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MAPPING, MODELING AND MEASURING PHOTOVOLTAIC POTENTIAL IN URBAN ENVIRONMENTS USING GOOGLE PROJECT SUNROOF

Tendai SYLVESTER MHLANGA [1]

Özge YALÇINER ERCOŞKUN[1]

[1]*Gazi University, Architecture Faculty, Department of City and Regional Planning, 06570, Ankara, TURKEY*

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Abstract

The knowledge of available photovoltaic potential on rooftops in urban environments is fundamental in achieving sustainable development and urban energy resilience. The use of solar energy in built environments has recently gained significance in urban energy planning. However, the implementation is marred by obstacles mainly in the triple fold. The quantification of rooftop solar energy potential, accessibility of data, cost, and savings that could be achieved for a particular rooftop or region. The article examines the utilization of 'Google Project Sunroof' software to simulate solar energy potential in urban settlements using the case study of Riverside, California, America. The study shows the importance of adding smart solar grids to the national electricity grid and how urban planning supported by solar stimulation tools influence urban energy resilience.

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1. INTRODUCTION

The world has significant economic growth, technological advancements, rapid population growth as well as the expansion of human settlements. Economic growth and urbanization move in tandem [1], [2] as experienced on economic growth and greenhouse gas emissions during the last century. Half of the world's population lives in cities and trends are projected to rise constantly in the future to 70% in 2050 [1], [2]. This subsequently increases the global energy demand utilized in the growing economy, technology, and urban environments. Cities consume 80% of the energy produced globally and constitute an approximate of an equal percentage of greenhouse gas emissions [1], [3], [4]. This compromises the goals for mitigating global warming and the impact of climate change. The immediate use of renewable energy sources in urban environments is required. Since 80% of the energy produced globally is utilized in urban areas, it is important to make use of urban solar grids. This validates the essentiality of reducing the emission of carbon dioxide through the use of renewable energy like solar energy. As the urban energy demand is constantly increasing, it is also crucial to increase energy production and supply to ensure sufficient energy and urban energy resilience.

There is a paradigm shift in urban energy planning from the use of non-renewable to renewable energy, mostly wind and solar. Globally, many cities are adapting to the use of solar energy to supplement the available energy sources and replacing fossil fuels with renewable energy. However, the installation of solar panels in the built environment is hindered firstly by the complexities in the quantification of the amount of photovoltaic potential available on a particular rooftop or city. Secondly, the uncertainty on data accessibility for a specific rooftop or city. Thirdly, the costs and savings that are achieved when using solar energy as compared to other sources. This knowledge gap is a major hindrance to the use of solar energy in the cityscape. Nevertheless, this study aims to fill this gap by examining the utilization of "Google Project Sunroof" software to simulate solar energy gain in urban settlements. Recently Google has solved all these difficulties through launching Google Project Sunroof in August 2015. Google Project Sunroof is a free online tool that allows the user to obtain estimations of potential solar production on their rooftops, and

* Corresponding author: sylvestermhlanga@gmail.com

provides all essential data from a rooftop to a city level, costs, and savings that are achieved through the installation of solar panels as compared to other energy sources [5]. This is done through analyzing high-resolution aerial mapping, 2D and 3D modeling of building rooftops to sun's positions, shadows cast by close objects, past weather patterns, and average electrical consumptions. It was launched in 2 states in the USA. Its coverage expanded quickly to 10 states by the end of the same year and to 46 states by the year 2016 [6]. In 2018 it widened its coverage into new markets across the globe. It has mapped more than 107 million rooftops in 21,500 cities across the United States, Germany, France, Canada, Argentina, Puerto Rico, Italy, the Netherlands, the United Kingdom, and Australia [7]. "Google Project Sunroof" is working only in these countries, it does not apply to other points of the world including Turkey. This is a weak point of that software, although data collection is ongoing to cover the whole world [8].

Although mapping, modeling and measuring solar potential using other software and solar maps such as Geographic Information Systems (GIS) is well documented in the international literature [9], [10], [11], there is a knowledge gap both in theory and practice on the use of Google Project Sunroof. There are various other solar simulations and energy gain software that are used to analyze the energy performance of buildings. These include Ecotect, Design Builder, Energy Plus, Revit-Open Studio, 3D Max, ArchiCAD, and open studio for Sketchup among others [12], [13]. Most of these software are from the Autodesk family, sophisticated software which are generally used by architects, engineers and urban planners. The study examines the application of Google Project Sunroof tool for mapping modeling and measuring solar potential through 2D visualizations and 3D representations using a case study of Riverside, California, America. This quantitative knowledge needs to be interpreted and integrated into architectural, landscape, and layout designs for the effective application of the Zero Energy Building Concept.

Solar energy is among the best environmentally friendly renewable energy source with the least negative impacts on the environment [14]. The production of energy through renewable sources, the abandonment of the use of fossil fuels, minimizing energy costs, and the dependence of the national urban grid in the demand side, constitutes the fundamentals for sustainable energy policy formulations [15]. These policies include new energy frameworks, legislations, and incentives for solar investments [15], [16], [17]. This makes the implementation of smart solar grids in the built environments a matter of significant interest. Restraining global warming to 1.5 °C would "require rapid and far-reaching transitions in the uses of energy, land, urban and infrastructure (including transport and buildings), and industrial systems" [2]. Urban energy efficiency has incredible potential in the reduction of greenhouse gas emissions. The Nearly Zero Energy Building concept emphasizes on the use of environmentally friendly energy as well as designing of compact cities that reduce transportation use to combat climate change.

