GOMap – Geospatial Opportunity Mapping tool: An open-source GIS application for urban scale renewable energy generation

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ABSTRACT

As part of a project awarded to Glasgow City Council (GCC) by Innovate UK, an interactive GIS-based Geospatial Opportunity Mapping (GOMap) tool was developed to identify land within the city of Glasgow that is policy unconstrained and technically feasible for the deployment of urban solar photovoltaic power stations (PVPS).

The development process included workshops with GCC and ScottishPower Energy Networks (SPEN) regarding policy and technical aspect information respectively. Relevant factors associated with each aspect affecting site selection were identified. GOMap, based on the QGIS system, represents spatial relationships between policy and technical factors on a 10 m x 10 m city grid and implements a scoring system to differentiate factors that support or curtail PVPS deployment. User-directed weightings can be applied to explore alternative action plans. Finally, GOMap outputs are utilised by a PVPS model to estimate annual energy generation as a function of local weather and installation design (array spacing and panel tilt).

KEYWORDS

Solar PV; urban opportunity assessment; policy/technical rating; QGIS; GIS opportunity mapping.

INTRODUCTION

There is presently much UK legislations driving sustainable energy supply solutions by investing in renewable energy technology (RET) to reduce carbon emissions [1 – 3]. Identifying suitable deployment sites is key to enabling local energy production that brings economic value [4]. UK City Councils control the policy aspects that underpin city development in relation to site selection, urban expansion, natural resource management and regional integration [5 – 7]. However, the planning process generally excludes the technical aspects that underpin power production by dictating site suitability.

Urban site selection tools have been developed and applied to estimate energy availability as a function of factors such as terrain type, proximity to power grid transmission lines [8 – 10], and the policy constraints relating to environmental, social, and economic issues [11 – 13]. While these tools can provide high-quality site opportunity maps, they often focus at the regional level so that the underpinning policy and technical factors are not applicable at the urban scale. GCC commissioned the Energy Systems Research Unit (ESRU) to develop a new tool, GOMap, focused on the city of Glasgow that encapsulates the latest information available from the local planning authority and utility provider [14, 15]. The project was funded as part of the Future City Glasgow Demonstrator Project [16], with the GOMap application made publicly available at no cost under an open-source licence [17]. GOMap indicates city areas where community-scale renewable energy schemes could most readily be deployed while highlighting the policy and/or technical constraints affecting all other locations.

To construct GOMap, comprehensive information was obtained: from GCC for policy constraints and from SPEN for technical constraints. GOMap was then utilised to assess the potential for deploying PVPS on vacant and derelict land (VDL) throughout Glasgow. The results from the project have been comprehensively published elsewhere [18].

The evaluation procedure encapsulates 5 policy and 4 technical aspects as follows.

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Policy

Biodiversity - wildlife and plant information related to protection and conservation of special areas.

Developmental - urban development information related to the location for commercial, housing, leisure or industrial development use.

Environmental - ecological information related to protection and conservation of special areas and buildings.

Visual Impact - social information related to distance to and visibility from residential areas.

Visual Intrusion - safety information related to glare that might constitute a safety risk to aircraft or vehicles.

Technical

Overshading - shade information related to site overshading from nearby buildings.

Substation Connection Distance - distance information related to grid connection points.

Substation Congestion - grid network information related to the capacity of the circuits connected to a substation to absorb new energy generation.

Terrain - topographical information related to slope, landcover and elevation to identify terrain suitability and flood risk.

Each aspect comprises multiple factors (e.g. the Environmental aspect contains factors 'Conservation areas', 'Green corridors' *etc*.). With multiple possible factors affecting each of the policy and technical aspects, the aim of GOMap is to score and weight the factors to give a realistic screening of all possible deployment sites throughout a city.

For each location on a high-resolution grid, all factors are scored on a 3-point scale where those underlying the policy aspects are categorised as being 'Possible', 'Intermediate' or 'Sensitive', and those factors underlying the technical aspects being categorised as 'Favourable', 'Likely' or 'Unlikely'. In the case of the Environmental aspect, a 'Showstopper' score is imposed on an underlying factor where mitigation plans are considered impossible. The individual factor scores are combined to give an overall aspect score, and the aspects scores combined, as appropriate, to yield overall policy and technical ratings. A critical feature of GOMap is to weight each aspect in a manner that reflects city policy with respect to the encouragement of local RET development. The weightings determine those policy or technical aspects that should be prioritised, allowing planners to encourage or limit RET deployments depending on circumstances.

