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The solar map as a knowledge base for solar energy use

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Abstract

Our existing urban environment has a significant potential to increase the use of renewable energy, mainly by using solar irradiation for heat and electricity. Quantification of the solar potential by means of a solar map is the first step in the acceleration process for using more solar energy in our urban environments. A solar map is a GIS system providing the annual solar irradiation on building surfaces, mostly accompanied by information of the output of solar thermal or photovoltaic systems. Many solar maps are already in place today; almost all of them are however using different approaches. In this paper, an analysis is done of current solar maps in order to see on which principles the solar maps were based upon.

Solar maps; solar cadastre; cities; tool; urban planning, solar resource assessment

1. Introduction

Cities, home to more than half of the earth's population, consume the majority of energy in the world [1]. In order to become more resilient for the future, cities need not only to reduce their energy need, but also start producing their own energy [2]. One way to generate renewable energy within our existing urban environment is by making use of solar energy. It is important to get a more detailed overview of the amount of energy we can produce with solar thermal (ST) or photovoltaics (PV) on existing buildings. One way to analyse the potential of the existing built environment is by means of solar maps [3-8]. A solar map or solar cadastre is a GIS system providing the annual solar irradiation on building surfaces (roofs and / or facades), mostly accompanied by the output of solar thermal or photovoltaic systems, and connected to a website. Many city administrations already have solar maps in place and they mainly serve two purposes: as a front-end platform to inform citizens about the potential of their own roof, and as a back-end tool for city administrations to base energy decisions upon. Current solar maps have different levels of advancement; the amount of information provided to users can differ a lot. Sometimes, solar maps are part of larger programs to get more renewable energy production in cities and provide users with direct information of suppliers and installers of solar systems. Other solar maps simply provide the solar irradiation to users without any further information. Furthermore, all solar maps so far take only roofs into account, not facades.

1.1. Common methodology for solar maps

The most common methodology to produce a solar map is shown in Figure 1. LiDAR data is Light Detection and Ranging data; 3D data collected by laser scanning. DEM –Digital Elevation Model- is 3D data of the terrain, and LAI –Leaf Area Index- is 3D data describing the "exchange of fluxes of energy, mass (e.g., water and CO2), and momentum between the surface and the planetary boundary layer" [9]. A growing number of cities are obtaining LiDAR data, making it in theory possible for these cities to produce a solar map. The process to obtain a solar map might be the same, but parts of the methods can be performed very differently. Maybe the most important part is the used calculation method, both for the solar irradiation and the output of the solar technology (PV / ST). Jakubiec & Reinhart (2013) note that 'limited attention has been paid to the assumptions and calculation methods underlying solar maps' [10]. In their analysis of North American solar maps, it was found that the most used calculation method were the 'constant irradiation level' method, Solar Analyst, and PVWatts, while Jakubiec & Reinhart use Radiance / Daysim as calculation method.

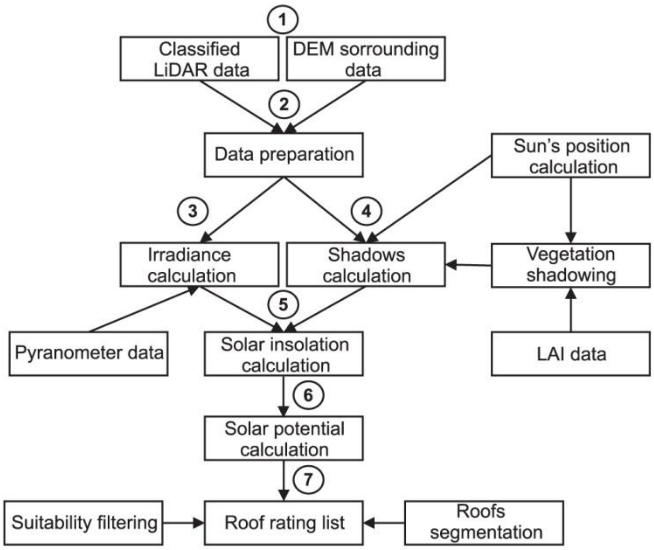


Figure 1. Methodology to produce a solar map [11]

In this study, the focus is onother parameters than the calculation method:

- which assumptions are made in the rating of the suitability of surfaces?
- which additional information is provided to accelerate the implementation of solar energy?
- how is the information provided from the solar maps used (by front- and back-end users)?

It was expected that this information would reveal the underlying status of solar energy in the cities.