2. NEARLY ZERO ENERGY BUILDING CONCEPTUAL FRAMEWORK

The Nearly Zero Energy Building (nZEB) concept proposed building to be partially independent of accessing electricity from the national grid but rather an on-site power generation strategy. This is achieved through a combination of methodologies such as building design, which maximizes the use of natural daylighting, solar energy, natural cooling, and the uses of renewable energy sources among other strategies [18]. Buildings require energy for cooling, and heating purposes as well as electricity for lighting and for electrical appliances. Buildings in European countries account for more than 40% of energy consumption, of which 63% of the total energy consumption in the building sector is used in residential buildings [19]. Therefore, it is fundamental to implement innovative and cost-effective strategies to increase building energy efficiency using onsite-based renewable energy by reducing building energy demand and increasing building energy generation. Solar, wind, and biomass are the most used energy sources under the Nearly Zero Energy Building (nZEB) Concept. Previous studies show that to achieve the (nZEB), there is a need to improve the building's energy efficiency in the design stage through energy simulation analysis and adopting renewable energy especially solar and wind energy.

The Pearl River Tower in Guangzhou, China is a typical example of an energy efficiency building installed with wind turbines for onsite power generation [20]. The tower is also integrated with a double skin insulation thermal curtain walls, solar panels, underfloor ventilation, and utilizes maximum sunlight. The Bahrain World Trade Center in Manama Bahrain is yet another example of a high energy performance building that also uses wind turbines for power generation [21] The use of wind energy within the city boundaries is uncommon, it is generally sited a short distance outside the city [22]. Urban morphology reduces wind speed, hence, wind turbines are mostly installed at seashores, mountaintops, and in suburbs where there is a relative abundance of space for wind farms, and high wind speed because of fewer obstacles [23].

Solar energy refers to radiant heat and light from the sun that is converted into electrical or thermal energy using various technologies such as photovoltaics and solar thermal [24]. Solar energy is a renewable and clean source of energy that is abundantly available across the globe. With technological developments, government policies supportive of the development and utilization of renewable energy have recently led to the reduction of solar prices and phenomenal growth in the use of solar energy [25], [26]. With the high adaption of the use of solar energy, this has led to onsite electricity production under the Nearly Zero Energy Building Concept. A solar map is an online-based tool that assists, informs, and educates users about solar technology through estimations of solar power generation on building sites or open spaces and provides data about related benefits [27]. Solar maps enhance greater community awareness about solar energy, enable users to realize the amount of solar potential that can be taped on their properties, and enable improved solar usage amongst property owners. The construction sector supported by solar stimulation software has a significant role to play in the successful implementation of the (nZEB) concept.

3. METHODOLOGY

The research used the case study of Riverside California, USA because of its accessibility to Google Project Sunroof Tool. The study area was selected because of its accessibility to Riverside Green Solar Maps that was also used to examine the distribution of solar systems installations in the city. Besides, Riverside California had implemented vast projects on solar panels and the study used some of the examples for comparisons on the effectiveness of the implemented projects on solar energy generation. Buildings and neighborhoods were selected at random to examine the variable that determines the generation of solar energy in urban environments, such as layout form, landscape, vegetation cover, building density and height as well as building orientation, roof angle, and type (flat or pitched). Google Project Sunroof automatically calculates the total amount of solar potential for a particular selected city, location, and building [28]. It does not require additional work to redesign the existing model using CAD software such as in Ecotect, Rivet, Design Builder, Open Studio which require high skills in Autodesk software [12], [13]. Besides, Google Project Sunroof is a free online tool that can be accessed by everyone as compared to other software that requires a license. However, Google Project Sunroof does not provide the energy performance of the building as compared to other Autodesk software. It only provides estimations of solar energy production would the roof installed solar panels. Another important data set was acquired from the National Energy Renewable Laboratory (NREL) [29]. Other data sets were obtained from the website energy tool of the U.S Department of Energy, energy efficiency, and renewable energy [30]. This method was also applied by NREL on the estimation of solar potential in San Jose, California. An interview on email with the project manager of Google Project Sunroof, was conducted on the development and growth of the project.

4. RESULTS AND DISCUSSION

Following the preset assumptions criteria and methodology of Google Project Sunroof, the solar energy production potential on rooftops was calculated for all buildings (residential, commercial, industrial buildings, institutions, etc.) in the study area. The buildings were then classified into different color shadings relating to their degree of solar energy generation capabilities, roof suitability, orientation, and roof pitch (Figure 1).