GOMap is built on top of the open-source QGIS framework [19], a mapping application that supports the viewing, editing and analysis of geospatial data. The application is designed to perform all geoprocessing operations during the import of information and any changes to parameters during the execution of the tool, including enabling/disabling aspects or altering weightings, immediately updates the final opportunity map. Figure 1 shows a typical GOMap session via which policy and/or technical factors can be weighted (or disabled) and the corresponding land areas categorised and quantified. Suitable sites can then be assessed for renewable energy generation (here darker shades represent increasing barriers to PVPS deployment). The central image depicts the Glasgow City boundary with all aspects scored and displayed as a combined policy/technical rating. Supplementary shapefiles (a standard GIS vector format [20]) are included to provide contextual information such as city buildings, electric power lines and municipality boundary lines. The panel to the left allows individual aspect factors to be disabled while the panel on the right allows aspects to be weighted. For all defined cases, the lower left panel reports the available land within the three categories along with an estimate of the energy production potential of the selected technology.

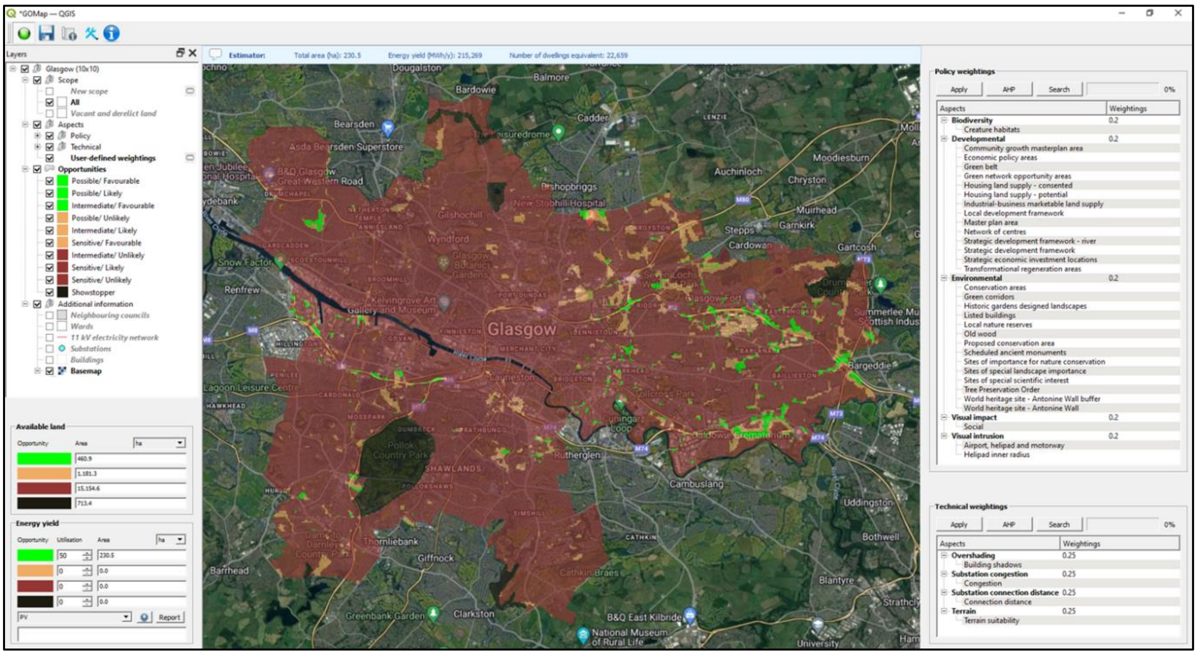

Figure 1. GOMap applied to Glasgow City.

METHODOLOGY

This section considers the required GIS grid resolution, describes the implementation of the scoring and weighting processing scheme, and elaborates on the PVPS model as embedded in GOMap.

GIS framework

GOMap is built upon QGIS, an open source, freely available GIS software where its performance can be extended by modifying the source code directly. The core functionality of GOMap is written in Python (version 3.7) and is compatible with QGIS (version 3.16).

Tool development

To facilitate all policy and technical information, Python is used to integrate the GOMap tool with QGIS. The main functionality of GOMap comprises three parts: the grid system, the scoring system, and the weighting system. With these systems translated into Python and implemented, external Python scripts are used to import spatial information, including automatic adjustment to the local coordinate reference system used to accurately represent objects on a two-dimensional projected map.

