpha, \beta) \)
and albedo or the reflected irradiation or \( R_h^I = (\alpha, \beta) \)
the hour of the year is represented by the subscript \( h \). thus the map of solar irradiation is given by:

\[
I_h^I(\alpha, \beta) = b_h^I(\alpha, \beta)(1 - S) + d_h^I(\alpha, \beta)(1 - S) + d_h^I(\alpha, \beta) + R_h^I(\alpha, \beta) \ldots \quad (6)
\]

\( S \) is representing the shading coefficient.

In roofs that are sloped, \( S = S_{Hillshade} \in \{0,1\} \) and is computed with Hillshade. While in roofs that are flat, the shadow produced by the solar panels else should also be considered, and thus, it is illustrated as \( S = \max\{S_{Hillshade}, S_f\} \). The shadowing coefficient, like irradiation, for one hour, is deemed constant and is measured hourly through the year. After the irradiation per hour is identified, the cumulative annual irradiation chart is actually aggregated over a year.

3. Results

3.1. The calculation of the surfaces suitability

A significant objective of this work is to measure the area suitable for PV device implementation. First, attention is given to the entire area of the city. Then reduction specifications eliminate unusable areas. The shape of the building is discriminated against by the first data from the surveying department. Second, any significant or historical structures, in addition to a free circumference area for servicing, are excluded. Then, utilizing solar potential map of the residual roofs, the optimum roof portion for the installation of the PV panel should be selected, which relies on the quantity of the obtained solar irradiance by the PV panel for each particular location. No single roof selection mechanism exists. Maximum loss from the optimum is given in this text. If these losses are too great, mean incorrect installation of the panel is performed.

The CTE categorized PV systems into three groups, based on if they are built on a particular structure, immediately on the roof, or incorporated into the design of the house. Depending on orientation, shading and inclination, the various maximum loss is defined for each class (Table 1). Local for cooperation with the limit obtainable by a panel, annual irradiation is:

\[
I_{MAX} = \sum_h I_{MAX}^h = \sum_h G_h(\alpha = 0, \beta = \beta_0)
\]

And it is possible to discard the areas where losses surpass the ones shown in Table 1. Tiny isolated areas (< 1 m²) emerge after filtering using the above criteria, which are technically accessible, but there was scarcely enough space for a PV device in practice. An algorithm, therefore, discriminates and removes those locations from the accessible surface.

| System Type            | Inclination and orientation | Shadow | Total |
|------------------------|-----------------------------|--------|-------|
| General Type           | 10%                         | 10%    | 15%   |
| Superposition Type     | 20%                         | 15%    | 30%   |
| Integration Type       | 40%                         | 20%    | 50%   |

It should be noted that for flat roofs, due to the need for row separation, the maximum area for the panel is only a fraction of the area of the acceptable portion of the roof. Eq.(3) is used to compute this fraction (Figure 4).
The effective production of yearly energy is computed by Eqs. (1) as well as (6). The factors e and PRh rely on a specific installation form; even so, several means can be included. As shown in Table 2, the model takes into account various panel technologies with their average efficiencies. PRh contains several distinct types of losses. The total of all losses usually contributes to an output proportion of 0.75 - 0.85. There are different costs for panels with different technologies per Wp., as shown in Table 2. The panel accounts for 30–40% of the overall expense of the PV system [9]. Other costs are independent of technology. The materials are only cost connected to the area of the PV system, and for each technology, this is different. Currently, these expenses are 5% of overall costs [10]. The various forms of losses are discussed below, and the shadow and temperature losses in particular. Shading losses calculation is a tremendously difficult process, and the panel form and the shadow shape must be included in an accurate definition [8]. The actual impact on the PV field's output by partial shading was nonlinear; in addition, it relies on the modules' interconnections. In an array of PV, every cell string's current was restricted by the current of a worse cell in the set.