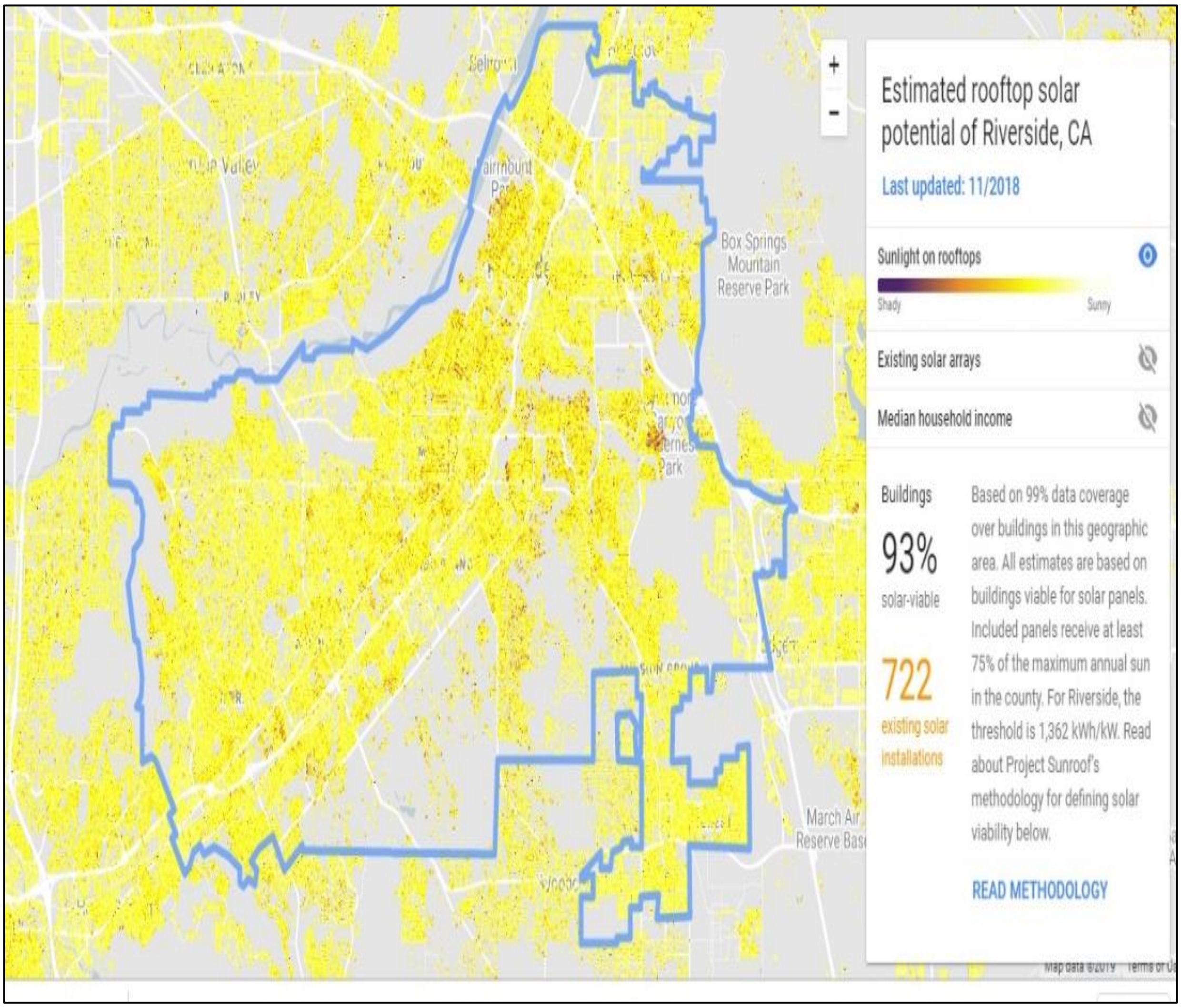


Figure 1. Riverside CA, Google Project Sunroof Map [5].

Figure 1 shows the total input of the Riverside city in Google Project Sunroof. It shows the potential annual solar energy radiation that can be obtained from each rooftop through different shadings. The estimations are based on 99% of data coverage on buildings in the study area. All of the estimations are based on the viability of buildings for solar panels. Panels receive a maximum of at least 75% of the annual sun that hits the rooftop. Findings show that Riverside, California has a threshold of 1,362 kWh/kW and 93% of the roofs in the city are suitable for solar systems installations. An estimation of 722 (0.94%) rooftops out of an estimation of 76,600 (93%) suitable rooftops in the study area are installed with solar systems. [5].

Figure 2 shows the result analysis of solar energy generation to building orientation (face of the roof) and roof slope, angle (pitch). The findings show that Riverside, CA has a potential of annual solar energy generation of 2,304,300 MWh. The flat roofs produce 626.8 MW followed by South facing 324.2 MW, West facing 283.4 MW, East 203.8 MW, and North facing 51.8 MW annually respectively. Therefore, an average estimation of 1,500 MW can be generated annually [5]. The results show that there is a positive relation between layout pattern and landscape design to solar energy generation in cities. This shows that flat roofs have more potential for generating solar energy than all roof types.

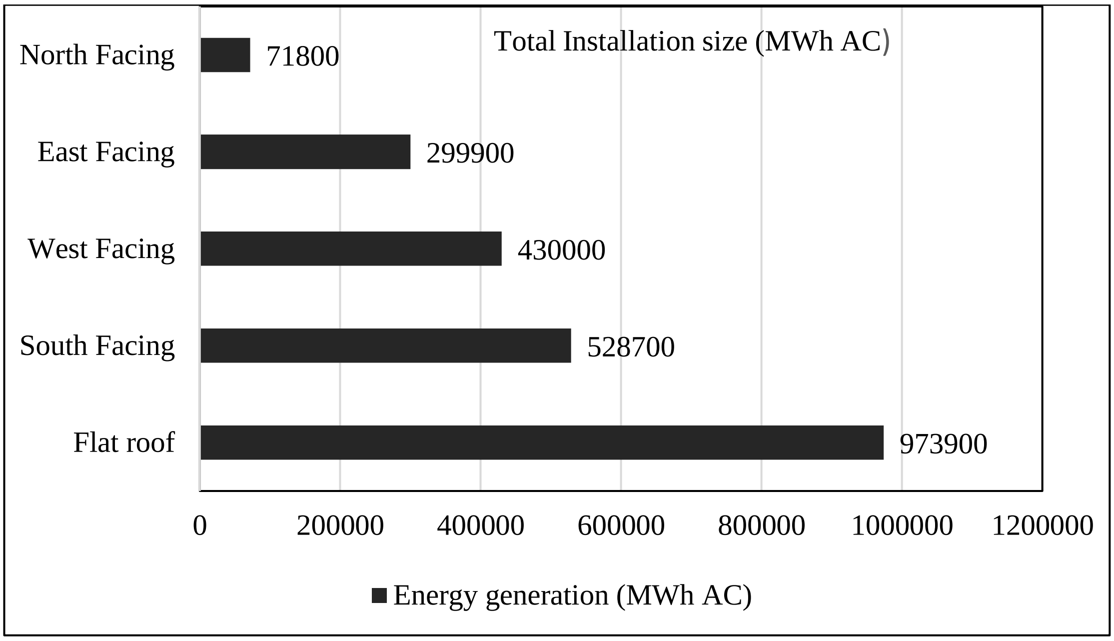


Figure 2: Total Yearly Solar Energy Generation Potential for Riverside, CA [5].

