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Identifying solar energy potentials and intensifying the climate-friendly use of photovoltaics within urban areas.

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Abstract. Limited non-renewable fossil energy reserves and the essential ideas of sustainability have caused an increase in the demand for solar energy. The intensified use of renewable energy in Germany is primarily encouraged by the German renewable-energy-law. Solar panels mounted on roofs generate electricity using the energy radiated from the sun by taking advantage of the photovoltaic effect. However, not every roof is usable for power generation through solar energy. Therefore, web-based solar energy registers for multiple regions in Germany have been developed that provide detailed information on roofs suitable for carrying solar panels. The analyses are based on a digital object model derived from airborne laser scanning data of high accuracy and a fully automated technology to classify the points. First, roof points are separated according to their single roof sides and are converted into polygons. Then, exposure, slope, size of the roof, and particularly shading effects are computed to calculate the solar potential of each roof side. The web-GIS provides detailed information about the roof's suitability, such as the installable capacity and the expected generation of electricity. Thus, it helps house owners to calculate their investment and later revenues.

1. Introduction

The usage of renewable energy has a high socio-political significance due to increasing global warming and due to the question of how to encourage sustainable development. Therefore, the German Federal Government pursues an increase in the proportion of renewable energy in the total electric power supply up to at least 80 percent in 2050. A federal law primarily manages the intensifying and sustainable use of renewable energy, called EEG (Erneuerbare-Energien-Gesetz).

In this context, the generation of electric power through photovoltaic systems (PV-systems) was insignificant until recently, in comparison to other renewable forms of energy. Solar panels mounted on roofs generate electricity using the energy radiated from the sun by taking advantage of the photovoltaic effect. In comparison, windmills transform the wind energy to electric energy as wind-powered rotors move a generator. Wind energy was and still is the leading energy producer regardless of its need for large areas. However, PV-systems mounted on roofs do not demand additional space. Rather, existing roof areas are used both economically and ecologically. In addition, negative effects such as noise or shading on residents as in the neighborhood of windmills do not need to be considered. Thus, it becomes evident that PV-systems offer great advantages.

However, not every roof is usable for power generation through solar energy. Therefore, solar energy registers for multiple regions have been developed in Germany to help distinguish the suitability of roofs for PV-systems. The approach discussed in this article has been developed by the

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company Geoplex, a spin-off of the Institute of Geoinformatics and Remote Sensing under the supervision of the author [1].

The availability of data about installable capacity, the expected generation of electricity, and the estimated earnings per year have three main advantages:

- The house owner and user of the solar energy register receives unbiased information regarding the solar potential and the positive effects of a PV-system on his roof. This is important for his investment decision.
- The data are helpful or often a prerequisite to get loans from local financial institutes or to get subsidies from the government for the investment.
- The city or council government, which initiated the installation of a solar radiation register, gains knowledge about the overall potentials of PV-systems in the region.

A solar radiation register is especially useful to intensify the climate friendly use of photovoltaic within urban areas [2].

2. The data base

A digital object model (DOM) is the main dataset for analyzing buildings and roofs as well as solar radiation (figure 1). Due to its high accuracy, airborne laser scanner data is the most suitable technology [3]. Airborne laser scanning delivers a DOM of measured points (up to 15 points per m²). Each measured point possesses only information on its location and elevation (x-, y-, z-coordinates, so called first-pulse data, positional accuracy < 0.2 m, elevation accuracy < 0.5 m). Beyond that the point cloud is not further classified. Consequently, it is not known if a measured point is situated for example on a tree or on a roof.

In addition to the DOM, building layouts are used to improve the building detection and to receive knowledge of the building structures. Furthermore, several less important datasets are employed mainly for visualization purposes (e.g. WMS, city borders, city logo).

