Estimation of London's Rooftop Solar Energy Potential

Using GIS as a tool

Ömer Faruk Eriş (20198890)

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1.Introduction

As cities grow, so the demand of energy is increasing, and electricity is one of the widely used form of energy in various industrial sectors as well as residential applications. In current status, fossil fuels are commonly preferred to harvest electric energy. However, this process results in huge amount of green house gas emission which directly connected with global warming. An alternative solution to this is looking for renewable energy sources. Sun as a great energy source of all kinds is also a perfect tool to harvest electric energy in a renewable and healthy way. Solar photovoltaic panels are one of the most effective and efficient way to directly harvest energy from sun in order to meet energy demand for our cities. But how much can it meet our energy demand? Do we know the real potential of solar photovoltaic modules?

If we look at energy demand of one of the biggest cities in the world, London consumed 272 GWh of electricity in 2019 (Douts et al. 2011). Just by looking this amount we can easily say that demand and supply of electricity is not sustainable because it is mostly derived from fossil fuels. There should be limit with the current supply process, and global warming is a harbinger that we are approaching actual limit. Therefore, transforming to green energy from fossil fuels should be an essential point in these days. Government as an decision maker should lead people to use solar photovoltaic panels and warn people about the risk of global warming and the benefits of solar green energy. Although the number of huge solar panel fields has increased recently, application of PVs in city is still limited due to the restricted size of site (Carl, 2014). However, rooftop of buildings can be a perfect location to install photovoltaic panels in cities to harvest energy efficiently by making available space that is already unused. This idea raises a research question: How much energy could be generated if all roof area covered with PVs rationally and efficiently, and how much of this energy produced meets the demand of the city? In this paper, these questions asking the technical potential of the PVs will be answered by using GIS based tools. In addition, there will be not only technical potential but also environmental and economic potential of PVs.

2. Literature Review and Data Used

2.1 Study Area

Selected study area is the capital and largest city of UK: London. It is located on 51° latitude with an oceanic climate. It has more than 8 million population and 1,572 km2 area. London covers 33 boroughs and mean electricity consumption per meter in 2019 is 3.447 KWh (Doust et al. 2011). There are high-rise buildings for both residential and commercial purposes.

Therefore, shadows on building rooftop are highly probable. In this paper, technical and environmental potential of PV panels on rooftop in London will be researched and the generated output from potential panels will be compared with current electricity consumption delivered in London Database Website. To calculate rooftop area, building footprint data in London is taken from OS OpenMap updated in October 2020.

2.2 Solar Radiation

Electricity generation from photovoltaic panels depends on several global, local and spatial conditions. But the most important factor is the amount of incoming solar radiation to solar panels. There are three different type of solar radiation: direct beam, diffuse and ground-reflected radiation (Perez et al. 1987) as shown in Figure 1.

