NORTH SEA
SUSTAINABLE
ENERGY
PLANNING

Final Activity Report turned in 2012, May 23rd

Work Package 4
Activity 4.5

Photogrammetric Plotting

Final Report

23.05.2012

Jade University of Applied Sciences

Authors
Prof. Dr.-Ing. habil. Thomas Luhmann,
Hans-Peter Ratzke, Andreas Voigt

The Interreg IVB North Sea Region Programme

European Community
European Regional
Development Fund

Confirmation of publishing permission

Oldenburg, May 23rd, 2012

Hans-Peter Ratzke
Jade University of Applied Sciences

Table of contents

1 Introduction

Rising prices for energy lead responsible thinking people to look for possibilities to save energy rsp. for alternative technologies to produce energy. Great potentials are in the prevention of energy losses.

But also on the production site potentials are existing, which are currently uninvested. Especially solar power plants (PV) to produce electrical energy have such an uninvested potential. The electrical power produced by these plants is fed into the public grid and is one of the technical available alternatives to generate a save energy supply for the future. Especially public property owners have to face the challenge to establish this technology and playing a guiding role for the city/community - to motivate public to invest into this technology.

Even if the solar energy can be used in many ways (e.g. roof integrated photovoltaic, roof integrated solar water heating or open landscape photovoltaic), this work will focuses on the roof integrated modules, only. Aim of the work is to define a workflow for identifying those houses inside of a certain region, which are most applicable for installing photovoltaic panels. The assessment criteria consists of

- exposition
- style of roof
- roof pitch
- roof area
- non utilisable areas
- height(s) of the building
- shadowing impacts

and are taken from state of the art aerial images.

According to the analysis, the following question can be answered:

How high is the potential in a certain area

for the implementation of solar power plants?

The result can be presented in a geo-referenced map, a simple address list or any other designated format, containing all needed information (street, house number, coordinates, applicability) for the local authorities or local solar companies to call house owner's attention to self-generated energy along with economic and ecologic aspects.

2 Parameters for the evaluation of solar applicability

The resource for solar electricity, the sun, isn't as consistent as we would like to have it. During the year there are changes in the distance between earth and sun, in the angle of incoming solar rays, in the ecliptic and by reason of rotation of the Earth in the hours of daylight.

2.1 Different kinds of incoming solar radiation

The amount of Earth's atmosphere reaching solar radiation is called as 'solar radiation'. It's an almost constant value of 1367 kW/m² and fluctuates due to Earth's elliptical shape by 3% per year.

There are two different ways in which the solar radiation reaches the Earth's surface:

- direct radiation
- diffuse radiation.

Direct radiation goes straight through the atmosphere, requires a cloudless sky and reaches any object in direct line of sight to the sun on Earth's surface.

The **diffuse radiation** is reflected in many ways before it reaches an object on the surface of the Earth. Reflection is due to the atmosphere, air pollution, fog, buildings, vegetation and the Earth's surface itself, which all reflects the primary direct radiation in many ways, so that the rays are no longer parallel. Direct and diffuse radiations are combined to the value of **global solar radiation** in ratio of 40% for direct and 60% for diffuse radiation for Northern Germany. In Southern Europe the ratio is by 35% for diffuse and 65% for direct radiation.

Appr. 75% of solar radiation reaches the Earth's surface as global solar radiation. This value is specified in kilowatt hours per square meter per year [kWh/m²/a] over a surface perpendicular to solar rays. For Germany and mid-Europe the mean value of global solar radiation is around 900 to 1200 kWh/m²/a on a midsummer day. In the desert (Sahara) the mean value is by 2500 kWh/m²/a.

2.2 Evaluated parameters of the roof

As said, the global solar radiation is given by kWh/m²/a on a surface perpendicular to solar rays. But most of solar panels are in fixed positions on the roof and non-tracking the sun, so that the usable amount of the global solar radiation must be calculated individually. The two most important parameters that must be analysed are related to the position of the power plant relative to the sun: direction and slope of the roof, or to be more precise:

- direction and
- slope

of the solar panels.

The **direction** can be defined as the angle build by the horizontal value of the roof's normal vector corresponding to best orientation. In North hemisphere best orientation is south (180°), due to sun's trajectory in its movement from East to West is symmetrical in this situation.

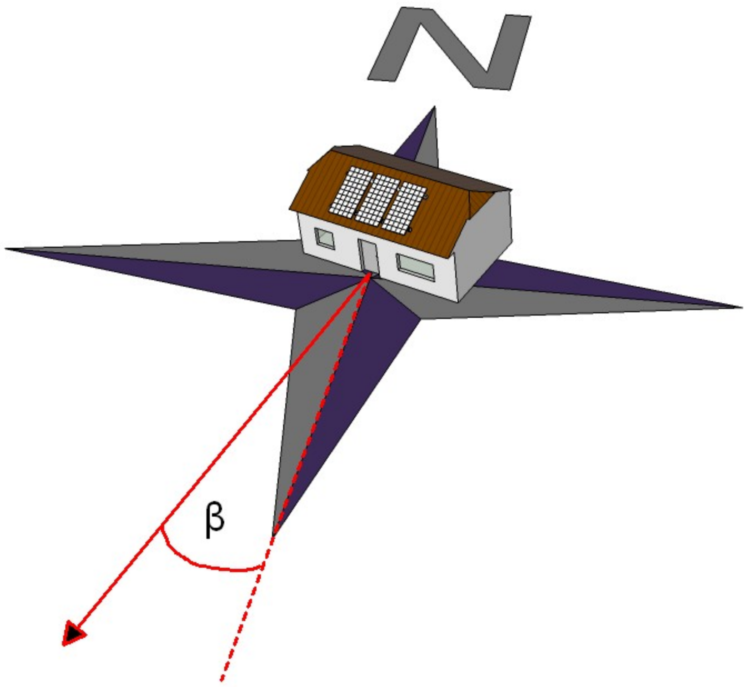

fig. 1: direction of roof

Slope is the angle formed by building's floor space and roof's maximum inclination. For most efficient use of sun's power, the roof should be orthogonal to solar radiation. Because of the changing of solar inclination (maximum in summer, minimum in winter) a mean value for best slope must be calculated regarding to where the house / roof is located.

