Geospatial products in the registration of photovoltaic installations and their parameters

Agnieszka CIENCIAŁA, Agnieszka BIEDA and Szymon SOBURA, Poland

Key words: geospatial data, photovoltaic installations, geographic information systems, public database, GIS, UAV

SUMMARY

The global trends and activities of individual countries in the promotion of renewable energy sources, as well as the development of geographic information systems bring demand for new opportunities in the field of creating databases related to their attributes, including their spatial location. For example, more and more often data on already implemented photovoltaic installations are registered and made available in public registers or open access Geographic Information System (GIS) tools. Such portals often enable to provide information on the location of existing installations, their peak power and productivity, predict areas that would be suitable for situating newly planned installations. In turn, modern surveying and photogrammetry provide products to quickly and efficiently record the location of panels and allow one to determine their parameters. There is widespread recognition that effective control over future photovoltaic installations requires proper knowledge about the remaining technical potential and the local demand to use the generated electricity. Recording the location of existing installations can constitute an important activity in the process of comparison of the capacities of newly designed installations with the remaining regional potential, as extensive and uncontrolled installation of photovoltaic plants can lead to problems with the electricity grid, including grid failures.

For the purposes of the presentation, the results of the research of the authors on the subject of recording the location of photovoltaic installations in public databases from selected countries will be listed in order to develop standards and to specify good practices in the field. Moreover, the usefulness of geospatial products, gathered on the basis of modern surveying and photogrammetric methods, in the process of the acquisition of the aforementioned data will be analysed.

1. INTRODUCTION

There is increasing interest in photovoltaic installations worldwide, both among individual households and in the public sector. As indicated by SAPL (2018), at the end of 2016 worldwide there were solar photovoltaic installations of approximately 300 gigawatts (GW) (more than 1.5% of the demand for global electricity). The report emphasises that the observed rapid growth in solar capacity arises from the installations in the United States and China and that, according to the International Energy Agency, the growth will continue over the next few years, reaching almost 740 GW by 2025. According to Thebault, Berrah, Desthieux, Ménézo (2019), many countries are developing strategies at national scales to largely implement solar energy, for example France and Switzerland. The global interest in the implementation of photovoltaic panel technology for energy production can be attributed to two reasons: modern photovoltaic panels are more efficient than 15 years ago and the scope of photovoltaic farms is greater (Huerta Herraiz, Pliego Marugaan, et al., 2020). According to the authors, this can be confirmed by the fact that there was the largest registered photovoltaic power plant in 2008 (in Spain) of a capacity of 60 MW and located on 285 ha, while in 2017 there was a power plant within 5260 ha of a capacity of 2000 MWp (located in India). In London in 2016 solar PV generated 80 gigawatt hours (0.2% of the city's total electricity demand), more than 800,000 homes had solar panels installed, and the goal is to achieve two gigawatts of installed solar energy capacity by 2050 (SAPFL, 2018). As of June 2020, the UK's Government reported that the country had 1,037,150 photovoltaic installations (BEIS, 2020). The available solar potential is enormous. Interestingly, in Graz, among the 14 million square meters of roof area, about 40 % are 'very suitable' or 'suitable' for the installation of solar plants (Kapfenberger-Pock, Barbara Horst). The plans concerning the implementation of solar energy and the reduction of the application of fossil energy are very ambitious. As emphasised by Quirós, Pozo et al. (2018) the International Energy Agency predicts that in the next five years in the countries such as China, USA and in the selected countries of the EU about 30,000 solar panels will be installed every hour. In 2018 the world's largest markets in the field of solar photovoltaic capacity were China, USA, Japan, Germany, India, Italy, United Kingdom, Australia, France, Republic of Korea (Vega, Vlaminck et al, 2020). At the end of 2018, Germany had more than 1.7 million solar PV systems, bringing the total capacity to 45.3 GW. Meanwhile, Amsterdam aims to have 250 MW of solar panels (1 million panels) in 2022, 550 MW in 2030 (400 MW on large roofs) and 1100 MW in 2040 (GSR, 2019).