Figure 1. The Digital Object Model made of airborne laser scan data

3. The analysis
The roof's suitability for PV-systems depends primarily on the insolation. Global radiation refers to the direct and indirect insolation. It is measured in kWh/m^2/year. The German Weather Service provides these data for each region in Germany. In order to calculate harvesting energy from the sun, the following factors need to be considered:

- exposure of a roof's side
- inclination of a roof's side
- shading of a roof's side, for example caused by surrounding buildings or trees.

3.1 Roof Detection
To identify solar energy potentials in urban areas the roofs of buildings need to be analyzed. Therefore, all roof sides in the reference area need to be detected. On the basis of airborne laser scanning data, Geoplex has developed a fully automated technology that detects more than 95 % of all buildings – from a garage up to an industrial complex [4]. The technique does not require additional information such as floor plans or cadastral data, which certainly can provide layouts of the buildings. This helps to avoid problems with incompatible or incomplete cadastral data that possess different time stamps. However, as the detection with this method is rather complex and time-consuming, cadastral data are often used in practice.

The laser scanner points are classified related to three groups: building, ground, and vegetation (figure 2). The unimportant points, which represent vegetation and ground, are deleted. Subsequently, the program separates the detected roofs into their single roof sides. The detected roof sides are converted from point shapes into polygon shapes. These roof sides are now ready for the calculation of the solar potential (figure 3).

3.2 Calculation of the solar potential
Based on the detected roof sides (polygons, 3D-data) the suitability for carrying solar panels can be calculated. Four essential site-related factors have to be computed: exposure, slope, size of the roof, and particularly shading effects.