Figure 3 shows the rooftop solar capacity distribution of the number of roofs with the potential capacity to generate solar energy between 5 kW and 50 kW per rooftop. A total of 73,687 (96% of total suitable roofs in Riverside, CA) roofs have the potential capacity to generate solar energy between 5 kW and 50 kW per rooftop. The mode falls in the range of 5-10 kW with a total of 21,700 roofs, 51% of the rooftops that can generate solar energy between 5 kW and 50 kW. Most of the rooftops that can generate an estimate of 5 to 50 kW of solar energy are in the range of 5-10 kW and 15-20 kW. They add up to 42,800, which is 58% of the total rooftops that have the potential capacity to generate 5 to 50 kW of solar energy annually. Suppose all the rooftops within the range of 5 to 20 kW of generation capacity are installed with solar panels, they would produce a minimum of 214,000 kW (214 MW) which is more than the 45.3 MW that was being produced by the end of the year 2018 [31].

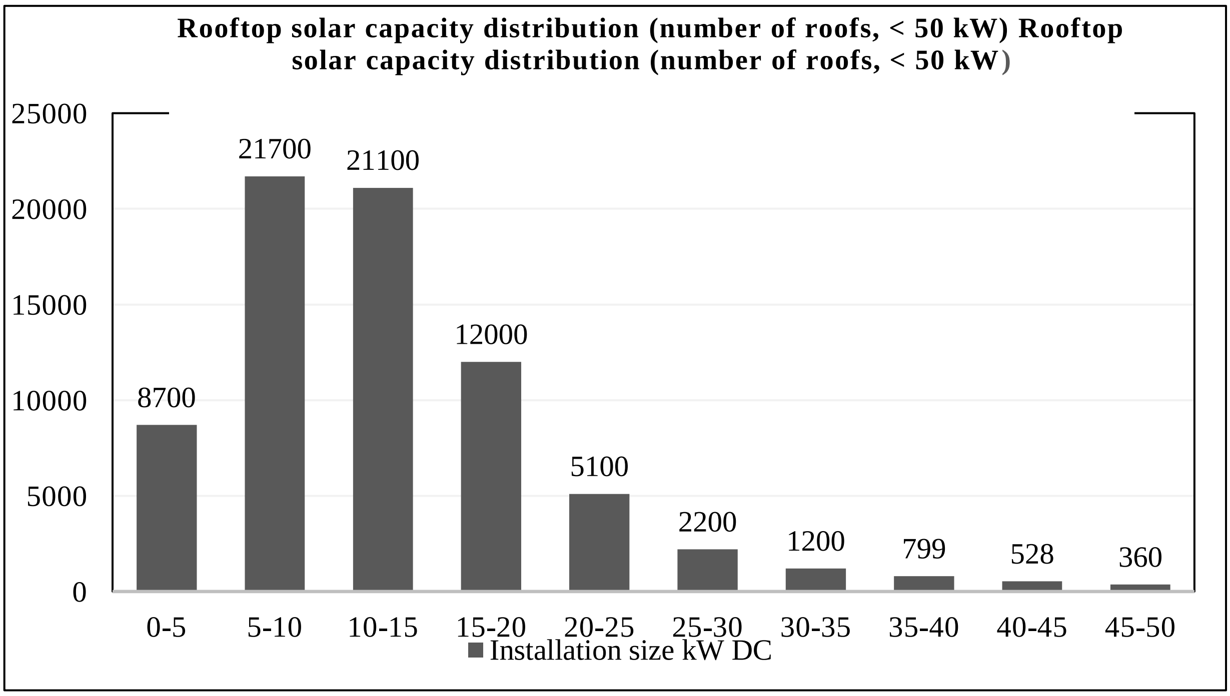


Figure 3: Total Yearly Solar Energy Generation Potential for Riverside, CA <50 kW [5].

Figure 4 shows the rooftop solar capacity distribution of the number of roofs with the potential capacity to generate solar energy more than 50 kW per rooftop. A total of 3001 (4% of total suitable roofs in Riverside, CA) roofs has the potential capacity to generate solar energy above 50 kW per rooftop. The mode falls in the range of 50-100 kW with a total of 1,600 roofs, 53% of the rooftops that can generate solar energy between 50 kW and 100 kW. A larger number of the rooftops that have an annual potential generation capacity of above 50 kW falls in the range of 150 to 200 kW. They add up to 2,223 which is 74% of the rooftops that can generate solar energy above 50 kW annually. Presuming that, all the rooftops that can generate 150 to 200 kW of solar energy annually are installed with solar panels, they would generate at least 111,150 kW (111 MW) which is double above the 45.3 MW produced by the end of the year 2018 [31].