2. Method

In order to get an overview of current solar maps, a simple Google search was done with the words "solar map city". Additionally, literature and scientific databases were also searched for with the same search terms. In total, 19 solar maps were identified. The authors are aware of the fact that there are more solar maps available worldwide, but many of them rely on exactly the same process (e.g. bought from the same company), and were therefore not included in the list. Table 1 shows the overview of the 19 analysed solar maps.

Table 1. Overview of analysed solar maps

	Country	City	Name	Owner
1	Austria	Graz	Solardachkataster	City of Graz
2	Austria	Vienna	Solarpotenzialkataster	City of Vienna
3	England	Bristol	Solar energy Bristol	City of Bristol
4	Germany	Aachen	Stadt Aachen Solarkataster	City of Aachen
5	Germany	Berlin	Solaratlas Berlin	City of Berlin
6	Germany	Dusseldorf	Solarkataster Dusseldorf	City of Dusseldorf
7	Germany	Marburg	Solarkataster Marburg	City of Marburg
8	Germany	Osnabrück	Sun-Area	City of Osnabrück
9	Germany	Solingen	Solarkataster Solingen	City of Solingen
10	Netherlands	Amersfoort	Zonnescan	City of Amersfoort
11	Netherlands	Arnhem	Zonatlas Arnhem	City of Arnhem
12	Portugal	Lisbon	Carta do Potencial Solar	City of Lisbon
13	Sweden	Gothenburg	SEES	Göteborg Energi
14	Switzerland	Basel	Solarpotenzial	City of Basel
15	Switzerland	Geneva	InfoEnergi	City of Geneva
16	Switzerland	Porrentruy	Cadastre Solaire	City of Porrentruy
17	USA	Boston	Renew Boston Solar	City of Boston
18	USA	Los Angeles	LA County Solar Map	LA County
19	USA	New York City	NYC Solar Map	NYC Solar America City

The owners were contacted to obtain additional information how the system was set up and what the conditions were, based on the following questions:

1. In your solar map you have different categories (good, very good, not suitable) for the assessment of solar energy. How did you choose the actual limits for the different categories? (based on financial motives, subsidies, etc.?)
2. How do you plan to work with the gained information from the solar potential map (or how do you already work with it)?
3. Is it only meant for citizens or do you use it as an instrument for urban / energy planning? (Is it used for deciding political goals for the use of solar energy?)
4. Is the total potential summarized for the city or for different areas or categories of buildings?
5. Are there analyses done for ranking or comparing areas with e.g. apartment buildings and single family buildings respectively?

Unfortunately, only 11 out of 19 answered to our short questionnaire (Aachen, Amersfoort, Arnhem, Basel, Dusseldorf, Geneva, LA County, Lisbon, NYC, Marburg, Osnabrück)

Of the different solar maps, the following parameters were analysed: (Table 2):

- Annual solar irradiation level (kWh/m^{2}a),
- Considered technologies (PV, ST),
- Total output per roof (kWh/a),
- Assumed efficiency of the technologies. In the case that the efficiency of the solar technologies was not provided, the efficiency was calculated using the total output, the area, and the solar irradiation levels (marked with a *).
- Heritage limitations (are buildings with a cultural heritage are marked),
- Threshold value per category (kWh/m^{2}a),
- Minimum surface of the solar system (m^2),
- Maximum annual solar radiation (For European cities, the maximum solar irradiation level was acquired by using PVGIS [12], even though some solar maps stated other maximum values. In USA, mainly the solar maps of NREL were used [13]).
- The percentage of maximum available annual solar irradiation level,
- Information on which parameters categories were based upon.

In Table 2, N/A means here that this data were either not specified or not elucidated in the answers. The percentage of maximum available annual solar irradiation was calculated because it makes comparisons between solar maps easier. Not all solar maps had the same categorisation. If necessary, categories were re-labelled to the common categories -very good, good, and suitable.With the information from the owners and the websites of solar maps, an inventory was made of the categorisation method used in the maps.

3. Results

In this section, first a quantitative analysis of the solar maps is provided, followed by a qualitative analysis.

3.1. Quantitative analysis

Table 2 provides an overview of all the analysed parameters. The colours in the table represent different categories:

- Blue: Reasonable
- Light green: good
- Dark green: very good
- Grey: solar maps did not divide areas in categories or did not specify –either in the documentation or in the reply- how categories were set up.