Figure 4. Indicates the successful occupation factor
Figure 5. The effective occupancy factor (which shown in red color) is the ratio of the surface of the roof to greatest area that it is possible to install PV panels on it.

| Utilized Technology | Si Mono | Si Multi | CIS | TeCd | Si amorfo |
|---------------------|---------|----------|-----|------|-----------|
| Penal Efficiency    | 16%     | 15%      | 11% | 10%  | 6%        |
| Module Cost (USD/Wp)| < 1.4%  | < 1.4%   | 0.9%| 0.9% | 0.8%      |

That is, the whole string strongly affected, even if only one cell is shaded, and the I/V features of the whole sequence are also severely impacted). This estimate is beyond the context of this paper. We were trying to quantify it as precisely as possible without the need to understand the PV system’s detail, such as module form, actual distribution of string within the space of the module, or by-pass diodes security. As so, only the shadows' own geometric impacts were taken into account. This implies that the decrease in electricity output is believed to be only equal to the portion for panels that are impacted by the shadow. This type of waste has been considered by the S component in the irradiation model (Eq. (6)). For sloped roofs, this factor is discovered with Hill shadow, whereas flat roofs often have a factor considering the shading of the inter-panel. Operating temperature efficiency of 25°C listed in Table 2 is; however, the temperature of the modules run at is generally more than that. Annual output for panels of different technologies as a percentage value, the PV Syst. program will evaluate those losses. The PV system has the added benefit of having the ability to imitate the air cooling distinct contributions for panels that were overlaid on the roof or for panels that were free-standing. Due to natural cooling by wind, the temperature difference in these two typologies can be about 10°-20°C. The fundamental equation was the balancing of energy between the temperature that were ambient and the temperature where incident irradiation heats the cell:

\[ U = (T_b - T_{amb}) = \gamma G(1 - E_f) \]

where \( U \) is the factor of the losing thermal that can be divided into a constant element, \( U_e \) and \( U_v \), a factor proportional to the speed of the wind.
v : \[ U = U_c + U_v \nu. \]

\( E_f \) is the module removed energy and \( \gamma \) is the coefficient of the absorption of solar irradiation, and default values are \( E_f = 10 \) and \( \gamma = 0.9 \) and \( U_c = 29 W/m^2 \), \( U_v = 0 W/m^2 \) for the panels that are free-standing, for this study, flat roofs are used for the mounted panels. \( U_c = 20 W/m^2 \), \( U_v = 0 W/m^2 \) to the panels that are overlaid, which are, panels on sloped roofs. PV-system, then for each technology, simulations of different panels are used, and an average amount of the yearly loss as a result of the temperature is determined. Temperature per hour for the plates, and from this, the hourly losses, will be a more straightforward way to measure, but the complexity of numerical parameters renders it futile to use such time-consuming procedures. As a percentage of overall annual output, other losses that should be incorporated are also taken into consideration. Standard literature loss values are used [11]. Below is a summary of the different sources of these losses and their relative value. The uncertainty of the real PV module parameters is defined by the manufacturer. This means an approximate loss of 2%. Accumulated dirt on the modules is a further source of device losses. Dirt may be either uniform, such as contamination from air or dust or, or droppings of birds. There is a reduction in radiation obtained in the first case, and there is a rise in parameter dispersion and hot spot generation in the second, resulting in losses. Air pollution, rainfall, the inclination of the module, bird droppings, space from the ground, in addition to the efficiency and intervals of cleaning, are the critical causes of module fouling. The computed fouling factor was 3% in this analysis. Losses are triggered by whatever operating temperature in addition to the STC, as described above, and this is true for other variables. Losses are often triggered by irradiation below 1,000 W / m². Incidence angle less than 90° contributes to angular waste at low irradiation, and the air mass higher than 1.75 leads to spectral waste. This waste is about 6% in total. In the DC portion for wiring, losses from overheating exceed 1%. The inverter losses which rely on the current instantaneous value are still uncounted for. The hourly loss and the total per year should be measured for a solid estimation of the yearly loss. But it is necessary to measure the annual percentage of losses, as is the case for temperature losses. These losses range from 4% to 9%. At last, the AC wiring losses are 1%. The implementation of the technology and module results in a reasonably accurate estimate of the overall losses. Losses average are shown in Table 3. With this method, an annual factor is calculated for the hourly output ratio, and thus, Eq. (1) becomes \( E_{annual} = A_{pv} e P R_h \sum h t_g \)