The global trends and activities resulting in the increase in PV installations bring demand for new opportunities in the field of creating databases related to their attributes, including their spatial location. Therefore, the aim of the following research was to analyse the literature on the subject and global solutions, the content of selected public registers of data concerning the existing photovoltaic installations, in order to specify the model content and good practices in the field. Moreover, the usefulness of geospatial products, gathered on the basis of modern surveying and photogrammetric methods, in the process of the acquisition of the aforementioned data will be analysed.

2. BACKGROUND OF THE RESEARCH

According to Stowell, Kelly, et al. (2020), measuring and mapping the energy transition at different levels and at various time scales may provide insight into the current and future energy scenarios, proving a helpful tool in planning climate resilient energy systems, as well as short-term solar PV forecasting. As emphasised by Mainzer, Fath, et al. (2014), significant levels of photovoltaic capacity could lead to major disparities between supply and demand, especially in rural areas. The authors claim that an efficient political control over future installations depends on accessibility of knowledge about the remaining potentials and the abilities to use the generated electricity locally. Already in 2010, Boemi, Papadopoulos et al.

(2010) indicated that the lack of a complete real estate cadastre and spatial development plans, on the basis of which renewable energy installations could be installed, may be an obstacle to their promotion and obtainment. In this context, it is advisable to create geoinformation portals providing data that could allow correct location decisions. In fact, the implementation of GIS results in the improvement of the quality of management, significantly reducing the time for analysis and decision-making (Mickrenska-Cherneva, Mladenov, 2020). As emphasised, the development of geoportals has resulted in easy access to spatial information (Ogryzek, Tarantino, et al. 2020).

Reliable, complete data on, among others, the location of photovoltaic istallations are useful in the process of land management. The verification and update of information registered in public databases determine their suitability and accuracy of decisions made on their basis. Worldwide there have been cases, among others in Italy and Germany (Fuhs, 2013; Henneaux, Labeau et. al. 2012), when the extensive installation of solar plants has caused the electricity grid to fail. As indicated by Kausika, Nijmeijer, et al. (2021), although small-scale consumers (up to 15kWp) in the Netherlands are required to register their photovoltaic panels in a national register (PIR: Productie-installatieregister), this is not reinforced either. The result is that the information concerning the installed capacity, locations, and energy generated is not complete, and sometimes even unavailable. The authors indicated that Cadastre, Land Registry and Mapping Agency (Kadaster) of the Netherlands has established a database of data on solar installations for the whole country for the needs of which detection of small- and medium-scale solar installations on buildings was performed on the basis of aerial images with the use of deep learning techniques. Meanwhile, the Renewable Energy Planning Database (REPD) constitutes a key source of public data for installations of 150 kW and more in the UK (Stowell, Kelly, et al. 2020). The authors emphasise that there are, even though, cases of small-scale solar PV systems connected to national grids that are not officially registered or the information gathered in the register is less detailed than the one concerning the large sites. This confirms the common view that the available databases are not always complete and that they do not fully reflect the factual circumstances.

3. RESULTS

The analyses of the literature on the subject and the research on existing databases have shown that the databases are realized at different levels of detail and advancement. Some of them present data for the selected areas of the world, countries, whereas the others concern cities, regions, or agglomerations. In some countries, official data concerning PV installations are registered for the needs of securing their planning permission, in others for subsidies or tax relief, but there are a lot of countries in which no official register on such installations has been implemented. The available databases enable creation, publishing, maintainance, and update of data on the location of solar photovoltaic installations and their selected attributes. Exemplary portals providing data on the location of photovoltaic installations, including power plants, have been shown in Fig. 1. There are also other geoinformation portals, not being the subject of the following paper, solar maps and solar cadastres that enable one to verify whether the investment in a solar installation in a selected location could be profitable and what savings it would bring (Bieda, Cienciała, 2021).

There is widespread recognition that solar technologies are versatile and can be installed in a wide range of locations and sizes, so the databases should provide suitable tools to gather data on them all. In fact, existing registers can include information concerning installations mounted on roofs, on the ground, and even floating solar photovoltaic (FPV) installations.

Fig. 1. Exemplary portals providing data on the location of photovoltaic installations – National solar thermal installations map for Spain [source: https://www.esios.ree.es/en/interesting-maps/solar-thermal-installations-map (on the left)], Wiki-Solar (source: https://www.wiki-solar.org)

There are several attitudes towards their presentation. In some of the available portals, the icon assigned to the PV installation is depicted; in others the aerial or satellite view is shown, although most of them provide both of the options (Fig. 2). Some portals offer the possibility of observation of the location of the above-mentioned objects on the background of the orthophotomaps, Google Map, topographical map, etc. There are cases in which photographs of the object or hyperlinks to, among others, site plans or sattelite views are provided.