Grid system

There can be multiple factors active at any given location and corresponding to some geographical resolution set by the local authority. A spatial representation system with variable dimensional capability is implemented whereby a grid covers the entire city at the required resolution. The agreed scores for each aspect factor are assigned to each grid cell via an independent GIS shapefile. As each cell possesses a unique ID number, it is possible to determine which factors converge within any cell. A 10 m x 10 m grid was found to be a suitable default for the examination of a city, which for Glasgow at this scale comprises 1.76 million cells. Setting this high resolution provides relevant city information while going beyond this would not yield any further significant information.

Scoring system

The scores for each policy and technical factor were derived from consultations with local authority planners and utility specialists through workshops and planning documents. Factor and score information are contained in its own GIS map layer representing the geographical data. Lower scores indicate factors encouraging deployment of PVPS. With the grid resolution determined, the scoring mechanism can be applied for each cell that overlaps a site. GOMap offers alternative methods to determine the aspect scores corresponding to two use cases termed ‘lenient’ and ‘stringent’. The lenient method is intended to encourage development by calculating the overall aspect score as the median value of the individual factor scores; the stringent method imposes pragmatic constraints by calculating the overall aspect score as the highest underlying factor score. The view of GCC planners is that developers often perceive policy-related aspects as greater barriers than they themselves do and for this reason, the lenient scoring method is preferred.

Weighting system

Weightings govern which policy or technical aspects to prioritise when undertaking a realistic screening of the available resource. Alternatively, weightings may be imposed to explore future policy changes and infrastructure developments.

Several tools employ Multi-Criteria Decision-Making (MCDM) methods to explore alternative solutions to complex problems where multiple criteria affect a single goal [21, 22]. The MCDM method can be used to determine the weightings of each policy and technical aspect. Another method commonly used in conjunction with MCDM is Analytical Hierarchy Process (AHP), a mathematical technique invented by Saaty in the late 1970s as a decision-making tool to resolve unstructured problems. This employs a hierarchical or network-based structure where the upper level contains the primary objective of the analysis, and the lower level contains the main/sub-criteria [23].

An MCDM/AHP method is used in GOMap to determine the weightings of each policy and technical aspect. Using the scale system for pairwise comparison, each aspect is given a scale in relation to its importance over the other aspects as discussed during the workshops with GCC and SPEN. The weightings of all policy and technical aspects are calculated and shown in Table 1 and Table 2 respectively.

Table 1. Policy aspect weightings.

Aspect	Weighting
Biodiversity	0.326
Developmental	0.114
Environmental	0.326
Visual impact	0.148
Visual intrusion	0.086
Σ	1.000

Table 2. Technical aspect weightings.

Aspect	Weighting
Overshading	0.484
Substation congestion	0.168
Substation connection distance	0.231
Terrain	0.117
Σ	1.000

Typically, a standard Weighted Overlay Analysis method involves reclassifying a raster by assigning each pixel a value from a suitability scale [21]. The GIS tool would use a modified version of the standard Weighted Overlay Analysis method by having similar logic performed on information based in vector format as this facilitates the weighting system to run concurrently with the grid and scoring systems in generating the final opportunity map. This allows for a single opportunity map to be updated in real-time as any policy and technical information can be independently switched on/off and the final scores recalculated.

Two methods of weighting are available as follows.

- Equal – All policy and all technical aspects are treated with equal importance and are given equal weightings.
- Non-equal – All policy and technical aspects weightings are determined using the MCDM/AHP method to set the order of importance based on city planning policies and expert knowledge [24, 25].

The final score is reached where the sum of the weighted scores is given as the final score of a grid cell.

PVPS modelling

GOMap has an embedded PVPS model, which employs equations related to solar geometry to determine the power output of a PV panel [26 – 28]. A land utilisation factor (or packing factor) is set and defined as the ratio of the total PVPS array area to the total land area occupied by the PVPS [29, 30]. In some studies, a typical fixed-tilt PVPS was found to have a land utilisation factor between 47% and 51% [31 – 33]. In GOMap, the land utilisation factor is a user-defined parameter required to ensure there is adequate space to deploy and maintain the PVPS installation.

The PVPS model as embedded within GOMap can take a site area as input and transform this to an hourly power output prediction for a PVPS installation over a year. This profile is then integrated to obtain the annual energy yield. To expand GOMap's functionality, the model can generate polygon features to represent the PVPS on the final opportunity map to determine the number of panels that can be realistically installed on a given site to provide a more accurate energy yield estimate based on the site's geometry. The optimal PVPS parameters for Glasgow were determined as shown in Table 3.

Table 3. Optimal PVPS parameters for Glasgow.