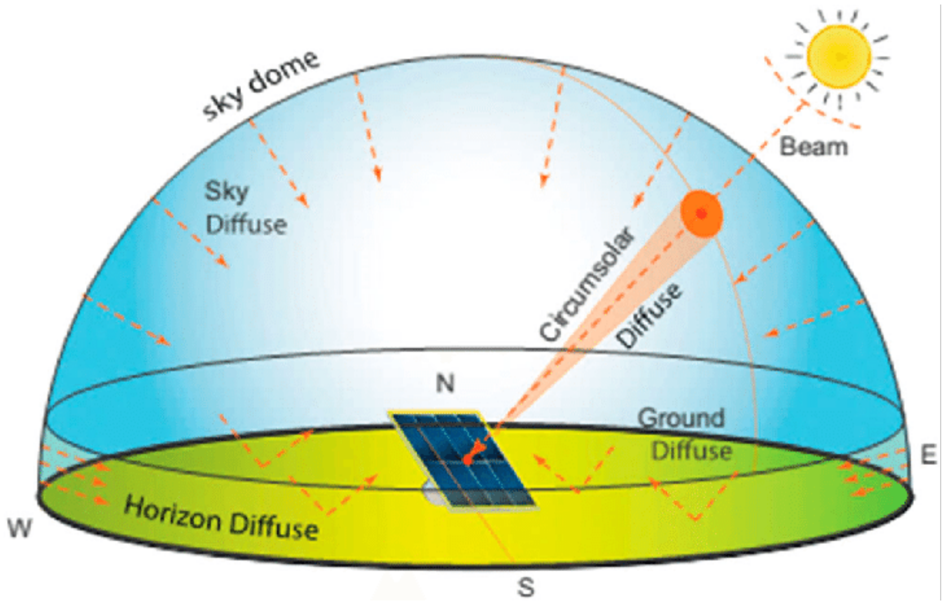

Figure 1: Solar Radiation

Direct radiation is the direct beam of solar ray coming to the surface without any obstacles. However, diffuse and reflected radiations are not directly touched the surface without any interactions, where diffuse radiation is affected by atmosphere and reflect radiation is secondary radiation reflected from ground surface (Perez et al. 1987). Each location in the earth is identical in terms of solar radiation. For example, if there are more cloud in the specific location, this causes to increase diffuse radiation and decrease direct radiation. Solar radiation data can be found from different datasets. In this research, NASA SSE Solar Radiation Archive will be used.

2.3 Constraints Affecting Solar Photovoltaic Panels

Energy output of PV panel depends on three important factors: Technical, Economical and Environmental as shown in Figure 2. As in solar radiation uniqueness regarding to location, each factor is identical according to location.

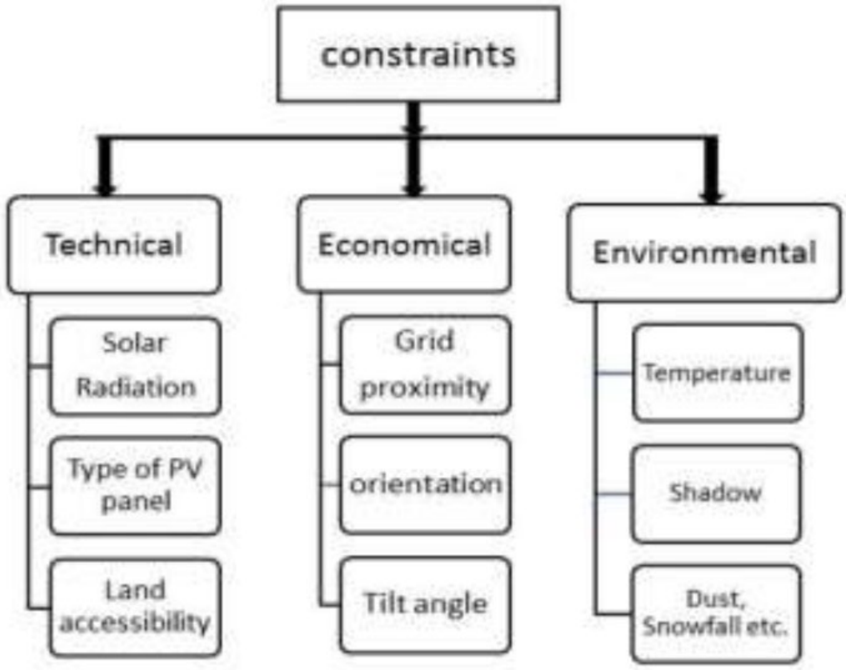

Figure 2: Constraints of PV Panels

Most important factor is solar radiation to surface mentioned above. For the environmental part, temperature is also another factor affecting the performance of the panels. However, the main environmental factor reducing output is shadows. Therefore, in this research shaded areas on rooftop considered as not suitable for PV applications and will be removed. In addition, because the main aim is maximising solar radiation for maximum energy output, the part of the roofs facing north will be also removed. Economically, building PV panels on these parts of roofs will not give efficient energy output.

2.4 Type of PV

There are two main way while planting PV panels on roof-top of buildings: Off grid and grid tie systems. Off grid system is completely disconnected with utility company, it means that in each building, owners are decision making for electricity generation and maintenance. In this system, all the electricity generated does not utilised completely because it is not connected to grid system. When the building satisfies its energy need, remain can be stored with batteries or disappeared. On the contrary, grid tie systems which is most common way, connect with utility and excess power can be attached to the grid (Jamal, 2014). As we are looking for maximum efficiency regarding to technical and economical, all the PV panels will be installed to rooftop are grid tie system.

2.5 Lidar Data

Light detection, and ranging is an optical remote sensing technology like RADAR. It uses laser light in order to produce high resolution digital elevation model (DEMs) that contains x, y, z variables (Wong et al. 2016). The data is taken from Defra Data Services Platform stored as raster format. The latest version of LIDAR Composite DSM data is delivered in 2017 with 0.5 average point spacing.