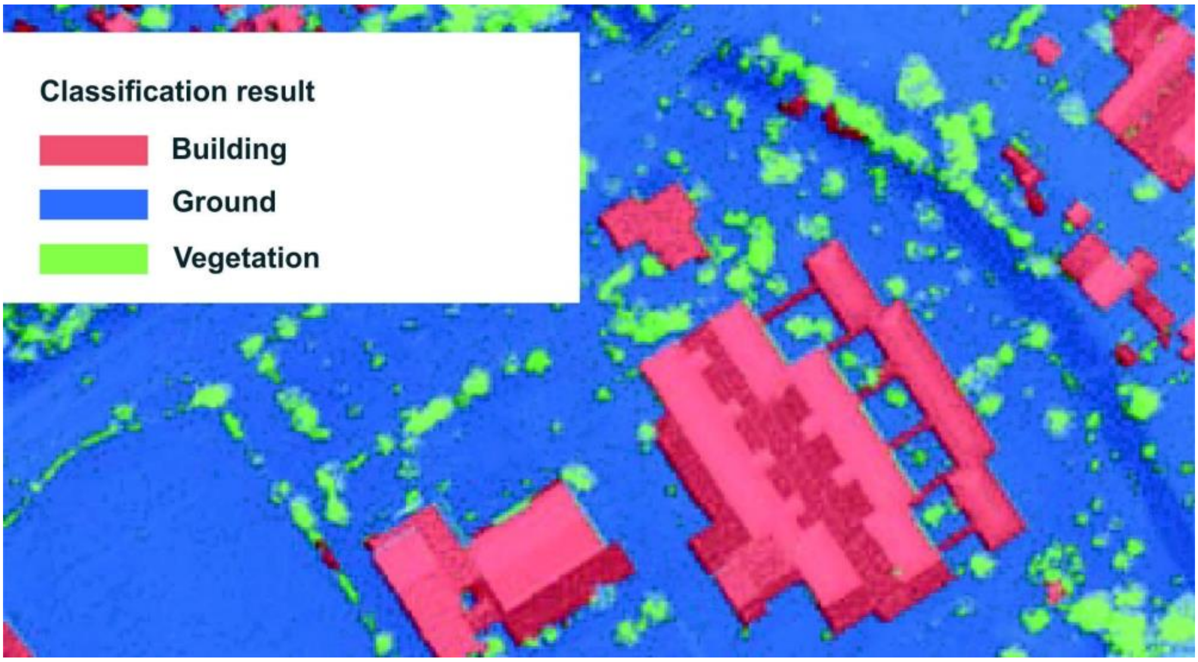

Figure 2. The classification of airborne laser scan data

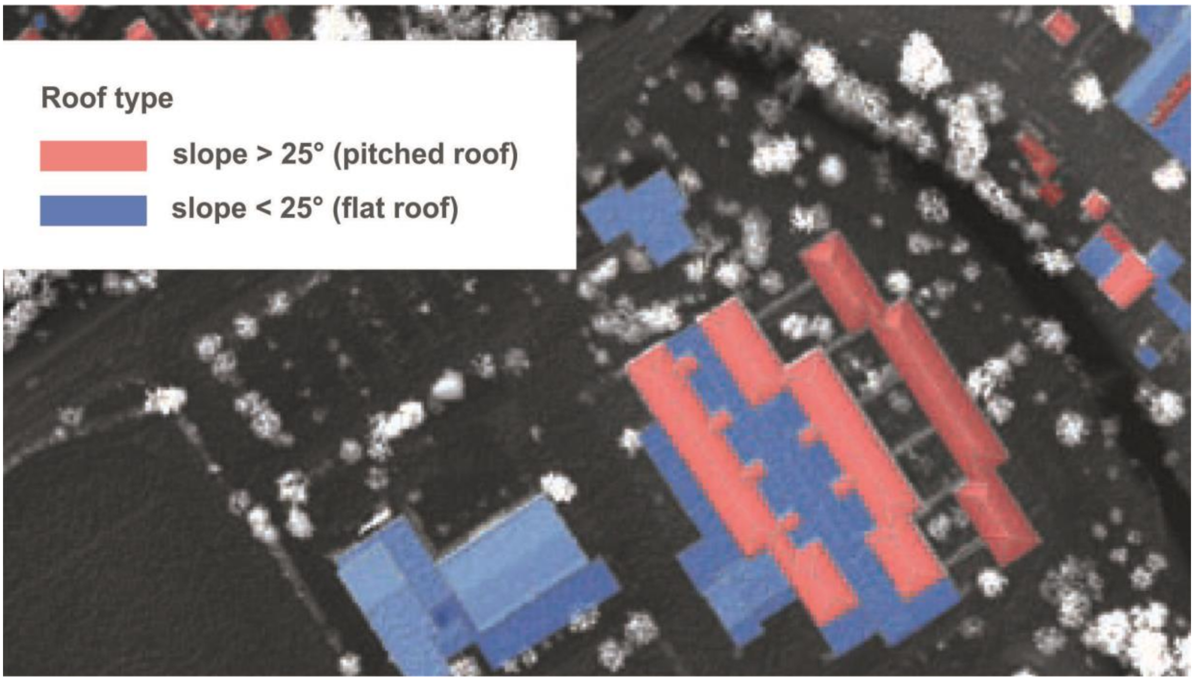

Figure 3. The detected roofs

Exposure: The optimal exposure for electricity earnings of a roof side in the northern hemisphere is southwards. Variation west- or eastwards means a loss of energy earnings. Consequently, every variation from the south direction limits the suitability of a roof side.

Slope: The optimal slope to generate electricity through the photovoltaic effect is approximately 30 degrees in Germany. The optimal slope is a bit steeper in northern regions than in southern ones. Thus, the latitude is considered while categorizing the slope results.

Size: The size of the roof is important to compute the installable capacity. The shape of the roof and panels, the arrangement of the panels, as well as the budget of the investor determine the number of panels.

Shading: As shading effects lower the energy earning of a photovoltaic system substantially, a separate layer called "shading" is computed, which is also presented in the web-GIS. This layer shows the shading in the reference area during the year (figure 4). The calculated value for shading indicates the percentage of the local radiation that is lost through shading. Shading is an important factor to consider for photovoltaic systems as the modules on the roof are connected to circuits. Even when only one module of the circuit is negatively influenced by shading, the whole output of the circuit decreases. The result of this layer enables the user to figure out where shading effects are serious and how to avoid these areas when installing the solar panels.