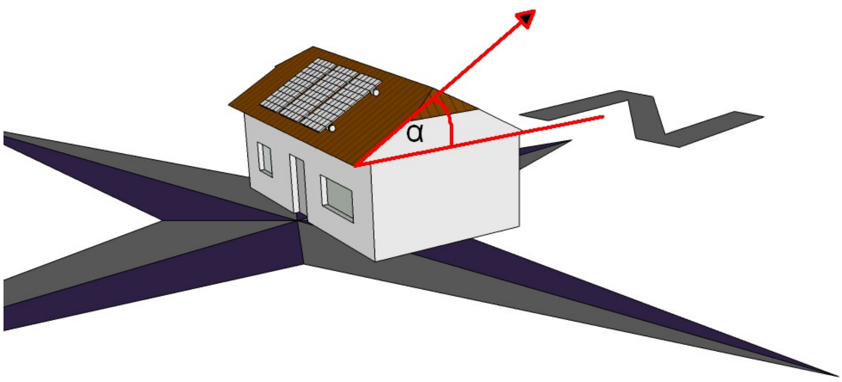

fig. 2: slope of roof

3 Exploration of qualified roofs

Even if there are only few parameters of each roof to be collected, it is a problem of the number of houses and surrounding objects belonging to an evaluated region. It's not only the roof's technical parameters (available area, slope and direction) that must be analyzed, but also the **influence of shading objects** around.

To start with a full-detailed analysis of all houses in a region is non-economical and can effect misinterpretation. Therefore a **four-step-workflow** has been developed at the Jade University of Applied Sciences in Oldenburg, Germany.

- **First step** is to determine all objects / houses, which are applicable for solar power plants. The result will be a simple red/yellow/green marking of the objects inside a region.
- **Second step** is a more detailed analysis of a sub-group of the houses of step one. This will result in information of direction, slope, available area and root-structures.
- **Third step** will be a full-year simulation of shadow on discrete houses.
- **Fourth step** is a detailed object-related measurement and design and a visualization of the planned solar power plant.

The technique of **photogrammetry**, used in several industrial and research sectors, offers a number of solutions to problems and questions generated during design process and was basis for the development.

Main topic of Activity 4.5 was to develop and to enhance the process of regional exploration of qualified roofs (first step). The other steps mentioned above have not been part of this activity.

3.1 Regional exploration of qualified roofs

In order to determine solar-qualified roofs a semi-automated process evaluates all buildings of an area in terms of

- height over ground (relative to surrounding objects),
- roof area direction (in three categories) and
- visible roof-structures ('existing' or 'not existing').

To start the evaluation process different kinds of data must be collected. First of all aerial images must be available. These images are taken normally from inside a plane (altitude > 300m), are more or less perpendicular to ground and overlap by 30% to 60 %. The overlapping is needed because of the following bundle adjustment and stereo analysis.

Photogrammetry uses aerial images since the mid of the 19th century. The images are used for orthophoto-creation, land-use planning, cartography, environmental studies and creation of digital surface models (DSM). For all this products the overlapping images must be orientated and transformed so that new images can be created and 3D coordinates can be measured.

3.1.1 Photogrammetric analysis and Bundle Block Adjustment

For measuring 3D-coordinates out of 2D-images the images must overlap. If there is a minimum of two overlapping images the effect of stereoscopy appears, in which two different images of a same region or object create the illusion of depth. In modern times this effect becomes more and more popular to cinema visitors but is known and used for specific applications since a long time.

The images used for regional exploration in the context of solar power shouldn't be older than 3 years due to changes in vegetation and building development. Furthermore the images should have a ground sample distance (GSD) of 20 cm or less (=better). The GSD is the distance on Earth's surface that is represented by one Pixel in the image. With a GSD of 20 cm for example a drainage pit is visible, with a GSD of 5 cm a fence post can be identified.

The photogrammetric software package that is used in this case at the Jade University is Imagine/LPS developed by ERDAS.

The images used for this analysis can be bought at private companies, public agencies or sometimes will be delivered for free in the case university research.

Along the images the orienting data are needed. These data consist at minimum of

- exterior orientation for each image (position of camera; location, altitude, roll, pitch and yaw of the plane; including the offset from plane's sensors to the camera),
- calibration data of the camera (image format, image extent, pixel size, focal length, principal point and lens distortion),
- date of the flight,
- orientation of the flight lines.

image	*x*	*y*	*z*	*omega*	*phi*	*kappa*
10_0649	3500019,873	5900903,937	2837,445	-0,25176	-0,34670	1,03941
10_0648	3499643,587	5900905,572	2836,195	-0,45630	-0,20584	1,06134
10_0647	3499266,790	5900908,823	2835,304	-0,51328	0,11739	0,65435
11_0462	3501522,870	5898904,645	2838,070	0,12964	-0,89211	-199,57374
11_0461	3501900,753	5898906,440	2841,805	-1,07055	-1,68301	199,86378
11_0460	3502281,894	5898905,775	2839,013	-1,38226	-1,84801	199,93862
12_0446	3498136,920	5896934,882	2831,438	0,09206	0,10472	2,22433
12_0445	3497756,765	5896930,043	2831,288	-0,07592	-0,27135	2,37455
12_0444	3497382,193	5896924,617	2830,731	-0,51980	-0,23341	2,46105