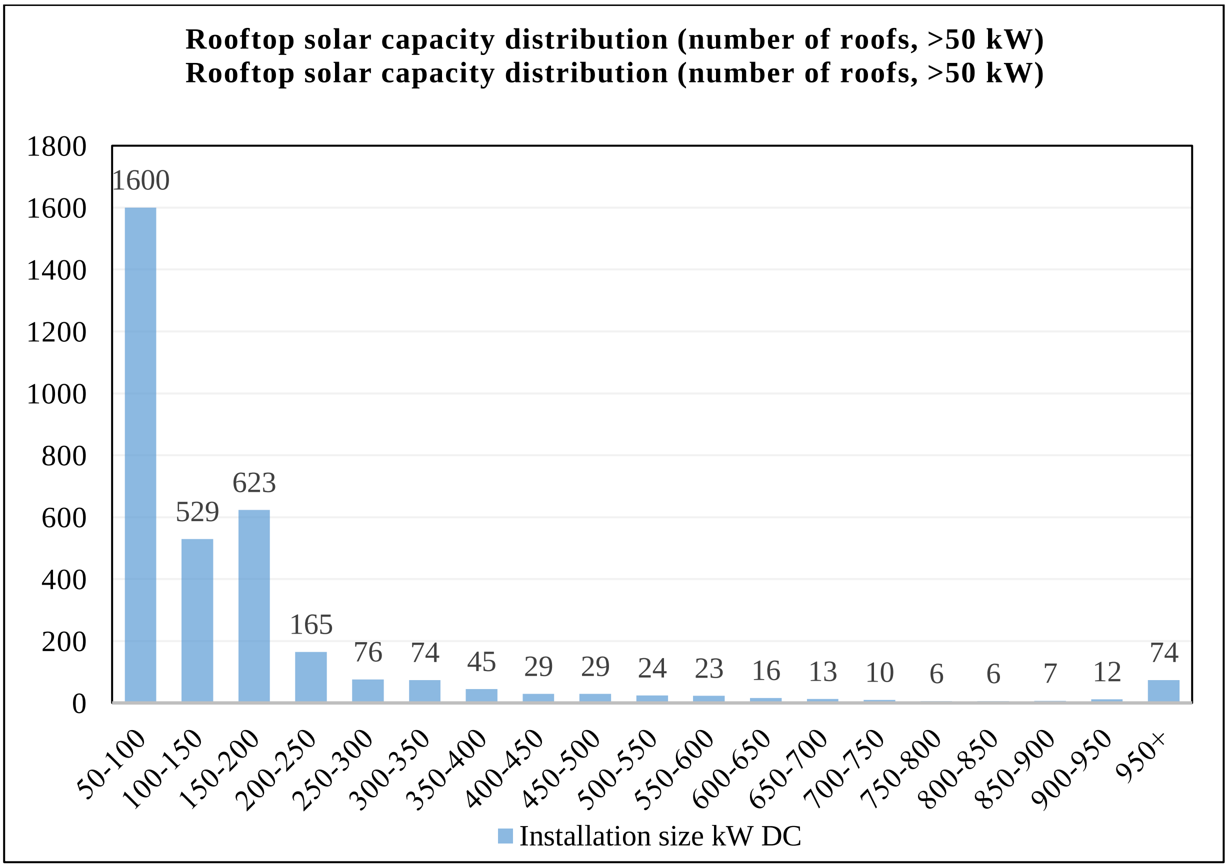


Figure 4. Total Yearly solar energy generation potential for Riverside, CA >50 kW [5]

Figure 5 shows that 93% of the total roofs in the city are suitable for solar systems installations and gives a total of 76.6 thousand (76,600) roofs (buildings) including residential, commercial, and industrial buildings. Therefore, 7% of the roofs are unsuitable for solar energy generation. Thus, 7% of the 76,500 roofs (buildings) gives a total of 5362 roofs (buildings) unsuitable for solar power generation. Using these results from Google Project Sunroof, it means that Riverside, California has an approximate of 81,962 buildings (93%, 77,500 suitable roofs + 7%, 5362 unsuitable roofs). The findings from a total estimate of solar energy potential on rooftops from Google Project Sunroof shows that Riverside, California has a technical potential to install 1,500 megawatts (MW) of solar energy capacity and can generate 2.3 million megawatt-hours (2,300,000 MWh) of electricity per annum generated from 76.6 thousand (76,600) roofs. A similar comparison analysis of Riverside, California was also done using data estimations from Cities-LEAP for the available photovoltaic potential for small building rooftops which is available on SLED to calculate solar technical potential on residential rooftops (Figure 6).

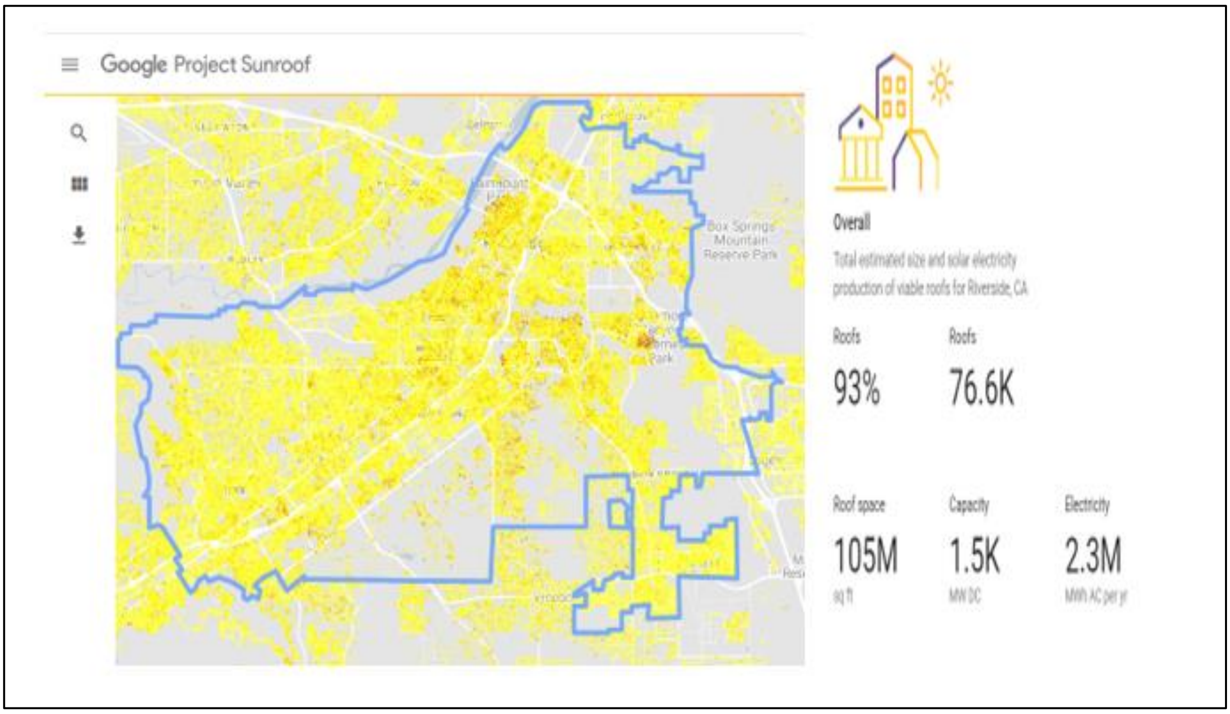
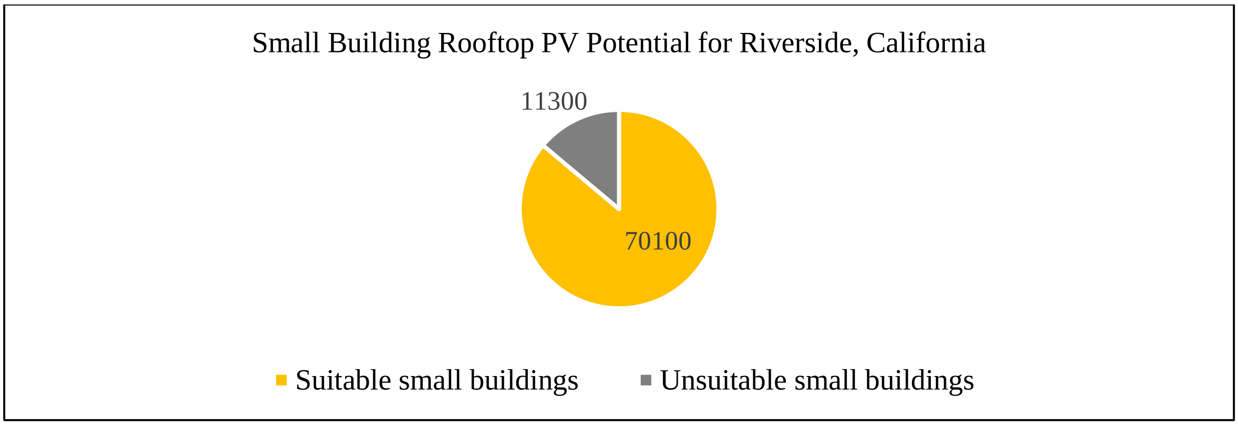