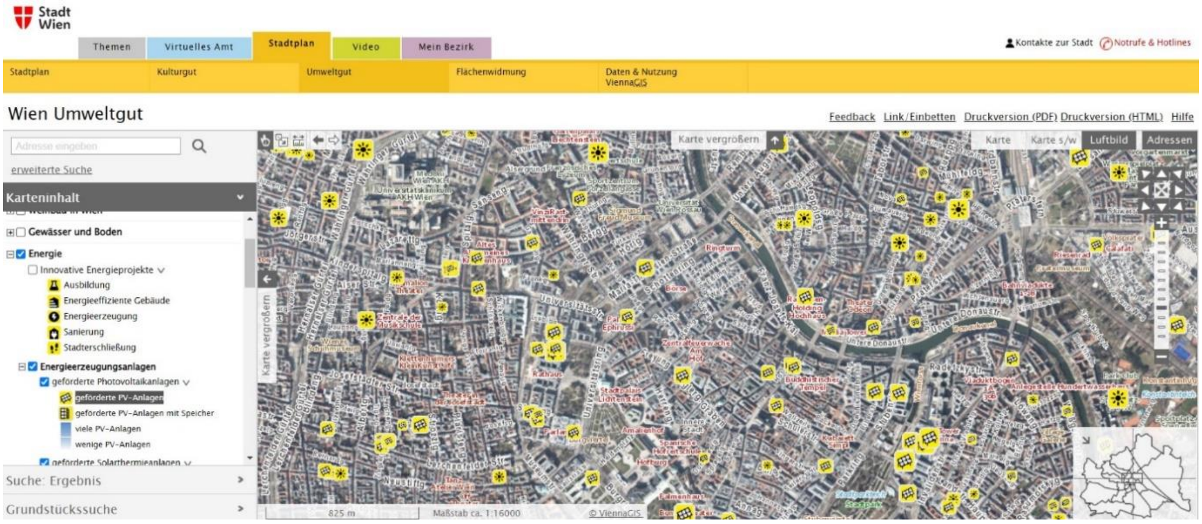

Fig. 2. Photovoltaic installations in Wien (Austria) (source: https://www.wien.gv.at/umweltgut/public).

An interesting feature comprises the ability to verify the growth in the number and capacity of solar panels over the years. For example, the City of Amsterdam portal provides the possibility of monitoring of its location for each year between 2015 and 2020. The juxtaposition of several orthophotomaps provides a picture of the trends and tendencies observed in the area, and confirms the growing interest in renewable energy sources in Amsterdam (the Netherlands).