fig. 3: exterior orientation for each image

```
LPS Camera File Version: 2.0
Camera Name: "lgn_UltraCam"
Camera Description: "UCX-SX-1-50810149"
Focal Length [mm]: 100.5
Principal Point:
        x0 [mm]: 0
        y0 [mm]: 0.144
Fiducial Coordinates:
        Number of Fiducials: 4
ID       X[mm]          Y[mm]
       1           5            -5
       2          -5            -5
       3          -5             5
       4           5             5
Radial Distortion Observations:
        Type: "Radial Distance"
        Number of Observations: 1
      ID   Distance[mm]   Distortion[microns]
       1           0                0
Radial Lens Distortion Coefficients:
        k0: 1.33e-008
        k1: -3.81e-011
        k2: 6.91e-015
Extended Parameters:
        Type: "NONE"
```

fig. 4: calibration data of camera

These data are used inside Imagine/LPS as approximate values and along with tie points and check points for each image pair the Bundle Block Adjustment (BBA) can be started. The method of BBA orients a certain number of images simultaneously into a global shared coordinate system. fig. 5 shows the image extents (footprints) of the 104 images used for regional exploration of qualified roofs in the region of Grasberg (GER), one of the areas of interest in this activity.

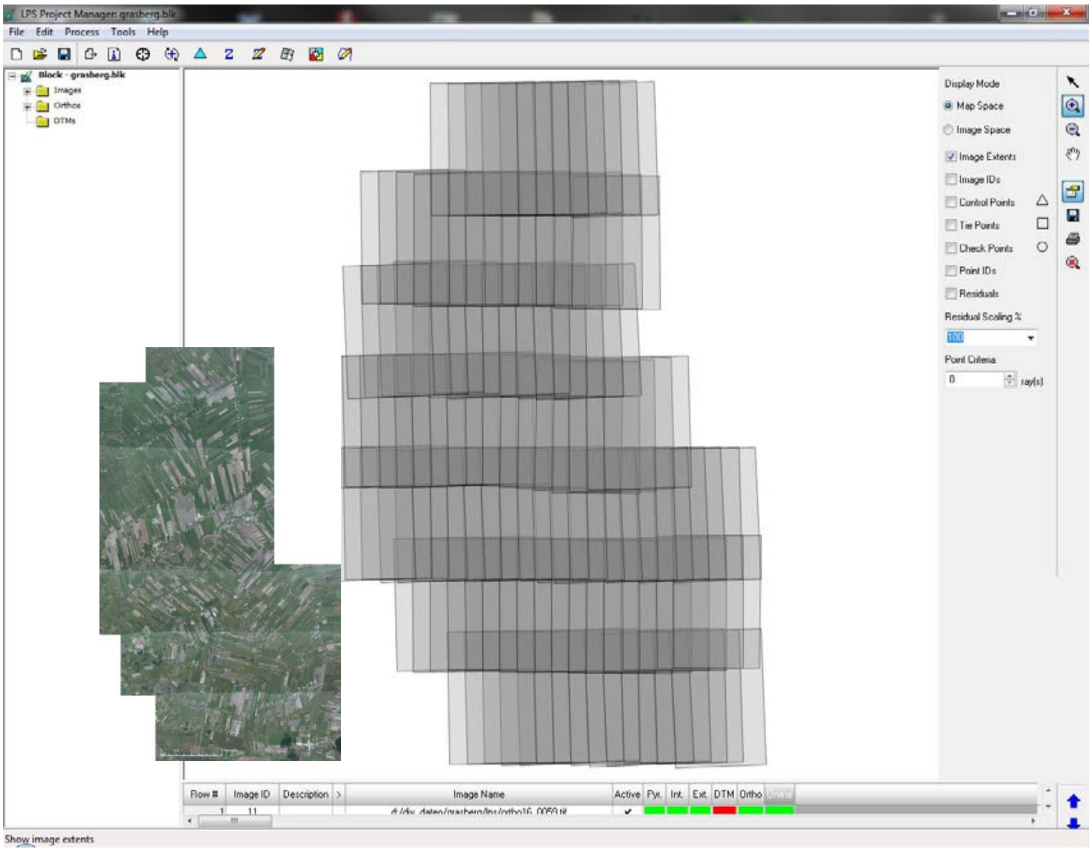

fig. 5: image-footprints of Grasberg and ortho-mosaic

Once the Bundle Block Adjustment has finished, an automatic process will calculate an equal grid of points to create the Digital Surface Model (DSM). Depending on the quality of the original images, the intended usage and the computing power the GSD of the DSM can be more or less precise. For the usage of semi-automated analysis for solar applicability the GSD of the grid was 10 cm to 50 cm.

fig. 6: digital surface model and ortho mosiac (region: Växjö, Sweden)

After this preliminary work it is possible to start the analysis. For the analysis each house can be classified according to the criteria listed in Fig 7 into:

- applicable,
- limited applicable
- not applicable.

	applicable	limited applicable	not applicable
direction	180° (+/- 20°)	135°-160° / 200°-225°	< 135° / >225°
slope	10° - 50°		< 10°
roof structures	no structures on the roof	few and/or small structures on the roof	many and/or large structures on the roof
shadow	not existing	< 10-15% of the roof	> 15% of the roof

fig. 7: table of criteria

Given that the slope has minimum effect to the efficiency of solar power plants on roofs, this value can be disregarded in the first step of the analysis. The only interesting part are the roof's with less than 10° of slope, because for this flat roofs in turn the direction can be disregarded, because on flat roofs a special hardware is needed to elevate the solar panels. These elevated tracks can be orientated independently to the direction of the building / roof area.

3.1.2 Evaluation of the objects

It's nearly impossible to pre-process the data in a way, that this analysis could be done 100% automatically and with an acceptable error probability. Because the analysis must be checked manually anyway, the rate of manual interaction can be raised from the very beginning on.

A well versed team of two people is able to analyse an area about 11 km² and appr. 6.100 objects to be analysed in appr. 6 working days, including pre-processing of the data. Quite twice the time can be scheduled for screening, collecting and getting the data.