2.6 Recent Studies

Several methods were used for calculating rooftop photovoltaic panel potential. It can be classified into three categories: Constant based method which is traditional and popular due to its simplicity and it assumed that there are typical PV panels and roof, Manuel selection method which is basically manually selecting rooftop from aerial photography, and finally but most effectively and widely, GIS based method which ideal values are given to computer and let the computer to calculate it (Melius et al, 2013). This research is more connected with NREL method which is a part of GIS based method. In NREL method, from LIDAR and footprint data, unshaded roof space area and roof orientation area calculated with the help of GIS tools. There are several studies that NREL method have been used for different cities such as Seoul (Hong et al, 2017) and Lisbon (Brito et al, 2012). In GIS based methods, new approaches are emerging day by day such as AI approach and 3-D Model approach. For example, machine learning algorithms, which AI help to calculate potential rooftop area, have been used in Assouline et al, 2017 and 3-D urban methods, which modelling all city and building solar analysis model on it, have been used in Lukac et al, 2016. All examples mentioned above is generally city scale calculations. In 2015, Google first launched new project called Project Sunroof. There are not only city-scale rooftop potential calculations but also global and nationwide estimations. In 2017, Google reported that every inch of U.S, approximately 60 million rooftops, is calculated for potential rooftop analysis (Fehrenbacher, 2017). Google uses simple methods to calculate energy and environmental characteristics output by creating rooftop footprint from Google Earth aerial photography and modelling solar analysis according to weather data. Because of vast information data they have, it has great potential for the future. However, there are still several limitations: Google assumes that all roof planes will be covered by PV panels (Google Project Sunroof, 2015). It results in large, generated electricity, and in some cases, results say that some parts of city are self-sustainable regarding to electricity, but indeed, covering all rooftop is not efficient economically. This is clear distinction between this research and Project Sunroof.

3. Methodology

The analysis of London rooftop PV potential has two main stages. While first one is more related to GIS tools, second one is related to constant methods. At the first stage, QGIS program is used in order to characterise which parts of rooftop area is suitable for PV installation. Suitability depends on two factors: Eliminating north facing part of rooftops and removing shaded area on rooftop. At the second stage, R Studio program is used. In that part, calculated suitable rooftop PV area is grouped according to wards in London. After this process, technical and environmental constants are applied to create solar potential map.