4. The web-based solar register

Figure 5 presents the solar potential analysis in the form of a web-based geo-information system (web-GIS). The main components of this GIS are the "suitability" layer and the "solar calculator". The "suitability" layer presents the suitability of each side of the roof for the installation of a photovoltaic system. The detected roofs are categorized according to their suitability for PV-systems. Categories range from very suitable (red) to not suitable at all (blue). For each roof more details can be acquired: the four main side-related factors (exposure, slope, size, and shading effects), the installable capacity, the possible generation of electricity and earnings for feeding the generated electricity into the electric supply network, as well as the CO_2-saving potential per year in comparison to the consumption of fossil fuels.

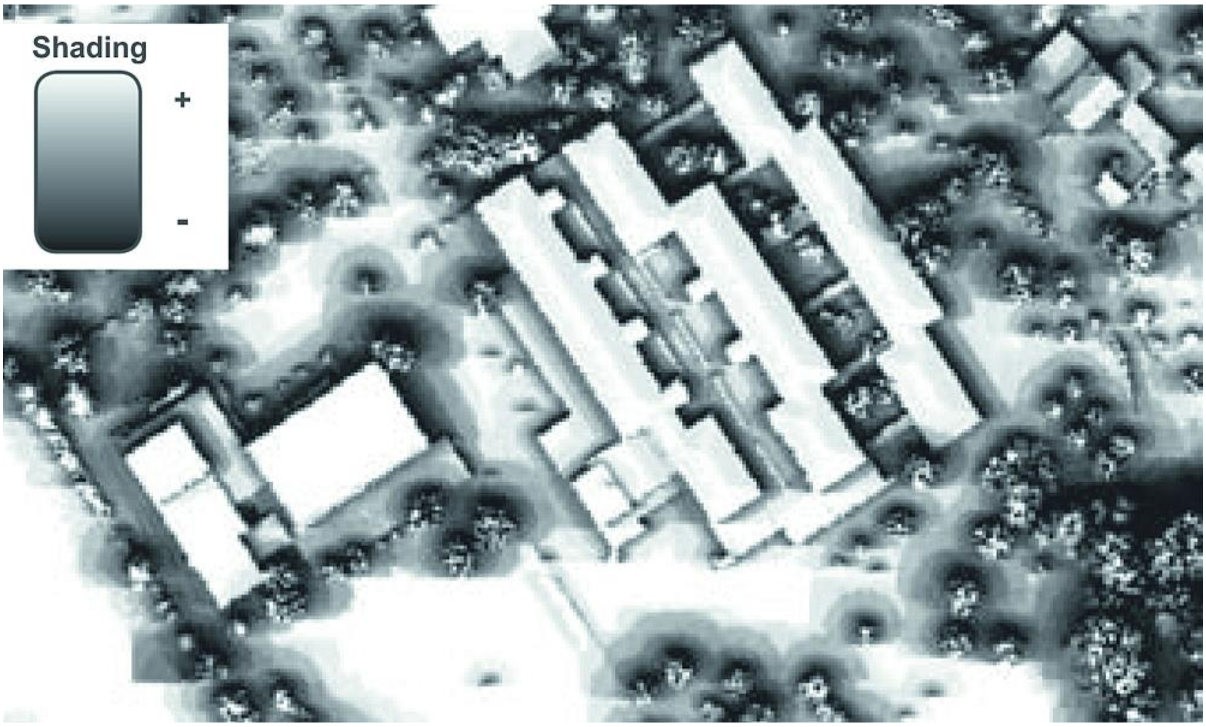

Figure 4. Shading effects

Figure 5. The web based solar register with the solar calculator

5. The calculation of the solar insolation

Solar irradiance refers to the power per unit area produced by the sun in the form of electromagnetic radiation. There is no unified measurement but the World Meteorological Organization recommends using megajoules per square metre (MJ/m^2). However, watt-hour per square meter (Wh/m^2) is the unit that solar energy businesses use. When divided by the recording time, this measure becomes insolation. Thus, the solar insolation is the instantaneous solar irradiance averaged over a given time period.

