

## Assessment of Potential for Photovoltaic Roof Installations by Extraction of Roof Slope from Lidar Data and Aggregation to Census Geography

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### Abstract

Leading topics in PV research include field performance and grid impact. A national understanding of roof features (slope, orientation, area) is essential for modelling the timing of PV installation scenarios with their associated irradiance data. However, such information is not currently available. This paper demonstrates the extraction of building characteristics from LIDAR (Light Detection and Ranging) data. These characteristics are then aggregated and scaled-up to produce a UK-wide map of PV potential, based on suitable roof tilts and azimuths.

### Introduction and Background to Topic

Knowledge of roof pitch and aspect is necessary to calculate the yield and timing of an existing or potential photovoltaic installation. Currently, this information is only available for small areas from commercial suppliers. Here, a description is given of how roof features may be derived from available data, and of how these building characteristics may be augmented to provide countrywide data.

Lidar is now widely accepted as an economical technique for obtaining high resolution feature height data across sizeable areas. Lidar is attainable at various resolutions for most of the UK. However, automated extraction of 3D urban features is a challenging problem. It has been intensively studied. NREL [1] review 35 studies and 6 patents in order to define 3 categories of roof potential estimation methods: manual selection, GIS-based and constant value. In this paper a GIS-based method is firstly employed to accurately obtain roof pitches and orientations for a single UK City (Plymouth). This is then scaled-up to the entire country using a constant value method.

There is no single GIS-based method which outperforms the others. Rönnholm et al [2] utilise a method based on Canny Edge Detection to identify roof ridges in a test site in Finland. This algorithm marks local maxima in the Lidar as edges and discards all pixels not in line to give a thin ridge. Another roof segmentation formula is the Douglas Peucker line simplification algorithm (1973), which has been used on test sites in Germany [3]. This procedure removes redundant points to

“smooth” the ridge line within a given tolerance. Other line fitting techniques e.g. Hough Transform and RANSAC, generally used in image analysis, have also been applied to Lidar data.

The basis of all the above-mentioned methodologies is the separation of the roof into planes. They are complex, require very high resolution Lidar and are computationally intensive. Additionally, most have been trialled over fairly small areas (e.g. 4km<sup>2</sup>) and often require visual inspection (human checking). Therefore, this research employs a simpler technique, which is applied to an entire city and, other than verification, does not demand manual intervention.

Roof slope and aspect are calculated by weighted least squares fit of a plane to a 3x3 neighbourhood centred on each Lidar point, as recommended in best practice for this type of analysis [1]. This slope computation is used by most GIS software but it is more usual to find it determining slopes of large terrain features such as hills, rather than looking at relatively small buildings. Details of the technique are shown in Figure 1.

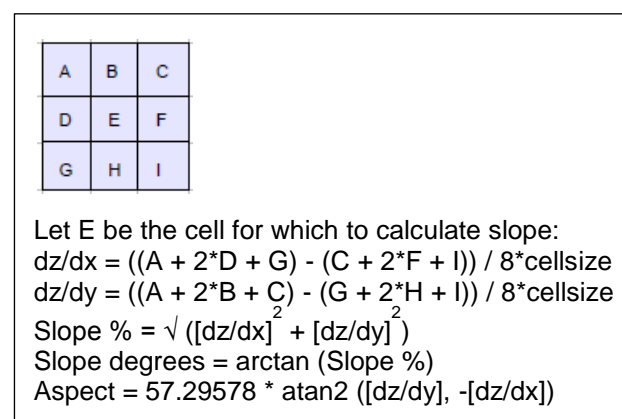


Figure 1: Slope and Aspect Calculations

The constant-value method of rooftop-feature estimation used by this research estimation applies a multiplier to the whole region (entire UK), in common with similar techniques.

### Data

Lidar data is available at no cost for non-commercial use from the UK Environment

Agency [4]. 2m resolution coverage is extensive, but not total, for England and Wales. Only small areas of Scotland have been captured. Hence, some form of scale-up is necessary, even at this low resolution. 1m data is missing for Scotland, much of Wales, Pennines, Yorkshire and Lincolnshire, whilst 50cm and 25cm data only exist for high flood risk areas. This research has focussed on establishing what may be achieved with the more wide-ranging 2m and 1m data.