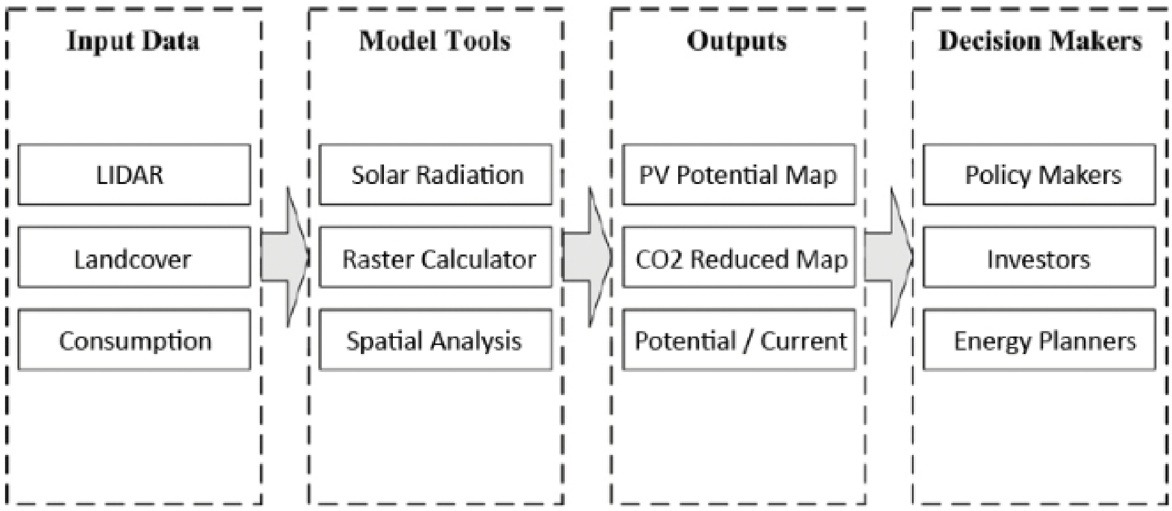

Figure 3: Framework of Analysis Procedure

3.1 GIS Calculations

3.1.1 Aspect Analysis

As mentioned above, LIDAR data is taken from Defra Data Services Platform and it is delivered In 2017. Firstly, with the help of QGIS, 0.5 point spaced LIDAR data is transformed to aspect data which give the slope data of each surfaces. Raster calculator classifies which parts of surface is suitable for PV installation. Binary raster data is created at the end of this process. While 135-225 degrees from North have value 1, other parts have 0 value. As a result, we have data cleared of north facing surfaces including building rooftops and roads, plants etc.

3.1.2 Shadow Analysis

Secondly, shadow analysis is applied to eliminate surfaces which are always shaded. To do this, UMEP plugin in the QGIS is used. It is an extensive plugin created for urban climate analysis in general. Although, it has an option of PV potential analysis which include detailed analysis by using weather and LIDAR data, it is only suitable for smaller area. Because we have a relatively large raster file of London LIDAR data, this option is not available for analysis. Instead, just shadow analysis is applied to remove always shady areas. The last step is processing generated binary raster file so that it can only contain building footprints. Therefore, with footprint data taken from OS Open map (October 2020), binary raster data is filtered into shape file which only include building footprints. As a result, we have total suitable rooftop PV area.

3.2 Constant Calculations

To make solar calculations, the generated data from QGIS is imported to R studio. In addition, ward data and electricity consumption data according to wards are imported. Total suitable PV area in general and in ward-scale are calculated. Because there is difference between LIDAR 2017 and Footprint 2020 dataset, approximately 200 buildings are missing. Average ratio of suitable area of total rooftop area is 0.72. Therefore, these missing values are traditionally calculated by multiplying ratio by total rooftop area. The next step is calculating solar energy output, environmental output.

3.2.1 Solar Output

Average solar radiation and rooftop area are the essential elements of estimating solar PV electricity output in addition to technological limitations. PV panel efficiency, slope and distance to grid are also important parameters. To calculate energy output, it is essential to consider all limitations and parameters. But before calculations, it is better to clear assumptions on this research. Potentially installed PV panels are considered as crystalline silicon PV systems which are popular but also technologically advanced currently. In addition, each location on earth is identical in terms of solar radiation values. However, due to the large datasets and limited time, average solar radiation value taken from PVGIS database is applied. PV-GIS (Photovoltaic Geographical Systems) is an effective tool to calculate solar radiation around world. Besides, slope of PV panels are assumed to be optimal. The equation which PVGIS web tool to calculate the annual energy output of PV panels is:

$$E_p = E_{ma} \times kW_p \times \eta$$

Where E_p is annual average energy produced in kilowatt hours (kWh), E_{ma} is available solar radiation on the time of year and weather conditions. This value will be delivered from PV-GIS tool for London (1108 kWh/m^2). η is efficiency of cell and general accepted value of η is 0.77 (Carl, 2014). kW_p is peak nominal power with an equation:

$$kW_p = n \times W_p \ / \ 1000$$

Where n is the number of modules and W_p is nominal peak power of 1 cell. For the calculation, standard rooftop PV panels will be used. Single PV panel has 1.6 m^2 area and 250 W peak power.

3.2.2 Environmental Output

The regional greenhouse emission reduced by PV panels is essential parameter for decision makers. Although, greenhouse emissions produced because of traditional electricity production, the PV system is a great tool of both energy saving and carbon emission reduction (Sun, 2013). For the large PV implications as applied in this research, there is huge reduction in carbon emission. To calculate how much CO_2 pollution PV panels save, electricity consumption and greenhouse emission dataset from London database source are analysed. According to database, 0.2977 tCO_2e can saved per MWh that PV panels generated. This constant value is used to calculate CO_2 reduction.