Because the analysis deals often with more than 100 images with 500 MB (Mega Byte) each, the data couldn't be downloaded in an easy way, but must be send via hard disk.

The pre-processed images and the DSM are the basis for the analysis to identify the potential for solar power plants. The environment of the analysis is a Geographic Information System (GIS). In this case ArcGIS developed by ESRI was used. ArcGIS is a commercial system, which can be extended by a number of functionalities. In the case of the analysis of the potential for solar power plants ERDAS Imagine/LPS is one of these extensions and was used in this project.

Besides the extensions ArcGIS is able to handle a lot of data types and coordinate systems and provides so called toolboxes for converting, transforming and processing the data, so that this software package has been selected as most appropriate.

The main principle of the analysis is in fact very simple: each house, respectively each roof area is qualified by the criteria listed above. As result a point is set inside the roof area and coloured in

- green (applicable),
- yellow (limited applicable),
- red (not applicable),
- blue (no evaluation).

The category 'no evaluation' was needed due to the fact, that in some cases the images are not as actual as the official addresses taken for the points.

For example, very new houses (still under construction) are not represented in the aerial image, but have already an address.

Spatial and SQL-based queries give support to the user during the analysis. Providing that the data offers such information it's no problem to identify a special object via street name and house number or by entering the object's coordinates.

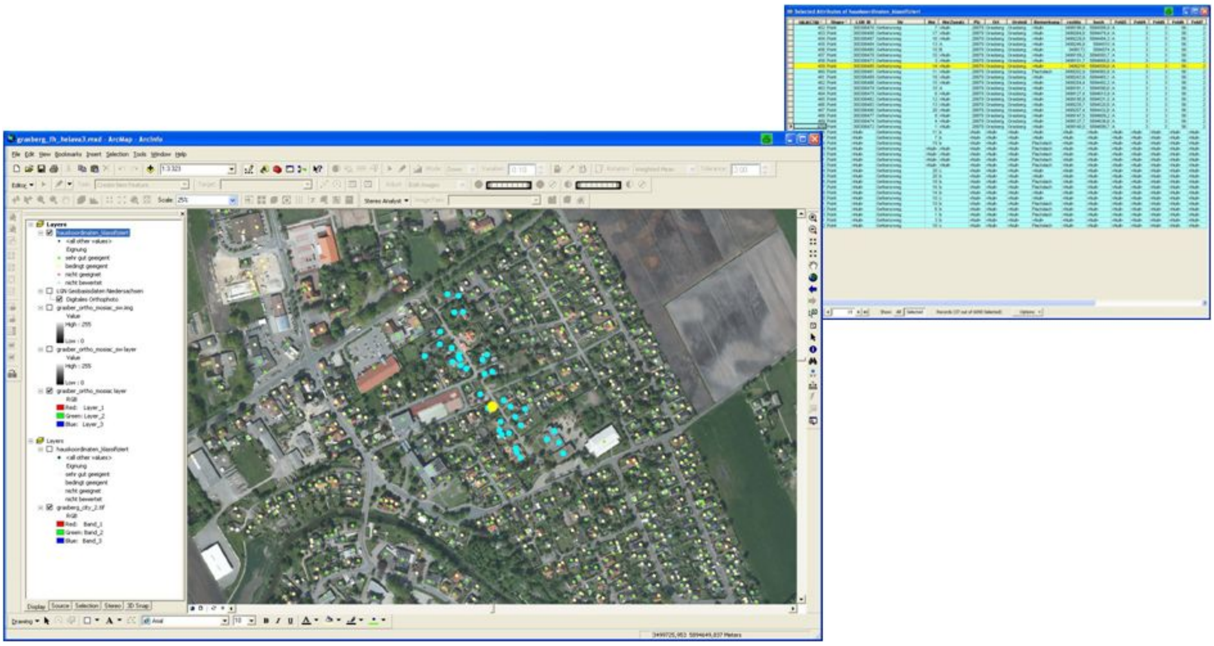

fig. 8: SQL-selection in ArcGIS

3.1.3 Presenting the results

The geo referenced original data, the use of a GIS and the orientation inside global coordinate systems offers many possibilities to present the result.

Simplest result will be a printed list of addresses including the solar applicability (fig. 9). But more comfortable and easier accessible will be a digital presentation. Either on a webpage, with accessibility for all interested parties or on local PCs e.g. in the city hall. The more people can access the data, the more important will become the fact of data security and data privacy.

The most interesting way of presentation (via WWW including address and image) is the most risky way. Many people would not like to have their building presented high detailed including address accessible for everyone. This could e.g. result in addition to the exhibition of estates in a mass of advertising from solar companies.

Another fact is, that high detailed images effort a wideband connection, which are currently not mandatory available in rural regions.

For each analysis an individual way of presentation must be found. In the following a few possibilities to present the result are demonstrated.

fig. 9 shows a simple text listing with coordinates and classified addresses.

fig. 10 shows the presentation via WWW in simple text listings without images. Therefore the addresses were processed inside a php script and embedded to the web page. The results can be taken from the drop down lists.

fig. 11 shows the representation in form of Google's KML-file. Therefore the addresses were transformed to Keyhole Markup Language (KML). KML is a standardized notation of place marks, images, polygons et cetera and became an official OGC (Open Geospatial Consortium) standard. The KML-file contains all important information and can be viewed in Google Earth.