Figure 5. Shows Riverside CA, Google Project Sunroof Map, and Photovoltaic Potentials [5].

Cities-LEAP estimates are based on the assumption that all buildings with a total area of 5 thousand (5000ft^2) square feet or less are for residential purposes. The results show that Riverside, California has a total approximate of 81,400 (100%) buildings (11,300 (14%) unsuitable roofs + 70,100 (86%) suitable roofs). The findings show a slight discrepancy in the total number of buildings or roofs computed by the two methods. Cities-LEAP estimates detected a total of 81,400 buildings (roofs) while Google Project Sunroof computed 81,962 buildings (roofs). This is subject to the difference in formulas and updating of data. Riverside, California has an approximate of 612 MW of installed capacity and 939,377 (MWh) megawatt-hours per annum of electricity generation obtainable from 70,100 roofs/ buildings (suitable roofs). Subtracting the rooftop technical potential of residential buildings (612 MW) (Figure 6) from the total rooftop technical potential (Figure 5) (1500 MW) produces an approximate of 888 megawatts (59%) of solar energy capacity and 1360623 MWh, per annum of potential generation from an estimation of 6500 from commercial buildings rooftops.



Suitable area	**4,279,750 m^2**
Capacity potential	612,066 kW
Energy generation potential	939,377 MWh

Figure 6: Small Building Rooftop PV Potential for Riverside, California [30].

4.1 Market potential estimations

Nevertheless, estimations on technical potential through roof azimuth, 2D and 3D model shading, tilt, pitch, and (angle) and tilt, of the available rooftop area suitable for solar systems installation don't consider market potential factor and estimations. According to NREL, 2018, "to adjust the technical potential to reflect market factors such as building ownership and the ability of the rooftop area to meet a sufficient percentage of occupant load, different approaches are applied to the residential and commercial sectors." Table 1 shows housing characteristics for occupied housing units in the study area.

Housing Type	Occupied housing units	Owner-occupied housing units	Renter occupied housing units
	Estimate	Estimate	Estimate
Occupied housing units	90778 (100%)	50384 (55.50)	40394 (44.50%)
Units in structure			
1, detached	60582 (66.71%)	46274 (91.84%)	14308 (35.42%)
1, attached	3559 (3.93%)	1,678 (3.33%)	1,881 (4.66%)
2 apartments	1339 (1.42%)	155 (0.31%)	1,184 (2.93%)
3 or 4 apartments	3605 (3.97%)	276 (0.55%)	3,329 (8.23%)
5 to 9 apartments	6287 (6.93%)	141 (0.28%)	6,146 (15.22%
10 or more apartments	5213 (5.74%)	80 (0.16%)	5,133 (12.71%)
20-49 units	3569 (3.93%)	129 (0.26%)	3440 (8.52%)
50+ units	4639 (5.18%)	82 (0.16%)	4557 (11.28%)
Others	1985 (2.19%)	1569 (3.11%)	416 (1.03%)
TOTAL	90778 (100%)	50384 (100%)	40394 (100%)

Table 1. Physical Housing Characteristics for Occupied Housing Units in Riverside, California [30], [calculations were done by authors].

Tenants renting buildings for residential purposes, without ownership of the building, generally live in an apartment with more than three stories and the building lacks sufficient space for solar systems installations [32], [33]. There is a strong correlation between property ownership and solar systems installations [34], [35]. Using the housing and urban development analysis in Table 1, it indicates that, 55.5% of the households are owner-occupied and 44.5% are rent-occupied. 96% of the owner-occupied households have less than four stories (Table 1). This shows a high potential for more roof space and the financial capabilities for solar systems installations. The majority of the overall solar energy generation potential of residential buildings is situated in single-family houses as compared to multifamily apartments. Using data from SLED, it shows that, 86% of small rooftops are technically suitable for solar panels installations (Table 1) [30]. This data was used to estimate the market potential of the rooftop for residential purposes in Riverside California. The number of estimated rooftops is multiplied by 5 kW [33], the average installation capacity for residential buildings which also dovetails with the analysis done from Google Project Sunroof for Riverside, CA to estimate the potential market of 207 megawatts of PV capacity. Photovoltaic Watts Calculator Tool also estimates a similar average of 5 kW [29]. To calculate the megawatt-hours that can be generated from 5 kW, the NREL's Photovoltaic Watts Calculator Tool was used [29]. The tool estimates that 5 kW can produce an average of 7.7 megawatt-hours (MWh) as shown in Table 2.