The following example of a building in the county of Osnabrueck at about 52° north shows the use of the solar register (figure 5). First, it is essential to know the amount of sunlight available at a particular location at a given time. These global irradiance data can be received from the German Meteorological Service. The global radiation in the county of Osnabrueck corresponds to 1,137.44 kWh/m²/year (20-year mean). This highest possible value of irradiation is measured in the county of Osnabrueck on a roof that does not suffer from clouding, that has an inclination of 34.0 degree, and that benefits from its due-south orientation (180 degree). Every deviation from this optimal value leads to a smaller value of radiation on a roof and therefore is less suitable for photovoltaics. The web-GIS calculates the insolation as a percent of maximum insolation regarding exposure and inclination. For example, a roof facing west (e.g. exposure 250°) with an inclination of 35° receives about 85% of the maximum solar insolation.

The following calculation refers to a roof of a small house in the county of Osnabrueck (figure 5). The analysis indicates an area of 60.2 square meters available for the installation of photovoltaic panels. This is about 93.3% of the whole roof area. The roof is exposed to south-south-west, its slope is 26.4°, and shading is about 0.3%. Thus, this roof is able to receive 96.6% of maximum insolation at this location. The calculation of the insolation for one square meter is as follows:

1137.44 kWh/m2 /year * 0.966 = 1099 kWh/m2 /year

This value can be used to classify the roof. The solar register, made for the Osnabrueck region, offers four classes of fitness: 1. very suitable (insolation more than 1080 kWh/m^2 /year), 2. suitable (insolation between 1030 and 1080 kWh/m^2 /year), 3. partly suitable (insolation between 915 and 1030 kWh/m^2 /year), and 4. not suitable at all (figure 5).

The important tool of the solar register is to calculate the profit that can be expected if the roof is covered with solar panels. In general, a PV-system consists of solar panels that produce direct current. Silicon-based solar cells are plugged into solar panels. While PV-semiconductor materials are not limited to silicon, the dominance of silicon in the PV-market is evident. Furthermore, an alternating-current converter and wires are needed. Overall, the performance of a PV-system depends on the efficiency factor of solar panels and losses due to the interconnection of mismatched solar cells, failure modes of PV-modules, as well as losses due to the converter and conduction losses. The system performance of a silicon-based solar module is 11.43%.

PV businesses use a special measuring unit to identify the rated power of a solar module. The maximum performance of solar modules under standard test conditions is defined as peak performance. An investor typically wants to know how much area is needed to produce 1 kWp The response depends on the type and design of the module, the module's inclination, and the amount of global irradiation that strikes the area. For example, to produce 1 kWp with silicon-based solar panels, assuming optimal irradiation conditions, 7 m^2 are needed for a slope of more than 20°, and 18 m^2 are needed for a flat roof below 10° (modules are elevated south facing in a 30° angle).

Now, the achievable profit in kWh/year per 1 kWp for the roof can be calculated for the example mentioned above. Therefore, the irradiation of a particular side of a roof is multiplied with the area needed for kWp installation in m² and with the system performance of the whole system.

1099 kWh/m2 /year * 7 m2 * 11.43% = 879 kWh/year.

This means a PV-system with 1 kWp on the roof (example, figure 5) produces 879 kWh/year alternating current for the grid or for own consumption.

Finally, an investor needs to define the number of solar panels to be installed. This decision depends on the shape of the roof and on the investor's budget. As shown in the example, the roof is rectangular, as is one solar module. A standard-sized solar module has 250 Wp, thus four panels are needed per 1 kWp. Therefore, it is possible to install 32 solar panels (four rows with eight panels) with sufficient space to the edge.