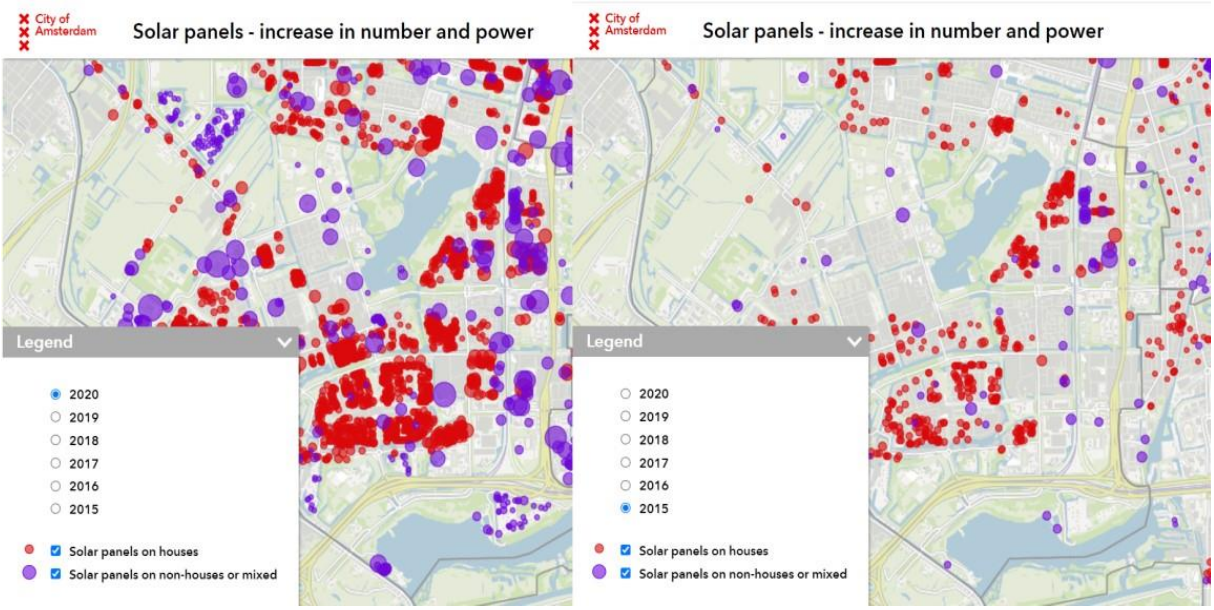

Fig. 3. Excerpts view of the Solar panels - increase in number and power map for a selected area of Amsterdam - comparison of 2020 (left) and 2015 (right) status [source: https://maps.amsterdam.nl/zonnepanelen/?LANG=en]

The most common attributes, available in geographic information systems, that are collected for each PV installation are, among others, details such as capacity, installation date, location, number of modules (or surface area), solar cell technology, operational status of the installation, etc. Usually, approximate location is determined on the basis of addresses and postcodes, so that objects are represented by a single geolocation point. Precise coordinate locations may also be determined, though the question is whether the knowledge of the precise location is necessary.

Below, a table of the selected attributes available in the analysed portals has been shown. The identified attributes have been divided into five categories: location, view of the site, technological characteristics, data on operational status /owner, and additional content/tools. Furthermore, for the research needs, some examples of the application and presentation of the above mentioned attributes in the geographic information systems have been analysed and compared.

Table. 1. Attributes available in the analysed portals.

Location	View of the site	Technological characteristics	Data on operational status/owner	Additional content /tools
• Precise, coordinate locations, • Approximate geolocation – via addresses and postcodes, • Mounting location (e.g. roof or ground), • Mounting type; fixed, offset, 1- or 2-axis tracker, rooftop, • Data on land use, • Site area (ha), • Mapping as polygons, • Mapping as simple points, • Information on generator orientation.	• Photographs of the site, • Indication on orthophotomaps/ Google Map, etc., • Hyperlink to site plan/ view on Google Maps / satellite view, etc.	• Installation capacity information (output), • AC rating (MW_{AC}), • Design yield (GWh/yr), • Equivalent power consumption expressed as number of homes, • Annual CO2 savings, • Equivalent carbon savings expressed as number of cars, • Solar cell technology, • Details of planning submittion (data, application reference, etc.). • Data on tilt, • Number of modules, • Surface area of the modules.	• Operational status of the installation, e.g. approved / under construction / operational, • Commissioning / Application date , • Data on the operator, owner, project developer, etc., • Solar module supplier, • Source of information, • Information on increase in number and power over years.	• Tool to add a new plant / installation, • Tool to edit a new plant / installation, • Url of internet page with details of the plant.

In addition, the review of the international literature on the usefulness of geospatial products, gathered on the basis of modern surveying and photogrammetric methods, in the process of the acquisition of the aforementioned data has been analysed. Creating an inventory of PV installations requires fast and efficient measurement tools. The literature review has shown that in many mapping initiatives, the main sources of information are aerial imagery, GPS traces, governmental data sources, and citizen information. The method of their obtainment and the precision required depend on the content of the registers. As emphasised by Malof, Bradbury et al. (2016) methods such as surveys and utility interconnection filings are expensive and time consuming. The authors researched the automatic detection of objects on the basis of aerial imagery (e.g., ortho-rectified imagery). If the location of a solar array is defined as a single point, there are more possible tools than in the case where the extent of the array as a multi-poligon. Such data are laborious to collect, especially if precise outlines have to be detected. Precise observations of the geometry of objects, for example on the basis of UAV flight, can be helpful in deformation and displacement measurements. In Japan, a country with a small area of land suitable for the establishment of solar power plants, land from the sea after reclamation is used for the establishment of photovoltaic farms (Matsuoka, I. Nagusa, et al., 2012). The authors emphasise that monitoring of the geometry of photovoltaic farms is of particular importance there, as solar power plants are often located on land reclaimed from the sea, prone to subsidence affecting the panels and bringing the requirement for periodic strain measurements. Conventional measurement methods in this case are labor intensive and expensive. In addition, low-altitude short-range photogrammetry has already been repeatedly investigated for the accuracy of photogrammetric measurements. Studies by other authors (Matsuoka, Nagusa, et al. 2012; Vega Díaz, Vlaminck et al., 2020) indicate that processed photogrammetric images from UAVs will allow solar panel deformation monitoring with the required accuracy.