Table 2 shows that Riverside, CA has a total approximate of 48,109 structures with both suitable and unsuitable small rooftops for residential purposes. 86% of the structures (41,374 rooftops) are suitable for solar panels installation. Given an average of 5kW of residential capacity for a rooftop, 41374 rooftops produce an average of 207 megawatts and 318,580 megawatts-hour annually.

Owner occupied housing type	**Housing Units**	**Structures**
1 detached	46,274	46,274
1 attached	1,678	1,678
2 apartments	155	78
3 or 4 apartments	276	79
Total	48,383	48,109
Market potential at Cities-LEAD/SLED 86% suitable small buildings (0.86x total structures		41374 rooftops
Market potential at 5 kW per rooftop (number of rooftops x 5 kW)/1000 kW		207 MW
Market potential at generation of 7.7 MWh per 5 kW (number of rooftops x 7.7 MWh)		318,580 MWh

Table 2. Residential market potential estimations. [calculations were done by authors].

The capacity and size of solar panel installation for commercial and industrial buildings including private and public institutions such as educational and government buildings vary widely with the type and use of buildings [33], [32], [34]. Most commercial buildings have a bigger space for solar installation because of the bigger size of the rooftop area. However, normally most of the rooftop space is occupied by air conditioning systems. The bigger rooftop space available on commercial buildings means a higher potential for solar energy generation on commercial buildings. 52% of non-residential customers have the capability for solar systems installations [32], [33]. Therefore, using an estimate of 52% of non-residential customers who have the capability for installing solar systems in Riverside California produces an estimate of 3,380 rooftops (52% 6500 rooftops). The 3,380 rooftops would produce a market potential of 462 MW (52% of 888 MW technical potential) and 707,524 MWh (52% of 1,360,623 MWh technical potential) on market potential.

		Residential	**Commercial**	**Total**
Technical potential	Number of rooftops	70,100	6,500	76,600
	MW	612	888	1500
	MWh	939,377	1,360,623	2,300,000
Market potential	Number of rooftops	48109	3,380	51,489
	MW	207	462	669
	MWh	318,580	707,524	1,026,104
Total installed Capacity 2018*	Number of rooftops	722		
	MW	45.3		
Unrealized market potential	MW	624		

Table 3. Commercial market potential estimations * [31], [calculations were done by authors].

4.2 Rooftop level estimations and modeling

Figure 7 shows a detailed analysis of a specific building. From the results obtained, it was deduced that the building has 1,934 hours of usable sunlight annually based on annual weather patterns of the city and on that particular building. This size would cover about 98% of the building's electricity usage. Solar installations are sized in kilowatts (kW) 4.5 kW (317 ft^2). A total area of 1,180 square feet is available for solar panels installations. The estimated annual environmental impact of the recommended solar installation size reduces carbon dioxide which amounts to 3.7 metric tons annually. This is almost equivalent to the removal of 1 car from the road annually or the planting of 94 trees for 10 years. The total cost of procurement, installation, and using the solar system on the building for 20 years is $15,808.00 while the total cost of using electricity for the same period is $26,988.00 with an assumed 2.2% annual increase in the price of electricity. Hence, the analysis shows a 20-year savings of $11,000.00. Using this average for the whole city (76,600) suitable rooftops add up to a 20-year savings of $842,600,000.00.

Figure 7. Specific building analysis [5],[developed by authors using Google Project Sunroof].4

4.3 Layout and landscape designs on photovoltaic generation

Figure 8 shows the rooftop satellite image displayed in Google Project Sunroof. The results showed that solar energy production potential on rooftops is affected by many factors including the direction of the roof (building orientation), the roof pitch (angle of its tilt), and physical obstacles such as trees. The final output of the analysis shows different of shadings brownish and yellowish colors. Rooftops with yellowish color are optimally best-suited roof for solar energy generation. The images show that vegetation cover, urban form building density, and orientation affects solar energy generation. Therefore, urban planners must take considerations of these factors when designing layout plans and crafting policies on building and vegetation cover.