6. Harvesting solar energy

In Germany, the intensified use of renewable energy is primarily due to the renewable-energy-law, called EEG (Erneuerbare-Energien-Gesetz). This federal law in favor of the extension of renewable energy went into effect in 2000 and has been modified several times since. Up to the present, this law is the main political steering instrument in Germany.

The EEG regulates the favored feeding of electricity generated from renewable sources into the German electric supply network. It is noteworthy that the main features of the energy transition in Germany, the exit from nuclear and fossil-fuel energy to renewable energy, are anchored lawfully:

- The EEG obligates local network operators to use energy originated from renewable energies.
- The EEG guarantees compensation rates.
- The EEG settles different compensation rates depending on the energy type, determines greater compensation for smaller facilities as these require greater investment costs, and administers smaller compensation rates the later the facility's start-up.

It has to be pointed out that this policy is financed by everybody who is consuming electricity in Germany, through paying a surcharge on the electricity bill. In 2015 the so called EEG-surcharge is 1.14597 Cent/kWh.

The compensation rates per kWh supplied with current, for facilities up to 30kWh, were as follows: 2004: 57.4 Cent; 2006: 51.80 Cent; 2008: 46.75 Cent; 2010:39.14 Cent. In 2012, a modification to the EEG changed the compensation rates for facilities up to 10kWh as follows: 2012: 19.50 Cent, 2014: 13.26 Cent, 2015: 12.34 Cent. The distinctiveness of this model is that the compensation rate depends on the facility's year of construction and that this very compensation rate is guaranteed for twenty years. This arrangement led to the so called energy revolution in Germany.

To give an example, the yearly income for the selected roof in figure 5 can be calculated:
Installation of an 8 kWp PV-system in 2010: 8* 879 kWh/year * 0.3914 Euro/kWh= 2.752 Euro

This income needs to be reduced by investment costs and costs of operation. As well, the performance of the PV-modules decreases continually. If we assume investment costs of 22,500 Euro in 2010 for this 8 kWp PV-system, and yearly profit of 2,000 Euro, this example confirms the rule of thumb that the break-even point occurs after the 11th year of operation. This conservative estimate includes annual costs of insurance and cleaning the panels as well as unforeseeable reductions due to snow cover and performance losses.

We observed an increase in the installation of new facilities from 2001 to 2010 due to high compensation rates during these years that were regulated in the EEG. Especially, farmers used their barns for photovoltaic systems. Meanwhile, the rate of new installations decreased as a result of reductions in the compensation for electricity fed into the grid.

In addition to the other positive effects of renewable energy mentioned above, the internal consumption of the produced solar energy has become an important aspect. Considering an average electricity rate of 28.0 Cent/kWh in Germany, the benefit of internal consumption is 15.66 Cent/kWh when implementing a photovoltaic system in August 2015.

7. Conclusion and Outlook

The main benefits are as follows:

- The register is a trigger for investment decisions.
- The register offers important data about the installable capacity, the expected generation of electricity, and the estimated earnings per year.
- The register offers helpful data to get loans from local financial institutes.

Thus, the solar energy register is a driving force to a climate friendly and more intensive use of photovoltaics within urban areas. Local authorities such as city councils and county administrations, as well as local financial institutions, request development of a web-based solar register and compensate for the costs.

The analyses of buildings and roof-structures from laser scanning data generate additional benefit by the creation of 3D-city models and 3D-information-systems. In contrast to the conventional 3D city models we offer more than pure visualization. While processing the 3D models all building elements are enriched with additional attributes (slope, size, exposure etc). Within the web-GIS the attributes of all buildings and their elements are interactively available.

The 3D-city model can be used to analyze the dispersion of pollutants and noise as well as the impacts of flood hazards. The data can be merged with two-dimensional data, e.g. data from the last population and housing census, in order to estimate the energy consumption and the need for housing improvement.

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