The qualified addresses can also be presented in any GIS software. But because of the installation of the program, the adjustment to the software and tentative licence coasts, this option should only be chosen by professionals only.

additional report to aerial view of

Växjö

JADE UNIVERSITY OF APPLIED SCIENCES Wilhelmshaven Oldenburg Elsfleth

	Street	*Nr.*	*applicability*
Växjö	BASVÄGEN	8	applicable
Växjö	BASVÄGEN	9	applicable
Växjö	BLÅELDSVÄGEN	1	applicable
Växjö	BLÅELDSVÄGEN	2	not applicable
Växjö	BLÅELDSVÄGEN	3	applicable
Växjö	BLÅELDSVÄGEN	4	not applicable
Växjö	BLÅELDSVÄGEN	5	applicable
Växjö	BLÅELDSVÄGEN	6	not applicable
Växjö	BLÅELDSVÄGEN	7	applicable
Växjö	BLÅELDSVÄGEN	8	applicable
Växjö	BLÅKLOCKEVÄGEN	1	applicable
Växjö	BLÅKLOCKEVÄGEN	10	applicable
Växjö	BLÅKLOCKEVÄGEN	2A	applicable
Växjö	BLÅKLOCKEVÄGEN	2B	applicable
Växjö	BLÅKLOCKEVÄGEN	3	applicable
Växjö	BLÅKLOCKEVÄGEN	4	applicable
Växjö	BLÅKLOCKEVÄGEN	5	applicable
Växjö	BLÅKLOCKEVÄGEN	6	applicable
Växjö	BLÅKLOCKEVÄGEN	7	applicable
Växjö	BLÅKLOCKEVÄGEN	8	applicable
Växjö	BLÅKLOCKEVÄGEN	9	applicable
Växjö	BLÅSIPPSVÄGEN	1	not applicable
Växjö	BLÅSIPPSVÄGEN	2	applicable
Växjö	BLÅSIPPSVÄGEN	3	not applicable
Växjö	BLÅSIPPSVÄGEN	4	applicable
Växjö	BLÅSIPPSVÄGEN	5	not applicable
Växjö	BLÅSIPPSVÄGEN	6	applicable
Växjö	BLÅSIPPSVÄGEN	7	not applicable
Växjö	BLÅSIPPSVÄGEN	8	applicable
Växjö	BLIDENS VÄG	10	limited applicable
Växjö	BLIDENS VÄG	11	not applicable
Växjö	BLIDENS VÄG	12	not applicable
Växjö	BLIDENS VÄG	13	not applicable
Växjö	BLIDENS VÄG	14	not applicable
Växjö	BLIDENS VÄG	15	not applicable

applicable — limited applicable — not applicable — no evaluation — page 2 of 45

fig. 9: text listing (Växjö, Sweden)

The Interreg IVB North Sea Region Programme

European Community European Regional Development Fund

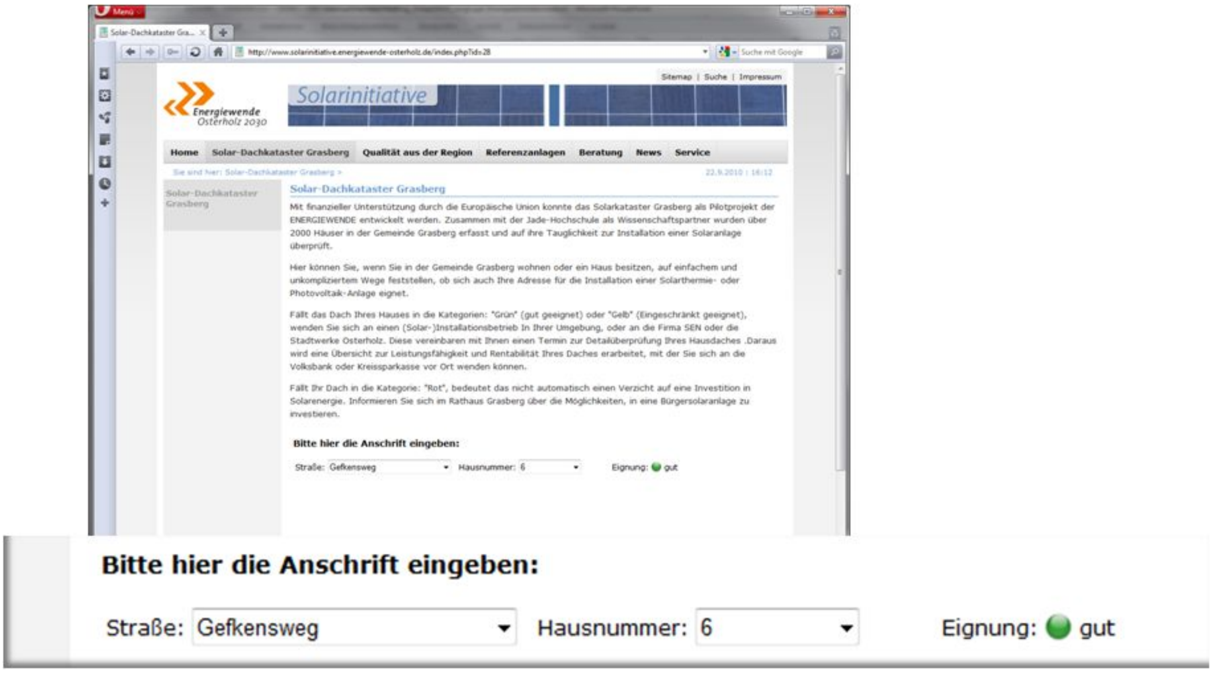

fig. 10: presentation via WWW without images (Grasberg, Germany)

fig. 11: Google KML-file

4 Google's API (geocoded addresses)

For making the presentation of the results more attractive, official (government-given) addresses have been chosen for naming the qualified roofs. This ensures the integratability of the data to other governmental data like land cadastre.

In the case, that official addresses are not available, an alternative solution can be chosen to receive information - Google Maps API Web Services. But, regarding to the *Maps API Terms of Service License Restrictions* it's only allowed to use these Web Services within Maps application. Anyway the functionality is very simple. A HTTP request, containing the name of the service and the required parameters, will return an XML-based HTTP response containing the requested information. Embedded into a script, a list of addresses can be geocoded this way. But these addresses are not governmental, so there are no information about the preciseness, the actuality and availability of the data.