Three case study areas are used. Individual residences in the commuting area around Loughborough supply the results to verify the slope and aspect calculations, as do individual public buildings in Bodmin. The slope of every building in Plymouth was ascertained for the country-wide scale-up operation.

### **Slope and Aspect Method**

The Environment Agency supply Lidar data in the form of rasters i.e. arrays of numbers which represent height. There are two coverages for each area: the Digital Terrain Model (DTM) or "bare-earth model" of elevation and the Digital Surface Model (DSM) which is elevation plus surface features such as trees and buildings. So it may be seen that the data is already partly prepared. It is only necessary to subtract the DTM from the DSM in order to obtain building height above ground level.

Once the building height raster has been prepared, building footprints from MasterMap [5] are used to cut out points on roofs. This avoids the need for building detection and extraction. Even though these Lidar points are positioned within known building outlines, problems with the data may still arise. The building heights span -14m to 64m for Loughborough. Mapping the points revealed that the 64m elevation is correct because it represents features on top of the University's Towers Hall, one of the tallest structures in the area. On the other hand, negative and low values are obviously incorrect. They are thought to represent basements, patios, window ledges etc. Two methods of elimination described in the literature were tried. Firstly, "rogue points" were removed by creating a 1m internal buffer of the building outline and classifying all points within this as suspect [6]. This resulted in slopes on test buildings of up to 6 degrees lower than reality, so an alternative method of applying a threshold value as described by [7] was tried. Different thresholds are more appropriate across various countries as building stock changes with culture and climate. For the UK, a minimum cut-off of 2m (to allow for low eaves

on bungalows) was found to give accurate results.

Having created an appropriate roof point height map, the Slope and Aspect algorithms may be run. The result is a tilt and orientation for every 1m pixel within each building outline. These are averaged to give the mean value for each building (slope) or each roof plane (aspect). Of course, slopes vary because there may be dormers but the majority of pixels will have the same value.

### **Scale-up Method**

Expanding slope/aspect results from a single city to countrywide extent involves finding the average for administrative zones within that city and their relationship to an administrative statistic, the "multiplier" e.g. population, which is known for every area of the UK. It was decided to choose Lower Super Output Areas (LSOAs) – zones of 400 to 1,200 households – as the administrative unit because these are extensively used for economic and socio-demographic data. Experiments were carried out with several multipliers in order to discover which is most precise.

The following values were calculated for Plymouth:

1. Average roof slope per LSOA. (This is the actual value against which estimations are checked).
2. The slope of an average roof in Plymouth divided by the average number of buildings per LSOA. This is multiplied by the actual number of buildings per LSOA to learn how well building number works as a multiplier where slope is not known.
3. The slope per square metre of roof in Plymouth to be multiplied by building area per LSOA.

Next, buildings were categorised to investigate if accuracy could be improved. The age and class categories from Landmap Features Earth Observation Collection [8] were obtained for all buildings in Plymouth. The average slope for each of the 7 age categories in this dataset for Plymouth as a whole was reckoned e.g. Sixties 26.9°. Next, the average slope for each of the 19 class categories was figured e.g. Very Tall Flats 11°. Lastly, an age/class combination was computed as an average for the entire city e.g. Victorian Terrace 34.24°. These average slopes can then be multiplied by the number of buildings in each category to estimate slope where no Lidar data exists.

Unfortunately, Landmap data is limited to the larger metropolitan areas, so for the purposes of this paper, a map of roof tilt was produced

	Pitch Method	Pitch Measure	GIS - 2m Lidar	2m Diff.	2m % Diff.	GIS - 1m Lidar	1m Diff.	1m % Diff.
1	inclinometer	29.9	30	-0.1	-0.33			
2	photo trigonometry	44	36	8	18.18	40.3	3.7	8.41
3	PV install	28.1	27	1.1	3.91	28.3	-0.2	-0.71
4	PV install	25	25	0	0	30	-5	-20.00
5	PV install	33	23	10	30.30	32.5	0.5	1.52
6	trigonometry	33	29	4	12.12	29	4	12.12
7	trigonometry	45	32	13	28.89	38	7	15.56
8	trigonometry	25.79	27	-1.21	-4.69	24.1	1.69	6.55
9	trigonometry	32.72	30	2.72	8.31	30.1	2.62	8.01
		Average		<b>4.2</b>	<b>10.7</b>		<b>1.46</b>	<b>3.35</b>

Table 1: GIS-derived weighted least squares fit mean roof pitch in degrees compared to measured pitches on 9 buildings using 2m and 1m Lidar

for England and Wales using an ONS dataset [9]. This has fewer house type classes which necessitates matching the Landmap classes to them as nearly as possible.