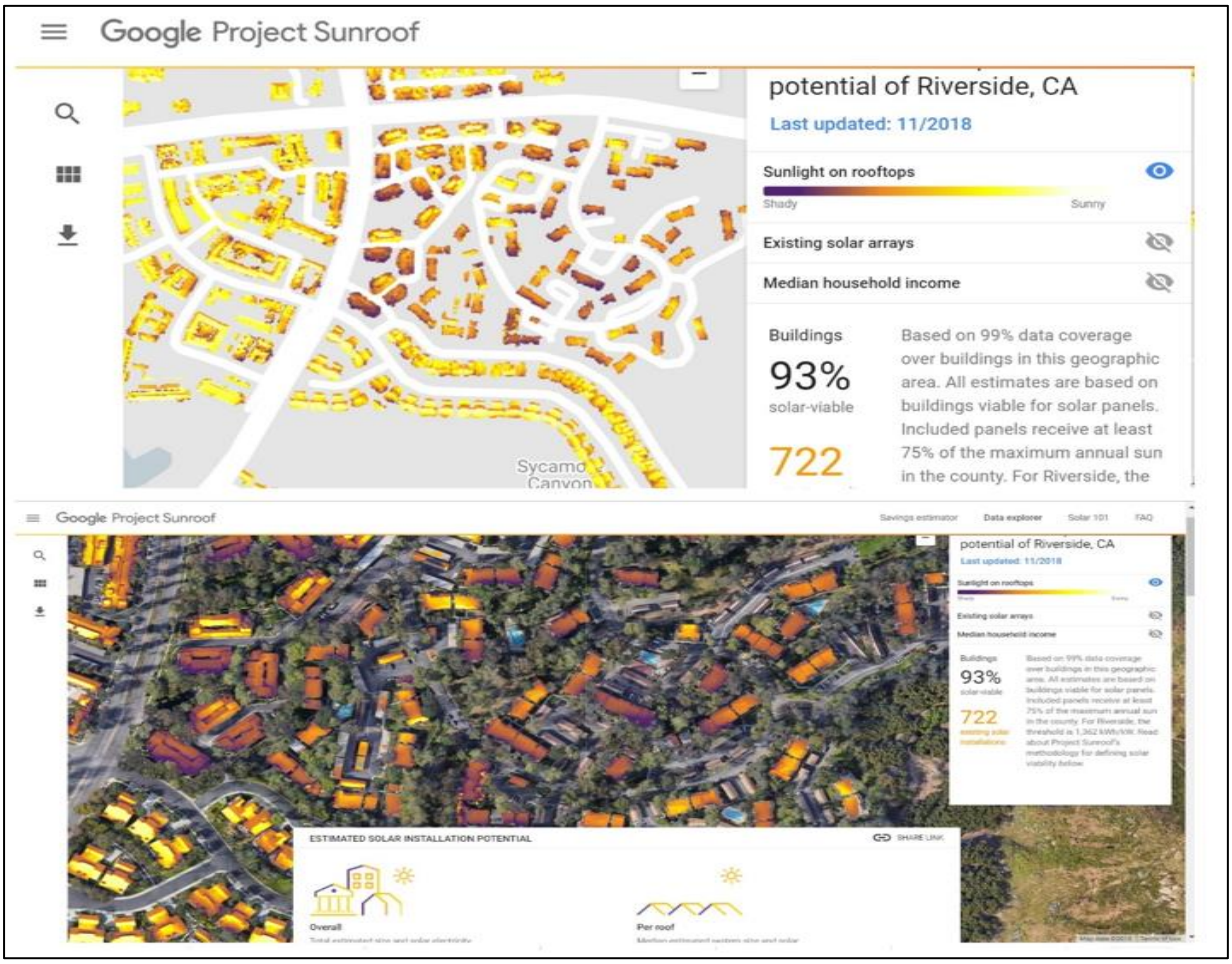


Figure 8 The Relationship Urban Planning Solar Generation [5], [developed by authors using Google Project Sunroof].

4.4. The Potential impact on CO_2 emissions

The use of solar energy in cities reduces the emission of carbon dioxide hence reducing the urban carbon footprint. Given that, all the suitable rooftops have solar panel installations, the amount of avoided CO_2 emissions from the electricity sector in Riverside would be 628,000 metric tons. This is equivalent to the removal of 133,000 cars from the road within a year. This is calculated using the eGRID subregion CO_2 equivalent non-baseload output emission rates [5]. This is also equivalent to the plantation of 16.1million tree seedlings within 10 years with calculations based on the assumption that 0.039 metric tons CO_2 per urban tree planted [5]. The reduction of 628,000 metric tons of annual emissions CO_2 is 27% of the total of 2,343,400 metric tons emission of greenhouses gases emitted in the study area in 2013 [5]. To strengthen the efforts to mitigate global warming and climate changes governments, local authorities and households must adapt to solar energy. Every level has a crucial role to play. Governments and local authorities must formulate policies and incentives in the production and importation of solar equipment to ensure a broader installation and affordability to the general public. The destabilization of the global climate because of the anthropogenic emission of greenhouse gases (GHGs) is one of the most urgent contemporary global issues [36] [37].

4.5. The contribution of rooftop photovoltaic to renewable energy

The estimated rooftop PV market potential of Riverside, CA is equivalent to 44 % of the 2,331,111 MWh consumed in Riverside, California in 2016. This estimate is based on data from NREL 2016. Comparing this figure from Google Project Sunroof findings shows that, Riverside, CA has a potential solar energy generation of 2,300,00 MWh annually and could meet 99% of annual electricity consumption in California overall. The installation of solar panels on the rooftops of residential, commercial, and industrial buildings reduces carbon footprint through the reduction of greenhouse gas emissions, promotes sustainable development, and combats climate change.

4.6. Integrating google project sunroof to urban planning

Analysis of solar energy potential on rooftops in urban environments is important to architects, local authorities, and urban planners among other professionals. Layouts and building designs have an impact on solar energy potential. Findings show that there is a relationship between building orientation, landscape, and building design with the amount of solar energy generation potential that can be obtained from rooftops. With the availability of these solar map tools such as Google Project Sunroof, they assist in the development of layout plans and the designing of building plans that promote the absorption and utilization of solar energy. Buildings would be designed in such a way that they would be energy efficient by enhancing the use of natural sun lighting and cooling systems to limit the amount of solar energy that is used by the building. Urban layout patterns influence traveling distances and the amount of energy spent on powering urban transportation systems. Mapping, modeling, and measuring solar energy potential in urban environments would assist urban planners in carrying out urban renewal projects to change roof types, layout and structural design on an existing building. However, roof types are also subject to climatic conditions of the area. For instance, in snow regions flats roofs might not be applicable. The analysis would also help in policy formulation such as determining building standards and codes in terms of building heights, vegetation cover, and tree heights as well as building density and form among others [38].

5. CONCLUSION

This study was conducted to provide a review of Google Project Sunroof as a contemporary methodology for estimating the amount of photovoltaic potential available, data accessibility, and cost analyses on rooftops in cityscapes. From the results obtained, it was deduced that 93% (76,600 roofs) of roofs in the study area, Riverside, California are suitable for solar panels installations. The total photovoltaic potential capacity upon the rooftop is 1,500 MW and a total of 2,300,000 MWh electricity annually. Urban solar energy potential is positively related to the urban morphology as well as roof type and orientation. Therefore, solar energy planning must be integrated into urban planning during the layout and building design planning process. For existing buildings, renovations on types of roofs are recommended as the results showed that flat roofs have more solar energy generation capacity. With the realization of the significance of and the amount of photovoltaic potential on rooftops, it is also important for architects and urban planners to take such considerations when designing buildings and layouts in urban environments. Integrating solar energy planning from a layout and building level, determining the building orientation, roof type, and tilt is required as this affects solar energy production. When solar energy planning has been taken into account at the early stage of the layout and building design process, it would produce more attractive solutions for the production of energy efficiency buildings under the concept of nearly zero-energy buildings.

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