This would be used to calculate the annual production of energy.
3.3. Results
The determination of the best area for panel installation has been discussed in the previous subsections (Figure 5), yearly output in addition to the number of hours that are identical. Figure 6 and Figure 7 demonstrate the outcomes using Te Cd panels for each building. For the other four technologies in this report, the same calculations were performed. Table 4 concludes the results for the overall yearly outcome of electricity, i.e., for the whole region of the analysis, from which it is clear that the energy and the power installed differ. The output was 324 MW h of the installing capacity for 241 kW hp utilizing the panels of Si amorphous while over 846 MW h for an installed capacity of 641 kWp with Si mono-crystal rows. With more powerful technology, an output increase of 160% could be achieved. The performance of the Si multi-crystalline panel is similar to that of the Si multi-crystalline, so its output is comparable.

Figure 6. Displaying each building's annual energy output, which relies on the available surface, the roof's orientation and inclination, and the shading. A significant factor in selecting the most

Figure 7. Display an equivalent hours number for any type of building using TeCd panels.
Table 3. The overall waste of the system of PV by the modules and technology

| Utilized Technology | Si Mono | Si Multi | CIS   | TeCd  | Si amorfo |
|---------------------|---------|----------|-------|-------|-----------|
| Overlaid            | 26%     | 26%      | 25.5% | 25.2% | 23.6%     |
| Structure           | 24%     | 24%      | 23%   | 22.8% | 22%       |

The other two medium productions are demonstrated by technologies (CIS and TeCd). Different temperature losses account for the minor variations in the number of identical hours. Si-Amorphous panels, for instance, that has better high-temperature efficiency, have somewhat a higher number of identical hours, in spite of the fact that the difference is not significant. When analyzing areas with higher temperatures, this kind of comparison becomes more important.

4. Conclusions

PV implementation involves a thorough multi-criteria review of a significant amount of spatial entity-related variables in urban areas. GIS acts appropriately to the requirements of this kind of research. The paper introduces a useful model developed using LIDAR data in an Arc GIS environment. The ability to distinguish two styles of roofs is a significant creative characteristic of this model. For the first one, PV panels were positioned parallel with the roof, while they were mounted on a framework for optimal placement in the second one. The irradiation that incident on PV panels was merely measured utilizing the roof orientation and inclination map and the shadow map for the first typology. This process for the second form was the same, however, because the panels were coordinated in rows that are parallel, so must enter the rectification factor to the inter-panel’s shading. For an exact representation of an actual PV capacity, the ability to realistically representing flat roofs is essential. The presumption which PV panels were often paralleled with the roof contributes to a considerable underestimate of the radiation available.

The disparity among the yearly irradiance at a level panel (inclination = 0) and the panel in the optimal situation (orientation = 0 and inclination = 32°) was around 12 percent when there is no shading (Figure 2& Figure 3). Another model feature is its capability to classify the acceptable roofs for a PV system by considering various variables. Two filters were used; the first one to differentiate between landmark and monument structures, while the second filter to remove a free surroundings area on roofs. Then the area that has very low annual irradiation is excepted. We used the specifics in the “Code Of Building ” as the threshold in this case. Lastly, isolated areas (<1m²) were excluded, so the effective utilizable surface can be evaluated. The photovoltaic power for each building's utilizable surface is computed, considering each PV technology their average efficiency. Finally, production effectively is assessed from the irradiation, considering panel different types of losses and efficiency.

This model compares the performance of various technologies and the yearly electricity generated in each building. The preference of the appropriate technology may differ. For instance, for this paper, the most efficient panels are Si amorphous, but their overall output is less than a third of Si mono crystalline panels production. Therefore, a significant restriction on the choice of technology is the minimum energy produced.

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