5 Location-based calculation of the global solar radiation

To get a theoretical value of the output of the solar power plant the value of annual global radiation in the specific region of interest must be known. This value along with the technical parameters of the planned solar power plant gives a first indication of the volume of electrical power, which can be produced.

There are several sources available to collect information about global radiation (see fig. 12). Some are free via internet with quite less information about the calculation algorithm (NASA) behind the information and some are free and based on the program PVGIS. It is also possible to buy this type of information from specialised companies, which are delivering services for operators of energy production facilities based on renewable technologies (wind energy, solar energy). Based on these services production forecasts are possible for wind energy plants and PV plants. This kind of forecast is of importance for grid operators to manage the grids.

In the case of this analysis data from focus solar GmbH, an Oldenburg based company and from the German Weather Forecast Service (Deutscher Wetter Dienst (DWD)) were bought. As data from DWD are available for Germany only, these data were used in this transnational project to calibrate the radiation data. According to the calibration data from focus solar GmbH were used for further calculations in the project.

The focus solar data set comprises half-hourly values of global, direct normal and diffuse irradiance with a spatial resolution of 1 km x 1 km at the sub-satellite point on the ground. The spatial resolution varies somewhat with the distance to the sub-satellite point depending on the viewing angle of the satellite. Satellite derived estimates of solar energy have been extensively tested against ground measurements with pyranometers. It was found that satellite data unfold their strength in mid to long-term estimates where the time period ranges from a day to a couple of years. The longer the time period

over which energy is accumulated, the more satellite images are available, and the better is the accuracy. For daily values of global irradiance the accuracy is normally in the range of 8-10% comparable to the accuracy of solar cell radiation sensors. A monthly irradiance estimate has an error of only 5% and annual irradiance values reach an accuracy of 2-3% coming close to the precision of pyranometers.
(http://www.focussolar.de/Content/KnowHowEn/Methodology)

	focus solar GmbH*[1]	**Nasa*[2]**	**PVGIS_ classic*[3]**	**PVGIS climate-SAF*[3]**	**DWD*[4]**
Grasberg (Ger) 53,167°N 8,983° E	975	996	960	1033	966
Tynaarlo (NL) 53,067°N 6,617°E	968	1048	978	1037	---
Växjö (S) 56,883°N 14,800E	911	1022	927	996	---
Kortrijk (B) 50,817°N 3,267°E	996	1062	1000	1080	---
Dundee (GB) 56,467°N 2,950 W	849	880	876	993	---

fig. 12: table of global radiation

*1: bought service from *focus solar GmbH*, Oldenburg (Germany)
*2: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php chosen with different radiation database (Classic PVGIS / Climate-SAF VGIS)
*3: http://eosweb.larc.nasa.gov/sse/RETScreen/
*4: bought service from *Deutscher Wetterdienst*; free for academic use; only available in Germany

6 Results

6.1 Analysed Areas

In this activity areas of interest in Grasberg (Germany), Tynaarlo (the Netherlands), Växjö (Sweden), Dundee (GB) and Leiedal (Belgium) have been analysed. The areas were selected by the partners themselves based on information from Jade University concerning dimension and structure of the areas. As premise for the areas of interest these should cover the following city characters:

- inner city,
- new housing areas,
- older housing areas,
- business park,
- rural area,

Each area should have a size of appr. 1 km².

The different city characters have been analysed to demonstrate, that these typical areas of a city or municipality can have different results regarding the implementation of solar power plants because of their architecture, shadowing effects and the possible potential for implementing solar power plants.

In fig. 13 to fig. 17 the areas of investigation in the 5 participating partner municipalities are shown.

fig. 13: Grasberg (GER) - area of investigation

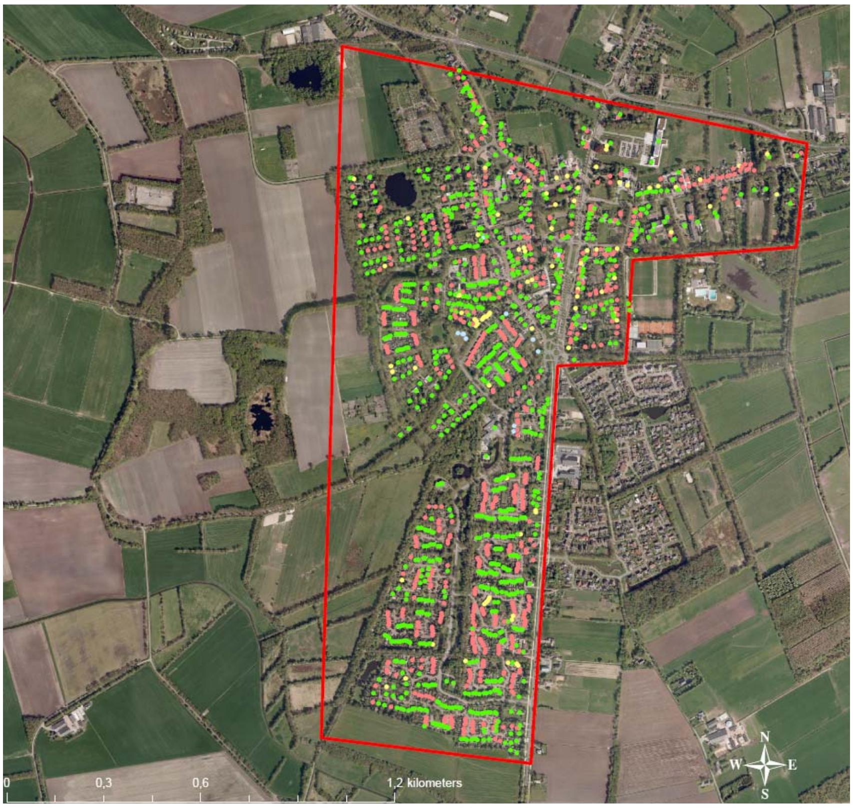

fig. 14: Tynaarlo (NL) - 1 of 6 areas of investigation

fig. 15: Växjö (S) - area of investigation

fig. 16: Dundee (GB) - areas of investigation

fig. 17: Leiedal (B) - 1 of 7 areas of investigation

Areas of interest were selected by the partners in the relevant municipalities and the aerial images were delivered to Jade University in Oldenburg, where the photos were processed. In size the areas went from 3 km² (Växjö, Dundee) to 10 km² in Tynaarlo. Together with the photos geocoded addresses were delivered.