4. Results and Discussion

As a result of various analysis explained above, approximately 176 million m^2 rooftop area is suitable for installation of solar photovoltaic panels. General ratio of eligible rooftop area to all rooftop area of buildings is 72 percent. After the energy output of PVs is calculated by formulas, the annual potential electricity generated is 12,032 GWh. London energy sales in 2018 is about 38800 GWh. It means that potentially 30 percentage of electricity sold in 2018 could be generated by solar PV panels installed in suitable rooftop areas. This result is higher than Decentralised Energy Capacity Study Report (DECS) of Greater London Authority in October 2011 (Doust, 2011). While in this research, 12,032 GWh is estimated, in the DECS estimation is 9,083 which is 23.1 percent of London's electricity demand. However, carbon savings (Mt CO_2) is equal in both analyses. This research focused also ward and borough scale. In Harrow, Redbridge, Brumley and Havering percentage of electricity demand generated by PVs panels are higher than %60 as shown in Table 1 and maps. On the contrary, in City of London, this ratio is extremely small: %3. This is mainly because of lower rooftop area in that area and greater energy demand, and because of high rise building, it is possible to have larger shaded areas.

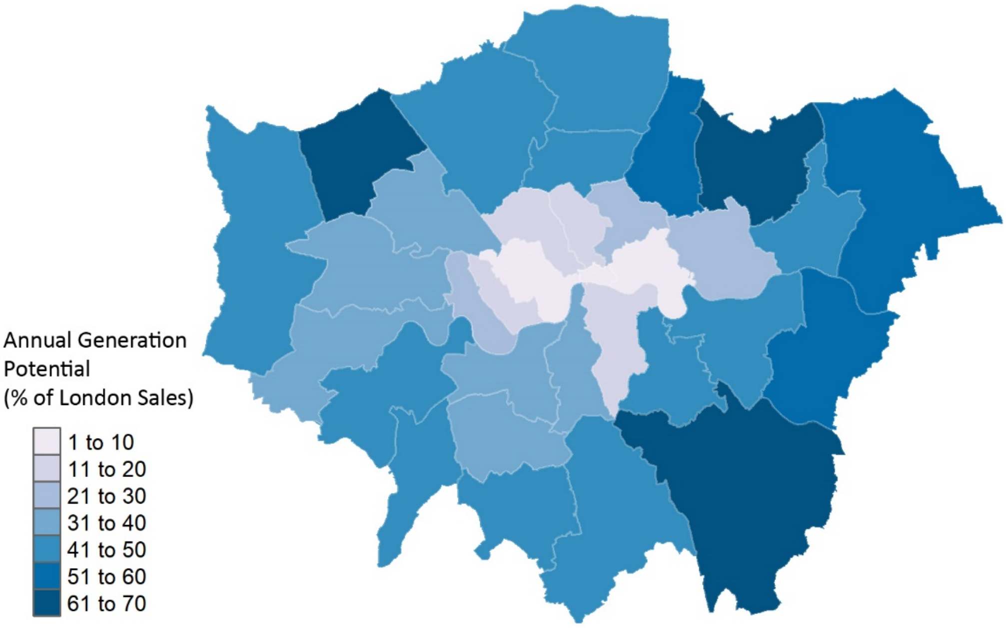

Figure 4: Annual Electricity Generation Potential (% of London sales)

This analysis plays an important role not only for energy planners but also solar investors. While energy planners and governmental decision makers investigate this data and design plans for future, solar investors can seek the potential of each area to install PV panels. However, there are several limitations of this research. Firstly, although the most recent data were selected for this project, there are historical differences among databases. For example, while LIDAR data is from 2017, building footprint is from 2020 that result in missing values. Secondly and as an answer of higher ratio than DECS report, this research assumed that each suitable rooftop has optimum angle and there are no obstacles to install PV panels such as windows, heater equipment etc. In addition, roof edges may not be suitable for PV installation due to structural challenges. Therefore, 1m buffer zone should be eliminated from suitable rooftop area for the future research as in Wong et al. estimation. Thirdly, because of limited time and technology, solar radiation model could not be applied into each ward. Because solar radiation is identical for each location and in this project, it is assumed as constant variable, there maybe differences with real potential.