4. SUMMARY

Definitely, knowledge on the proper and quick acquisition of data on the geolocation of the istallations, as well as its accurate presentation in geographic information systems, is a crucial matter in the reality of intensive development of demand for renewable energy sources. The need for solutions and the requirements in this area are underestimated. There is widespread recognition that the available databases that gather geospatial data on PV installations are not always complete and do not fully reflect the factual circumstances. The databases are realized at different levels of detail and advancement; however the aim is worthy. Existing installations can constitute an important activity in the process of comparing the capacities of newly designed installations with the remaining regional potential, as the extensive and uncontrolled installation of photovoltaic plants can lead to problems with the electricity grid, including grid failures. Repeatable inspections based on geospatial tools could also be helpful in fault detection and current maintenance, for example, of large-scale power generation facilities.

REFERENCES

1. BEIS 2020. UK Department for Business, Energy and Industrial Strategy (BEIS). Solar photovoltaics deployment statistics. https://data.gov.uk/dataset/9238d05e-b9fe-4745-8380-f8af8dd149d1/solar-photovoltaics-deployment-statistics.
2. Bieda, A., Cienciała, A. (2021). Towards a Renewable Energy Source Cadastre—A Review of Examples from around the World. Energies 14 (23).
3. Boemi, S.N., Papadopoulos, A.M., Karagiannidis, A., Kontogianni, S. (2010). Barriers on the propagation of renewable energy sources and sustainable solid waste management practices in Greece. Waste Manag. Res. 2010, 28, 967–976.
4. Fuhs, M. (2013). Ein bisschen Guerilla ist gut. PV Mag 2, 54.
5. Henneaux, P., Labeau, P.-E., Maun, J.-C. (2012). A level-1 probabilistic risk assessment to blackout hazard in transmission power systems. Reliab. Eng. Syst. Saf.
6. Huerta Herraiz, I., Pliego Marugaan, A., García Marquez, F.P. (2020). Photovoltaic plant condition monitoring using thermal images analysis by convolutional neural network-based structure, Renewable Energy 153, pp. 354 - 348.
7. Kausika, B.B., Nijmeijer, D., Reimerink, I., Brouwer, P., Liem, V. (2021). GeoAI for detection of solar photovoltaic installations in the Netherlands, Energy and AI 6.
8. Kapfenberger-Pock, A., Horst, B. City of Graz Solar Roof Cadastre GIS-Based Local Analysis for Solar Plants – a Planning Tool Dipl. Ing.
9. Mainzer, K., Fath, K., McKenna, R., Stengel, J., Fichtner, W., Schultmann, F. (2014). A high-resolution determination of the technical potential for residential-roof-mounted photovoltaic systems in Germany, Solar Energy 105, pp. 715-731.
10. Malof, J. M., Bradbury, K., Collins, L.M., Newell, R.G. (2016). Automatic detection of solar photovoltaic arrays in high resolution aerial imagery, Applied Energy 183, pp. 229-240.