In Germany these address points are delivered by the local Land Surveying Offices like *Landesvermessungsamt für Geoinformation und Landentwicklung Niedersachsen (LGN)*, in Belgium the data came from the *Intercommunale Leiedal,* in the Netherlands the data were delivered by *Gemeente Tyrnaalo* and in Sweden the data came from the *City of Vaxjö*. Only in Dundee (GB) this data couldn't be delivered from an official source. Therefore in Dundee the already described Google Maps API Web Services was used to get the necessary address information.

The resolution of the images varies from the minimum necessary resolution of 20 cm (Grasberg, GER) to very good resolutions of 10 cm in Tynaarlo (NL) and Leiedal (B). Origin of the images were public (Grasberg, Växjö and Leiedal), whereas the images in Dundee and Tynaarlo were delivered by private organisations. In fig. 18 the relevant information concerning the areas of interest and the images are summarised.

	Grasberg (GER)	Tynaarlo (NL)	Växjö (SE)	Leiedal (BE)	Dundee (GB)
analysed area (km²)	6	10	3	5	3
geocoded adresses	2.462	1.387	1.574	4.232	3.878
resolution of the aerial images on the ground (cm)	20	10	15	10	12,5
date of photo	2008	2009	n.n.	n.n.	2006
source of photo	public	private	public	public	private

Fig. 18: analysed areas and image data

The Interreg IVB North Sea Region Programme

European Community European Regional Development Fund

6.2 Calculation tool for solar power production

The aerial images were analysed using the criteria listed in fig. 7 and the results of this analysis were connected with the specific solar radiation at the region of interest (fig. 12).

	Source of information
Number of roofs	Evaluation result from the analysis of the aerial images
Number of addresses	Public organisation or web services (e.g. Google Maps API Web Services)
Size of the PV plant	Free to choose (in the case of the transnational project size was set with 6 kWp (typical size for a single family home)
Spec. radiation	Free to choose (in the case of the transnational project specific radiation was delivered by a private organisation)
Energy consumption	Free to choose (in the case of the transnational project the average consumption for a German 4-Person household was chosen to make results comparable)
Feed in tariff	Free to choose (in the case of the transnational project the actual German feed in tariffs (status: March 2012) were chosen, to make results comparable). If no feed in tariffs are existing please chose 0,00 €
Prize per plant	Free to choose (in the case of the transnational project the actual German market prizes for plants with 6 KwP (status: March 2012) were chosen, to make results comparable)
Percentage of roofs used for solar power plants	Free to choose (in the case of the transnational project the assumption for the calculation was, that 30% of the optimal and 10% of the limited applicable roofs were used for solar power plants to make results comparable)

Fig. 19: input parameters for the calculation tool (Fig. 20) for energy production and economical aspects

For the calculation of the theoretical energy production and the economical effects from the implementation of solar power plants, a calculation tool has been developed (fig. 20) during the project. This tool works with the parameters listed in fig 19.

To use the tool, the number of roofs has to be identified out of the aerial images and has to be fed into the tool as fixed parameters – divided into applicable, limited applicable and not applicable. Also the number of addresses (= households) has to be fed in as fixed parameter.

Variable parameters are

- the size of the PV plants,
- the specific radiation in the analysed area,
- the specific energy consumption for a 4-person household
- the feed in tariff
- the local price per plant (per 6 kWp electrical power)
- percentage of roofs used for PV plants

By using these 6 variable parameters together with the fixed parameters in the calculation tool, information can be calculated about the following indicators:

- the number of roofs used for PV plants
- production of electrical energy in a certain area (in kwh/a),
- the number of self sufficient households (4 persons)
- the local income based on feed in tariffs (in €)
- the total turnover for solar companies, that are installing the PV plants in the analysed area (in €)

6.2.1 Sample Grasberg (Germany)

In the case of Grasberg (Germany) 2.462 addresses were delivered but 6.095 roofs have been analysed (fig. 20). Reason for this discrepancy is the fact, that the municipality of Grasberg has a very rural structure with lots of farm and other side buildings, which all are connected to the addresses. The analysed areas of interest in Tynaarlo (NL), Växjö (S), Leiedal (B) and Dundee (GB) were more densely populated and showed a more urban structure.

Results — **Grasberg**

Evaluated buildings	Number of roofs evaluated	%	Roofs with PV plants	% of all roofs	Number of addresses
applicable	2.687	30	806	13	2462
limited applicable	3.213	10	321	5	
not applicable	178				
not evaluated	17				
SUMME	6.095		1.127	18	

Size of PV plant / roof	6	kWp	applicable	4.715.685	
			limited applic:	1.879.605	
spec. radiation	975	kWh/a	SUMME	6.595.290	kWh/a
Energy consumption / household (4 Persons/household)	4.500	kWh/a	SUMME	1.466	energy self-sufficient households

feed in tariff

feed in tariff according German EEG (€/kWh)	€
0,1935	1.276.189

turnover for the solar companies

€/plant	€
12.000,00	13.528.800

Fig. 20: calculation tool for energy production and economical aspects (Grasberg, Germany)

From the 6.095 analysed roofs in Grasberg 2.687 have been identified as applicable and 3.213 as limited applicable. Assuming, that 30% of the applicable and 10% of the limited applicable roofs were used to install PV plants with a capacity of 6 kWp electrical power appr. 6.600.000 kWh/a can be produced under the specific radiation in Grasberg of 975 kWh/m²/a. This is enough electrical energy to serve appr. 1.500 households (4-person with an energy consumption of 4.500 kwh/a) with electrical energy.