Table 2. Overview of the solar maps and their characteristics

	City	Technologies	Output / roof	Efficiency	Heritage	Categories	Thres-hold	Min. surface	Max solar rad.	% of max sol rad	Categories based on
1	Graz	N/A	No		yes	Good	N/A	12	1330	N/A	N/A
						Very good	N/A	12		N/A	N/A
2	Vienna	PV / ST	Yes (PV/ST)	PV: 14%*	yes	Good	900	5	1300	69%	N/A
				ST: 90%*		Very good	1100	5	1300	85%	N/A
3	Bristol	PV	Yes (PV)	PV: 9% *	yes	Reasonable	880	N/A	1170	75%	N/A
						Good	940	N/A	1170	80%	N/A
						Very good	1000	N/A	1170	85%	N/A
4	Aachen	PV / ST	Yes (PV / ST)	PV: 11.6%	no	Reasonable	800	10	1090	73%	N/A
				ST: 13.5%*		Good	870	10	1090	80%	N/A
						Very good	1020	10	1090	94%	N/A
5	Berlin	PV / ST	Yes (PV)	PV: 12%	yes	Reasonable	920	N/A	1150	80%	N/A
						Good	1035	N/A	1150	90%	N/A
						Very good	1092.5	N/A	1150	95%	N/A
6	Dusseldorf	PV / ST	Yes (PV / ST)	PV: 14%	yes	Reasonable	654	20	1090	60%	N/A
				ST: 14%		Good	872	20	1090	80%	N/A
7	Marburg	PV / ST	Yes (PV)	PV: 9-15%	no	Reasonable	825	N/A	1100	75%	Irradiation
						Good	891	N/A	1100	81%	
						Very good	1045	N/A	1100	95%	
8	Osnabrück	PV / ST	Yes (PV/ST)	PV: 15%	yes	Good	766	N/A	1090	70%	N/A
				ST: 50%*		Very good	909	N/A	1090	83%	N/A
9	Solingen	N/A	No		yes	Reasonable	N/A	N/A	1090	N/A	N/A
						Good	N/A	N/A	1090	N/A	N/A
						Very good	N/A	N/A	1090	N/A	N/A
10	Amersfoort	PV	Yes (PV)	PV: 11% *	yes	Reasonable	500	N/A	1110	45%	payback time
						Good	900	N/A	1110	81%	
11	Arnhem	PV	Yes (PV)	PV: 15%	no	Reasonable	700	11	1100	64%	N/A
						Very good	900	11	1100	82%	N/A
12	Lisbon	N/A	No		no	Reasonable	1000	N/A	1860	54%	Orientation
						Good	1400	N/A	1860	75%	
						Very good	1600	N/A	1860	86%	
13	Gothenburg		No		no	Suitable	N/A	N/A	1070	N/A	N/A
14	Basel	PV / ST	Yes (PV / ST)	PV: 15%	yes	PV good	900	N/A	1210	74%	N/A
				ST: 45%		PV very good	1100	N/A	1210	91%	N/A
						ST good	800	N/A	1210	66%	N/A

						ST very good	1100	N/A	1210	91%	N/A
15	Geneva	N/A	No		no	Reasonable	900	N/A	1400	64%	N/A
						Good	1000	N/A	1400	71%	N/A
						Very good	1145	N/A	1400	82%	N/A
16	Porrentruy	PV	Yes (PV)	PV: 12.75%	no	Reasonable	750	N/A	1250	60%	N/A
						Good	950	N/A	1250	76%	N/A
						Very good	1150	N/A	1250	92%	N/A
17	Boston	PV	Yes (PV)	PV: 11%*	yes	N/A	N/A	N/A	1307	N/A	N/A
18	Los Angeles	PV / ST	Yes (PV / ST)	PV: 18%	no	Reasonable	1204.5	N/A	1805	67%	Payback time
				ST: 64%*		Good	1460	N/A	1805	81%	
						Very Good	1789	N/A	1805	99%	
19	New York City	PV	Yes (PV)	PV: -	no	Suitable	1030	10	1456	71%	N/A

3.1.1. Categorisation

Table 3 and Figure 2 show the values of the categories ‘reasonable, ‘good’, and ‘very good’ of the different solar maps. In the box plot (Figure 2), the white part of the box represents the 2nd quartile of the range, the black box the third quartile of the range.

Table 3.Median for the categories ‘reasonable’, ‘good’, ‘very good’ (in % of local maximum annual solar irradiation)