11. Matsuoka, R., Nagusa, I., Yasuhara, H., Mori, M., Katayama, T., Yachi, N., Hasui, A., Katakuse, M., Atagi, T. (2012). Measurement of large-scale solar power plant by using images acquired by non-metric digital camera on board UAV. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXIX-B1, XXII ISPRS Congress, Melbourne, Australia.
12. Mayor of London (2018). Solar Action Plan for London. Greater London Authority.
13. Mickrenska-Cherneva, C., Mladenov, R. (2020). Implementation of GIS Application for Water Company Needs. Geomat. Environ. Eng. (14), pp. 47–56.
14. Ogryzek, M., Tarantino, E., Rząsa, K. (2020). Infrastructure of the Spatial Information in the European Community (INSPIRE) Based on Examples of Italy and Poland, International Journal of Geo-Information 9(12), 755.
15. Quirós, E., Pozo, M., Ceballos, J. (2018). Solar potential of rooftops in Cáceres city, Spain, Journal of Maps 14 (1), 44-51.
16. Renewables 2019 Global Status Report, https://www.ren21.net/gsr-2019, access: 29.04.2022
17. Solar Atlas of Amsterdam, https://www.zonatlas.nl/amsterdam, access: 29.04.2022
18. Spain Thermal Installations Map, https://www.esios.ree.es/en/interesting-maps/solar-thermal-installations-map, access: 29.04.2022
19. Stowell, D., Kelly, J., Tanner, D. et al. (2020). A harmonised, high-coverage, open dataset of solar photovoltaic installations in the UK. Sci Data 7**,** 394.
20. Thebault, M., Berrah L.-A., Desthieux, G., Ménézo, Ch. (2019). Towards a Solar Cadaster for the Monitoring of Solar Energy Urban Deployment: the Case of the Greater Geneva. IEA SHC International Conference on Solar Heating and Cooling for Buildings and Industry, ISES Solar World Congress 2019.
21. Vega Díaz, J.J., Vlaminck, M., Lefkaditis, D., Orjuela Vargas, S.A., Luong, H. (2020). Solar Panel Detection within Complex Backgrounds Using Thermal Images Acquired by UAVs. Sensors 20, 6219.
22. Vienna City Map, https://www.wien.gv.at/umweltgut/public, access: 29.04.2022
23. Wiki-Solar, https://www.wiki-solar.org, access: 29.04.2022

BIOGRAPHICAL NOTES

Dr Ciencała Agnieszka

Agnieszka Ciencała graduated from geodesy and cartography at the AGH University of Science and Technology in Cracow in 2008 and obtained her Ph.D. at the Faculty of Geodesy and Cartograpy, Warsaw University of Technology, Poland, in 2015. She has been vice-dean of the student affairs and teaching at the Faculty of Environmental, Geomatic, and Energy Engineering at Kielce University of Technology, as well as a head of the Department of Geodesy and Geomatics. Her scope of interests is land management, land surveying, cadastre, and GIS. She is a licensed surveyor (scope 1,2) and a court expert in the field of land surveying.

Dr Bieda Agnieszka, Assoc. Prof.

Agnieszka Bieda obtained her Ph.D. at the Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology in Cracow, Poland, in 2011. She has been a member of that faculty since the same year. In 2016 she completed her postgraduate studies in spatial planning at the Cracow University of Technology, Poland. She received her habilitation (postdoctoral degree) at the Faculty of Geodesy and Cartography, Warsaw University of Technology, Poland, in 2019. Her scope of interests are spatial planning, revitalisation, and cadastre, as well as real estate valuation and market analysis. Presently, she works as an associate professor in the Department of Photogrammetry, Environmental Remote Sensing, and Spatial Engineering, AGH University. In addition, she is an editor-in-chief of the academic journal 'Geomatics and Environmental Engineering'.

MSc Szymon Sobura

Szymon Sobura is an assistant at the Faculty of Environmental Engineering, Geomatics, and Power Engineering, as well as a long-term instructor for UAV control training. His research interests are focused on close-range photogrammetry and remote sensing applications in precision agriculture.

CONTACTS

Dr Agnieszka Cienciała
Kielce University of Technology
Al. Tysiąclecia Państwa Polskiego 7
25-314 Kielce
POLAND
Tel. +48 41 34 24 859
Email: acienciala@tu.kielce.pl

Dr Agnieszka Bieda, Assoc. Prof.
AGH University of Science and Technology
Al. Mickiewicza 30
30-059 Kraków
POLAND
Tel. +48 12 617 34 30
Email: bieda@agh.edu.pl

MSc Szymon Sobura
Kielce University of Technology
Al. Tysiąclecia Państwa Polskiego 7
25-314 Kielce
POLAND
Tel. +48 41 34 24 832
Email: ssobura@tu.kielce.pl