	Suitable PV Area (m^2)	Annual Generation Potential (GWh/year) Round	Annual Carbon Savings (Mt CO_2)	Annual Generation Potential (% of national sales)
City of London	1119975	76	0.0228	3
Barking and Dagenham	4287530	293	0.0873	46
Barnet	8233468	563	0.1677	50
Bexley	6210188	424	0.1265	54
Brent	6637277	454	0.1352	38
Bromley	8887001	608	0.1810	64
Camden	4016124	274	0.0818	16
Croydon	8421195	576	0.1715	47
Ealing	7700288	526	0.1568	38
Enfield	7190907	492	0.1465	48
Greenwich	5229818	357	0.1066	43
Hackney	3383133	231	0.0689	25
Hammersmith and Fulham	3406971	233	0.0694	24
Haringey	4776733	326	0.0973	42
Harrow	5459639	373	0.1112	66
Havering	6888402	471	0.1403	60
Hillingdon	8394123	574	0.1710	42
Hounslow	6238979	426	0.1271	32
Islington	3270410	223	0.0666	20
Kensington and Chelsea	2818293	192	0.0574	15
Kingston upon Thames	3982064	272	0.0811	45
Lambeth	4880307	333	0.0994	31
Lewisham	4874594	333	0.0993	48
Merton	4597267	314	0.0936	39
Newham	5542103	379	0.1129	27
Redbridge	6122986	419	0.1247	64
Richmond upon Thames	4694864	321	0.0956	50
Southwark	4732120	323	0.0964	19
Sutton	4703163	321	0.0958	47
Tower Hamlets	3481775	238	0.0709	9
Waltham Forest	5124968	350	0.1044	52
Wandsworth	5587601	382	0.1138	38
Westminster	4931825	337	0.1004	9