reasonable	65%
good	77%
very good	89%

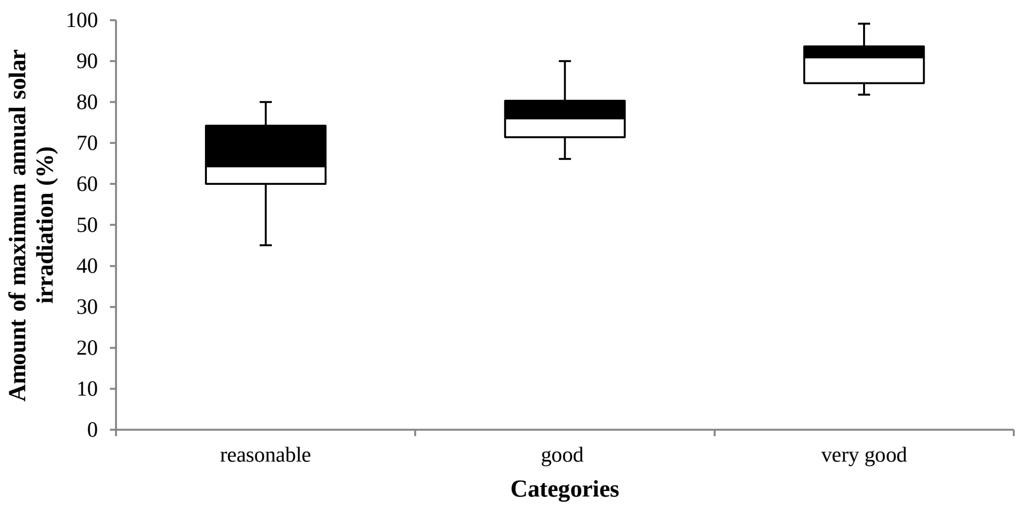


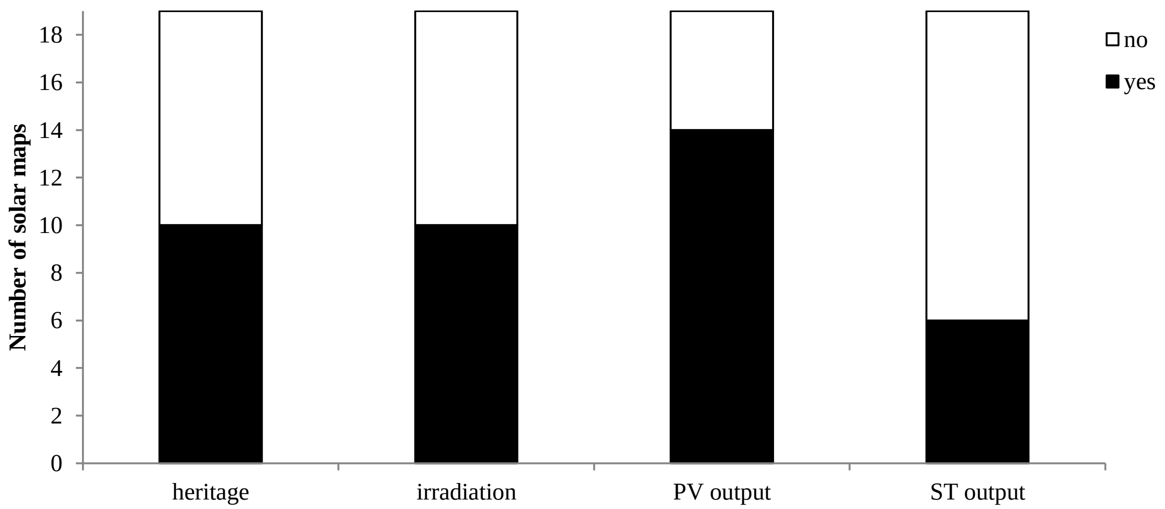
Figure 2. Box plot of categories applied in solar maps

Figure 2 shows that the categorisation of the solar maps is not straightforward. By comparing the categories as a percentage of the local maximum solar irradiation, the differences between the thresholds of the categories can only be explained from other parameters than solar irradiation, i.e. political, social, financial parameters. Interestingly, the maximum value of the 'reasonable' category range is higher than the minimum of the 'good' category. This is also true for the highest value of the 'good' category and the lowest value of the 'very good' category. The spread of the values in the 'reasonable' category is quite high (35%), while spreading in the 'good' category is smaller (15%), and 13% in the 'very good' category. The owners were asked to clarify on which information they based their categorisation of surfaces. It was expected that they would base their categories on a certain payback time of the applied solar technologies. There was a mixture of answers: sometimes owners answered that the categories were based on the radiation level (which does not answer the question); in other cases, categorisation was done by best guesses, and only in some cases, categorisation was based on detailed calculations of payback times. The LA solar map for example based the categories on a payback time shorter than 15 years, taking into account the general electricity costs and installation costs after subsidies.

The minimum system size of the solar system was often related to the payback time of the system and / or the resolution of the data. Most solar maps did not set a requirement for the minimum surface area, while other maps had minimum requirements (this was based upon the capacity and payback time). Owners responded that only with a certain system size (kWp), a reasonable payback time could be reached.

