DEVELOPMENT OF AN OPEN-SOURCE SOLAR CADASTRE IN QGIS

Summary

This study addresses the critical need for scalable urban energy planning by developing a comprehensive workflow to assess rooftop photovoltaic potential using the open-source geographic information system *QGIS* and open data. Applied to the case in *Nuremberg*, Germany, the methodology derives homogeneous roof areas from LiDAR and building footprint data, models annual solar irradiation under real-sky conditions, and calculates expected PV yields. Differentiating itself from standard literature, the approach integrates a modular layout algorithm to determine installable PV capacities alongside a multi-criteria scoring matrix for spatial suitability prioritisation. Results confirm that the derived geometric potentials, modelled irradiation, and estimated yields align robustly with existing benchmarks, providing a highly viable and data-driven tool for decentralized renewable infrastructure development.

Keywords: Solar cadastre, PV potential, GIS, open-source, open data, opportunity mapping

Field of application for the findings: PV expansion planning and decentralized infrastructure development

Addressed audience: Local authorities, planners, private building owners

1. Introduction

The global renewable energy transition necessitates extensive PV deployment, driven in Germany by the *Renewable Energy Act* (EEG, 2023, § 4). In response, local authorities are increasingly developing municipal energy concepts to exploit decentralized power systems. Solar cadastres serve as strategic tools in this process by systematically highlighting suitable roof areas. However, existing cadastres frequently rely on proprietary software and lack transparent, openly communicated modelling frameworks. This study develops an open-source workflow relying exclusively on open data to systematically optimise urban PV planning. Furthermore, contrasting with existing literature approaches, this data-driven methodology integrates a PV module layout algorithm and a comprehensive scoring matrix for spatial suitability classification.

2. Methodology and Data

The methodology utilises the open-source geographic information system *QGIS*, combining native processing algorithms and *GRASS GIS* radiation modules. Demonstrated through a high-resolution (1 km x 1 km grid) case study in *Nuremberg* (Germany), the modelling framework is designed for high scalability across varying geographic extents. The spatial analysis processes LiDAR point-cloud and building footprint data from the *Bavarian Surveying Agency* (LBVD) to generate a digital surface model (DSM) for the individual buildings. Based on the DSM, slope and aspect rasters are derived using the GRASS GIS tool `r.slope.aspect`. Coplanar roof areas are subsequently identified through a rigorous three-stage threshold reclassification of slope and aspect rasters, successfully extracting geometric potentials as described by Ludwig (2015, pp. 69).

To perform the techno-economic assessment, solar irradiation is simulated under real-sky conditions using the GRASS GIS tool `r.sun.insoltime`. The model integrates high-resolution meteorological input data, including monthly albedo rasters based on NASA Earthdata (Hook et al., 2023) and daily Linke turbidity values (Kayser, 2007, p. 39). Furthermore, it incorporates cloud-reduction coefficient rasters following the approach of Hofierka and Šúri (2002), which are derived from German Weather Service (DWD) measurements relative to clear-sky estimates. This irradiation is converted into specific PV yield based on the method proposed by Tro-Cabrera et al. (2025), which actively accounts for temperature-dependent performance ratio (PR) and module efficiencies.

The installable PV capacity is computed via a module layout algorithm that iteratively shifts a grid along a predefined orientation to identify the optimal spatial configuration. Representative coverage factors are derived and utilised to upscale specific PV yields into total electricity generation. Roof areas are filtered according to suitability constraints (e.g., $A_{PV} \geq 10\,\mathrm{m}^2$ and $E_{annual} \geq 890\,\mathrm{kW\,h/(m^2\,a)}$). Finally, a multi-criteria prioritisation matrix evaluates the PV expansion potential through a linear combination of energy yield, *Energy Returned on Energy Invested* (EROI), topographic demand estimation, and a heating/cooling density indicator.

3. Results and Discussion

In the following, the techno-economic results of the study are presented, their plausibility is benchmarked, and key limitations are addressed.

3.1 Geometric and Yield Potential

Figure 1 illustrates a subset of the study area and the derived roof facets after filtering. Each roof polygon is attributed with slope, aspect, area, sunshine duration, irradiation, and specific and total PV energy yield.

Fig. 1: Homogeneous roof areas of a subset of the study area. Background map from Bayerische Vermessungsverwaltung (2026). Note the high suitability of the green-shaded, flat, and mostly homogeneous rooftop.

The spatial analysis successfully extracts the resulting roof facets, effectively eliminating irregularities caused by roof superstructures and measurement artefacts. While the threshold-based segmentation exhibits a minor limitation in detecting small roof windows – potentially leading to an overestimation of usable roof area – a comparative benchmark against the official *Nuremberg* solar cadastre confirms a high degree of spatial accuracy and physical plausibility.

The evaluation reveals that the specific yields align robustly with expected physical principles. Five roofs per category were randomly selected to illustrate daily yield profiles, with average results summarised in Table 1.

Tab. 1: Average specific yields categorised by orientation.

Category	Specific Daily Yield in $\mathrm{W\,h/m^2}$	Specific Annual Yield in $\mathrm{kW\,h/m^2}$
South	489.88	178.80
West	414.37	151.24
East	362.21	132.21

The magnitude ranking South > West > East confirms that East- and West-facing roofs maintain economic viability, achieving 75 % to 85 % of the optimal South-facing yield, consistent with empirical data reported by Wirth (c.f. 2025, p. 40). Furthermore, the calculated yield ranges fall perfectly within the $138.42\,\mathrm{kW\,h/(m^2\,a)}$ to $157\,\mathrm{kW\,h/(m^2\,a)}$ bandwidth as reported by Ludes et al. (2013, p. 17), verifying the simulation as highly realistic. While the monthly temporal resolution of atmospheric inputs introduces modest day-to-day variability constraints, the seasonal magnitude of the modelled irradiation correlates seamlessly with nearby weather stations. Overall, the dynamic approach seems to be robust for PV potential screening.

3.2 PV-Module Layout Potential

Applying the layout algorithm to a random sample of 500 roofs yields a mean module coverage factor of 41 %. This data-driven parameter is highly competitive compared to literature values, which range from 40 % for residential buildings (Koch et al., 2022) to 53 % to 63 % for Swiss rooftop assessments (Anderegg et al., 2022). This inherent conservative bias ensures the screening results remain realistic for practical planning applications.

3.3 Potential Assessment

The spatial mapping visualises a roof-level suitability score, grouping expansion potentials into ten distinct colour-coded classes (ranging from 0 to 100). Despite the necessity of approximating local demand through topographic use classes and coarse heating/cooling densities, the holistic prioritisation matrix delivers a highly effective, data-driven roadmap for rapid municipal screening, enabling stakeholders to direct early-stage investments toward the most synergistic urban infrastructures.

4. Conclusion

This study provides a robust, fully open-source blueprint for the systematic optimisation of urban PV expansion. By leveraging the geospatial analysis capabilities of *QGIS* and open data, the developed cadastre ensures reproducibility, transparency, and high scalability. The findings confirm that the methodology is well-suited for its intended field of application, delivering actionable, data-driven decision support for planners and local authorities navigating the decentralized energy transition at both household and municipal scales.

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