Table 1: Annual Generation Potential and Carbon Savings Results at Borough Level

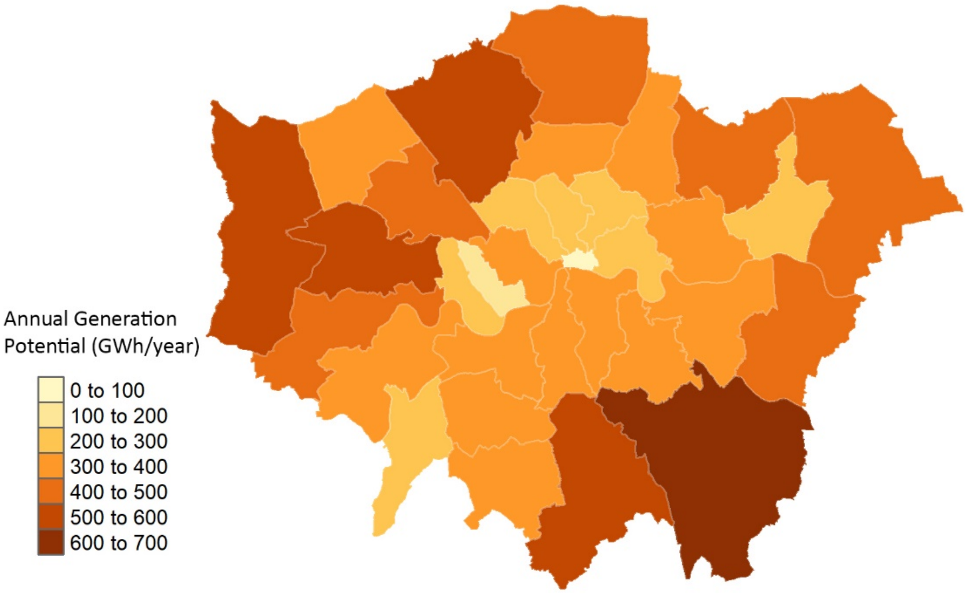

Figure 5: Annual Electricity Generation Potential

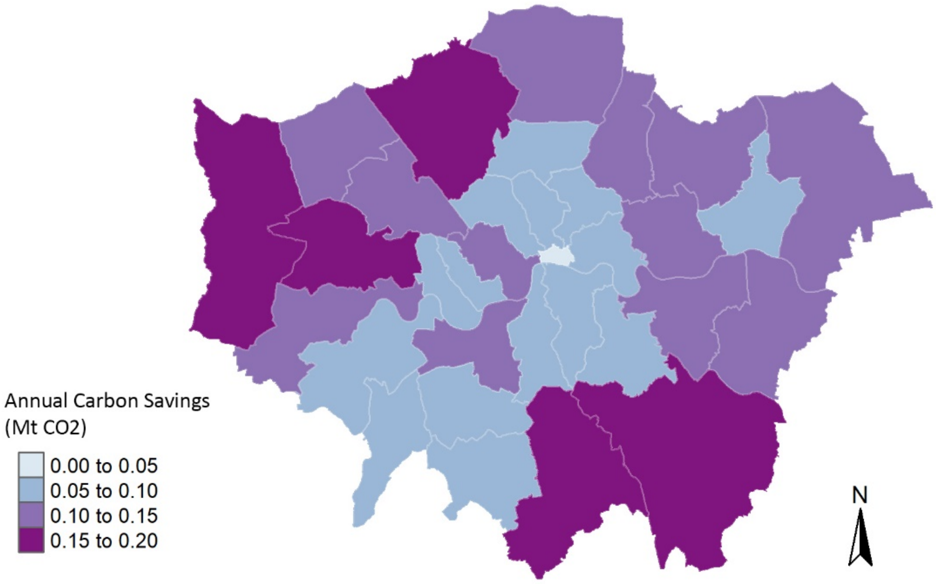

Figure 6: Annual Carbon Savings

5. Conclusion

Renewable energy sources gain importance as we approach the era where we will feel the devastating effects of global warming. There is great potential for electricity generation by rooftop grid-tie PV panel system. In this research, technical and environmental potential of rooftop solar photovoltaic systems in London is analysed. According to result, annually 12,032 GWh energy maybe generated if suitable rooftops are covered rationally. And this value corresponds to %30 percentage of London electricity sales. Although there are several limitations in this research, it can give the importance of solar PV panels applied on rooftops.

References

Assouline D, Mohajeri N and Scartezzini J-L 2017 Quantifying rooftop photovoltaic solar energy potential: a machine learning approach *Sol. Energy* 141 278–96

Carl, Caroline. "CALCULATING SOLAR PHOTOVOLTAIC POTENTIAL ON RESIDENTIAL ROOFTOPS IN KAILUA KONA, HAWAII." *FACULTY OF THE USC GRADUATE SCHOOL UNIVERSITY OF SOUTHERN CALIFORNIA*, May 2014.

Doust, Michael, et al. Greater London Authority, 2011, pp. 1–146, *Decentralised Energy Capacity Study Phase 1: Technical Assessment*. Available: https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/de_study_phase1_0_0.pdf

Fehrenbacher K 2017 There's Vast Untapped Potential for SolarRooftops in the US, Says Google *GreentechMedia* (www.greentechmedia.com/articles/read/theres-vastuntapped-potential-for-solar-rooftops-in-the-us-saysgoogle#gs.lmKjz4s)

Google. (2015) Project Sunroof About Page. Available: https://www.google.com/get/sunroof/about/

Lukac N, Seme S, Dezan K, Zalik B and Stumberger G 2016 Economic and environmental assessment of rooftops regarding suitability for photovoltaic systems installation based on remote sensing data *Energy* 107 854–65

Melius J, Margolis R and Ong S 2013 *Estimating Rooftop Suitability for PV: A Review of Methods, Patents, and Validation Techniques NREL/TP-6A20-60593* (Golden, CO: National Renewable Energy Laboratory)

Perez, R, R. Seals, P. Ineichen, R. Stewart, and D. Menicucci. 1987. A new simplified version of the Perez diffuse irradiance model for tilted surfaces. *Solar Energy* 39 (3): 221-231.

Sun, Yan-Wei, et al. "GIS-Based Approach for Potential Analysis of Solar PV Generation at the Regional Scale: A Case Study of Fujian Province." *Energy Policy*, vol. 58, 2013, pp. 248–259., doi:10.1016/j.enpol.2013.03.002.

Taskin Jamal, “Potential Rooftop Distribution Mapping using Geographic Information Systems (GIS) for Solar PV Installation: A Case Study for Dhaka, Bangladesh” pp. 203-209, 2013.

Wong, Man Sing, et al. “Estimation of Hong Kong’s Solar Energy Potential Using GIS and Remote Sensing Technologies.” *Renewable Energy*, vol. 99, 2016, pp. 325–335., doi:10.1016/j.renene.2016.07.003.

Appendix

Repository with Data and Scripts https://github.com/ucfnofe/GIS-Coursework

RPubs Website: https://rpubs.com/omereris/GIS-Coursework

Declaration of Authorship

I, Ömer Faruk Eriş, confirm that the work presented in this assessment is my own. Where information has been derived from other sources, I confirm that this has been indicated in the work.

Ömer Faruk Eriş

Date of signature: 11.01.2021
Assessment due date: 11.01.2021