3.1.2. Other parameters

Figure 3 and Table 2 provide an overview of the main parameters users of the solar maps can extract: Heritage limitations, Irradiation levels, PV output, and ST output. More than half of the solar maps provided an assessment of the output of a PV system installed on the roof, while less than half could provide an assessment of the output of a ST system. Half of the solar maps showed culturally / historically important buildings where the implementation of solar energy might not be allowed or needs to be considered very carefully. Also, half of the solar maps were able to show the irradiation levels on roofs, while the other half did not show the irradiation levels but rather the output of solar energy systems. This might be due to the fact that, for laymen, it is easier to relate to the output of a system and the corresponding surface area than the incoming radiation.



Many solar maps do not only focus on the quantification of the solar potential of roofs in the involved cities, but they also serve as a platform to inform inhabitants about the possibilities of solar energy. In the following section, the qualitative side of the solar maps is discussed.

3.2.1. Purposes of the solar maps

In general, the analysed solar maps served both as a front-end and as a back-end tool platform. Most solar maps came with a short description of what the solar energy potential is and which methods were used in order to calculate it. Many solar maps also provided a rather detailed set of assumptions which are needed to calculate the output of solar energy systems, however it is often stated that the solar potential is just a 'first estimation', and that the owner (of the solar map) cannot be hold responsible for the calculations.

One example of how a solar map can be used both as a back- and front end tool is in case of the City of Basel, Switzerland [14]. This city launched an environmental program where they encourage people to first renovate their roofs, and then install PV –if their roofs had the right conditions; for both of the measures, the city will provide subsidies. On one website, it is explained how inhabitants should proceed. Besides that, the city also approached the owners of the 500 best roofs to implement PV.

3.2.2. Follow-up of the information gained by the user and owners

Using the solar map and obtaining the solar energy potential of roofs is often the first step in decision-making for both inhabitants and cities. Front-end users need guidance in order to understand what the solar energy potential actually means. Some of the solar maps therefore focus on two additional items:

- Finances of the system: revenues and costs
- Installations: which installers are available etc.

With this information, a founded decision can be made on the implementation of solar energy.

For the back-end users (and most often the owners of the solar maps), solar maps serve as an underlying information base for local energy decisions. In their answers, the involved cities say that they use the solar map for estimating the solar potential of all their own real estate. Some cities have underlying information about building types and year of construction. Performing such analyses takes time and money; the benefit of such an analysis was not always clear to the cities.

4. Discussion and Conclusions

An analysis was done of 19 solar maps which are publically available on the internet. The solar maps were analysed, focussing on mainly the following elements:

- Annual solar irradiation (kWh/m^{2}a),
- Considered technologies (PV, ST),
- Total output per roof (kWh/a),
- Assumed efficiency of the technologies,
- Heritage limitations (are buildings with a cultural heritage marked?),
- Threshold value per category (kWh/m^{2}a),
- Minimum surface of solar system (m^2),

Besides this analysis, owners of the solar maps were asked to fill in a questionnaire, focussing mainly on:

- information on which parameters categories were based upon,
- what purposes the solar map serves.

4.1.1. Classification of solar maps

With the analysis of the solar maps and the results of the surveys, it is possible to classify the solar maps (Table 4). The *basic* solar map is a solar map with basic information: the irradiation level. Preferably, irradiation levels are also categorised. Such a solar map is the base for the *medium* and *advanced* solar map, of which features are all based on the analysis of annual solar irradiation of surfaces. The *medium* solar map provides the energy output of the suitable areas as PV / ST. The most advanced solar map is not only providing quantitative data, but also provides information about what to do next when people want to install PV or ST.

Table 4. Classification of solar maps

Basic	Medium	Advanced
-Irradiation levels	-Irradiation levels (not in all cases)	-Irradiation levels (not in all cases)
-Categorisation of irradiation levels (not in all cases)	-Output of solar systems (PV / ST)	-Output of solar systems (PV / ST)
	-Categorisation of suitable area for production	-Categorisation of suitable area for production
	-System effect (PV)	-System effect (PV)
		-Monthly output (not in all cases)
		-Financial considerations (investment costs, revenue)
		-Information regarding installers
		-Information about solar energy

A useful addition to solar maps could also be a feature which maps solar systems that are already installed within the city, with its according size and output.

4.1.2. In action

The role of solar maps as a decision support tool can be divided into three different aspects: 1) the difference in users (politicians, urban planners, investors, real estate owners), 2) scale (city, urban district, building), and 3) *soft* aspects (raise interest, vitalise the debate, get a common base for discussion).

By taking all these three aspects into account, a full deployment of solar energy in cities can be accelerated.

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