PVPS parameter	Value
Panel azimuth	205^o
Panel tilt angle	37^o
Array spacing	7.4 m
Energy yield	172.8 kWh/m^2.y

TOOL APPLICATION

This section describes the application of GOMap to a real-life case study undertaken by a spatial planning manager within the Development Plan Group at GCC and its application to Glasgow and several international cities.

PVPS in Glasgow City

The application of the tool allowed the identification of unconstrained land within Glasgow city that is available for the deployment of PVPS. GOMap was applied with policy and technical information as of 2020. At the time, the city had around 320,000 dwellings of which ~108,000 (34%) were socially owned and, of these, ~32,000 (30%) had no wall insulation and were in the hard-to heat category [18].

For this study, several scenarios were devised for future development intended to encourage the availability of greater land areas and enable a comparison of alternative land use strategies through policy and technical aspect relaxation. A future intention was considered: to supply energy for dwellings in regards to the heating requirements as part of the Scottish Government's Energy Strategy commitment to electrify home heating [34].

The parameters defining this scenario are summarised in Table 4. Certain policy and technical aspects are relaxed to explore the impact on the available land.

Table 4. Scenario information.

Scenario	Relaxed policy aspect	Relaxed technical aspect	Description
1	None	None	Base case scenario with all policy and technical aspects active and equally weighted.
2	Visual impact Visual intrusion	None	Assuming community-based education programmes are delivered, and glare is disregarded from PVPS due to low-risk.
3	None	Substation congestion Substation connection distance	Assuming future upgrades to the electricity distribution network.
4	None	None	As Scenario 1 with non-equal weightings.

The results are tabulated in Table 5 where it is shown that Scenario 1 with all aspect information active and equally weighted gives rise to 355.7 ha of VDL that could supply 8,339 of Glasgow's dwellings. To place these results in context, they indicate a space heating energy contribution equivalent to 2.6% of Glasgow's total housing stock, 7.7% of social housing and 26% of housing in the hard-to heat category.

Table 5. GOMap results for Glasgow.

Scenario	Area (ha)	Output energy (MWh/y)	No. of dwellings equivalent	Hard-to-heat dwellings equivalent
1	355.7	108,412	8,339 (2.6 %)	26 %
2	386.6	117,767	9,059 (2.8%)	28 %
3	520.7	158,578	12,198 (3.8 %)	38 %
4	969.6	295,475	22,728 (7.1 %)	71 %

Figure 2 shows an example of two sites identified in Scenario 1 where areas in green are depicted as being suitable for deployment and designated as policy 'Possible' and technically 'Favourable'; areas of red are depicted as being unsuitable for deployment and designated as any other policy and technical categorisation; and supplementary information such as 11 kV electric networks can be overlaid on the map. Scenario 2, with some pertinent policy aspects relaxed, explores the potential for policy-assisted development in future and results in VDL sites with an area of 386.6 ha, equivalent to heating around 9,059 dwellings or 28% of dwellings in the hard-to-heat category. Scenario 3 examines a case that disregards most technical aspects on the basis that resources are made available in future to create new energy infrastructure and results in VDL sites with an area of 520.7 ha, which can supply up to 12,198 dwellings or 38% with no wall insulation. Scenario 4 quantified the potential of non-equal weightings based on city planning policies and expert knowledge covering an area of 969.6 ha providing energy to 22,728 dwellings or 71% of housing in the hard-to heat category. This substantial increase in available land is due to the Environmental, Biodiversity and Overshading aspects given the highest weightings and their unconstrained factors encouraging deployment on VDL sites.

Figure 2. Two example sites identified in Scenario 1.

Although Scenarios 2 and 3 have shown the effects of relaxing certain aspects, it is likely that in a decision-making process, all available information should be included in the assessment to make a reasonable judgement. Depending on the use-case, aspect information may be equally weighted to provide an overall average evaluation; or the weightings may be defined if certain aspects are perceived to have greater significance over others. Therefore, Scenarios 1 and 4 are considered the more effective and informative scenarios.

CONCLUSIONS

The aim of the presented work was the development and application of a RET site evaluation method that combines policy and technical considerations relating to energy supply within the planning process for any urban city. GOMap provides opportunity maps for decision-makers and encourages collaboration between city planners and utility specialists. It does not address issues of technical design, infrastructure cost, revenues or opportunities to enhance integration with commercial development. Neither does it remove the requirement to go through the normal planning control process for a new development. With much interest at present in deploying clean energy systems, it is hoped that the GOMap tool can aid policy makers and developers and encourage RET deployment at the urban scale.

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