The final step in the scale-up task is to analyse the roof data with an alternative boundary size to discover whether any systematic inaccuracies are occurring. This is a frequent problem when geographic data is grouped into units for analysis. Postcode districts were selected for this purpose.

### Results and Discussion

Initially, the slope and orientation of individual buildings calculated from GIS weighted least squares fit were compared to values from a variety of sources in order to establish the accuracy of this technique. The results from large public buildings were very encouraging. For instance, the GIS method produced a mean roof pitch of  $26^\circ$  for the Radial Building in Bodmin, when the architect's plans suggest a value of  $26.5^\circ$ . Unfortunately, values for smaller homes and student residences did not equal this, as shown in Table 1.

The results indicate that Lidar resolution of at least 1m is necessary for reliable roof tilt estimates. Validation of roof slope is known to be difficult, due to lack of data and that fact that all the methods of measuring it have their own inherent imprecision. For this reason, the GIS technique was further checked by matching the pitches from houses of the same type in the same street. For instance, a cul-de-

sac of semi-detached bungalows and sets of detached houses were investigated. In theory, each home should have an identical pitch to that of its neighbour but actually for 1m Lidar, homogeneous houses vary by  $3^\circ$ . This approximates to the  $1.46^\circ$  difference noted in Table 1.

1m Lidar data delivers satisfactory average pitches but cannot be used for building segmentation, as illustrated in Figure 2. The south-facing extension is not distinguished on this predominantly east-west house and the carport on the west (left) is confused with the main roof to give an incorrect steep slope.

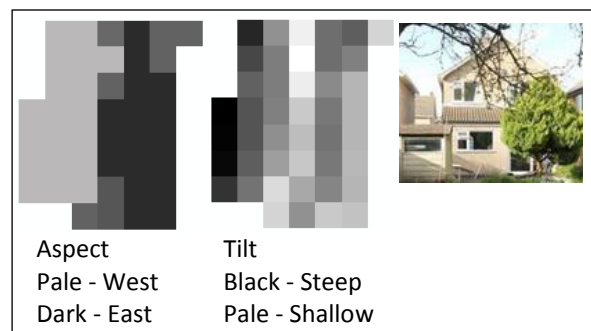


Figure 2: Slope and Aspect Details of individual house

Once reasonable individual roof tilts were achieved, the agreement between GIS-calculated average roof pitch per administrative area (LSOA) and scaled-up pitch was investigated. Attempts to scale-up using number of houses and building area resulted in unacceptable values. More complex multipliers correspond much more closely to reality (Table 2).

Multiplier	Average difference in Degrees from GIS slope calculation	Range of differences in Degrees from GIS slope calculation
Building Age	0.45	-3.85 to 8.32
Building Type (e.g. semi)	0.85	-4.63 to 9.57
Age and Type	0.39	-3.6 to 8.25

Table 2: Comparison of GIS-derived average roof slope per LSOA for 162 areas in Plymouth to that calculated from multipliers

Age performs better than Type, but Age and Type in combination is preferable. At this time, though, lack of data necessitated creating a national map using Type only with an accuracy of  $2.22^\circ$  (Figure 3). All multipliers are twice as likely to under-estimate slope than over-estimate it. No relationship was found between steepness of slope and size of error. The average roof slope was  $28.47^\circ$  for the 162 LSOAs and  $28.46^\circ$  for 90 postcode districts in Plymouth. Thus there is little difference depending on area of analysis.



Figure 3: Roof Pitch per LSOA – England and Wales (Pale = shallow, Dark = steep)

### Conclusion

Information on roof slope is a basic requisite of PV modelling. A method is developed which utilises the medium resolution Lidar, accurate building outlines and socio-economic data which are free for educational use in the UK,

based on recommendations of previous literature.

The next step will be to sample slopes in each of Great Britain's regions because these are known to vary (steeper in North). Long-term, a statistical method will be worked out to draw improved accuracy from accessible data.

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