In addition an investment of appr. 13.500.000,- € is necessary to implement these PV plants, based on installation cost from 2011. In Grasberg it is planned to realise this investment by using local organisations predominantly, so that the erection of PV plants could be a kind of business model for the region/municipality.

Based on the German legislation (EnergieEinspeiseGesetz – EEG / German Renewable Energy Act) this investment in PV plants will lead to an additional income in the municipality of Grasberg (appr. 7.700 inhabitants) of appr. 1.276.000,- €/a over a period of 20 years.

Based on the German Renewable Energy Act operators of solar power plants get a fixed monetary value for each kWh produced with their solar power plant. In March 2012 this is 0,1935 €/kwh for PV plants with a production of < 10 kWp. This monetary is paid for a period of 20 years starting from the day of launching operation.

6.3 Summarised Project Results

With the same tool and the same assumptions described above the results from the other participating municipalities resp. the analysed areas of interest in the municipalities have been calculated on their theoretical potential for the implementation of solar power plants. Results are presented in fig. 21.

Under the assumptions, which are used to generate the results in fig. 21, it can be demonstrated, that relative high percentages of private households can be served with electrical power generated by solar power plants in the partner regions.

	Grasberg (GER)	Tynaarlo (NL)	Växjö (SE)	Leiedal (BE)	Dundee (GB)
geocoded addresses (= house-holds)	2.462	1.387	1.574	4.233	3.878
households served with solar energy (absolute numbers)	**1.466**	**351**	**338**	**940**	**720**
households served with solar energy (percentage of geocoded adresses)	**appr. 60 %**	**appr. 25 %**	**appr. 21 %**	**appr. 22 %**	**appr. 19 %**

fig.21: percentage of households, served with electrical power based on PV plants in the analysed regions of interest

	Grasberg (GER)	Tynaarlo (NL)	Växjö (SE)	Leiedal (BE)	Dundee (GB)
applicable roofs	2.687	877	863	2.153	1.868
limited applicable roofs	3.213	85	194	618	753
plant capacity (kWp)	6	6	6	6	6
radiation (kWh/kWp/a)*	975	968	911	996	849
energy consumption per household (kWh/a)	4.500	4.500	4.500	4.500	4.500
persons per household	4	4	4	4	4
energy production (kWh/a)	**6.595.290**	**1.577.453**	**1.521.188**	**4.299.215**	**3.238.256**
geocoded addresses (= households)	2.462	1.387	1.574	4.233	3.878
analysed roofs	6.095	1.612	1.596	4.254	4.064
households served with solar energy	**1.466**	**351**	**338**	**940**	**720**

* based on solar energy report made by *focus solar GmbH*

fig.22: theoretical volume of solar power production and number of households served with electrical energy in the analysed regions of interest

Even Dundee (GB) and Växjö (S), with a quite poor radiation (s. fig. 21), would be able to produce 19% resp. 21% of the electrical energy, that is needed for private households, by the implementation of PV plants in the analysed areas. In Leiedal (B) and Tynaarlo (NL) this rate of energy supply would be at 22% resp. 25%. Even though in this both municipalities there is a higher radiation then in Dundee and Växjö, the existing architecture prevents from a higher rate of yield.

The importance of the architecture (=orientation of roofs) can be seen in detail, if the results from Tynaarlo (radiation 968 kWh/kWp/a) and Leiedal 996 (radiation kWh/kWp/a) are compared with Grasberg (GER) (radiation 975 kWh/kWp/a). In these municipalities radiation is on a comparable level. But due to the rural structure in Grasberg, a lot of neighbouring buildings are existing next to the geocoded addresses, which also have been analysed. This fact leads to the situation, that in Grasberg 60% of the electrical energy for private households can be produced by PV plants. This calculation is based on the assumptions described in fig. 19. As the neighbouring buildings are manly farm buildings (barns, stables), larger plants can be implemented with a higher energy production, so that a full supply of private households with electrical energy is not unrealistic in Grasberg.

6.3.1 Transformation into regional strategies

After having made the results from the transnational analysis on the theoretical potential for the use of PV plants available to the project partners, different strategies have been developed by the partners to generate regional benefits from this knowledge. As the solar market in Germany is much more advanced, than the solar markets in the other participating countries, the transformation into regional strategies is more intensive in Germany.

6.3.2 Grasberg (Germany)

In Grasberg a “Solar Initiative” was founded to bring as much PV plants as possible into operation. Partners of this initiative are the municipality of Grasberg, local solar companies, the local banks to finance the plants and the regional energy supplier.

This group initiated the "Solar Day" in Grasberg, where public was informed about all aspects related to solar power plants (technologies, financing, legal background) and where the results of the study have been presented to public.

To reach public more intensely the results from the analysis were published on a web page (see fig. 10). On this web page each house owner can get information whether his house is applicable to install a PV plant, just by selecting the street and the house number. He then gets the indication green (applicable), yellow (limited applicable) or red (not applicable). With this simple form of information he can contact a solar expert for detailed planning and – if necessary - the bank for financing the plant.

Based on the results of the study, the municipality of Grasberg itself redesigned the plans for a new housing area in a way, that negative shadowing effects by neighbor houses and/or trees are avoided to allow a maximum of PV plants in this new housing area.

6.3.3 Tynaarlo (The Netherlands)

Tynaarlo plans to develop a new housing area which shall follow ecological main features. The results from the analysis for the potential for solar power plans shall be integrated into the planning process to allow a maximum of PV plants in this new housing area and to deliver an input for the local energy supply.

6.3.4 Växjö (Sweden)

As the specific radiation in Växjö is quite low and no feed in tariffs for electrical energy produced by PV plants are existing in Sweden, the local housing organisation plans to install thermal solar power plants on the roofs of applicable houses. The heat, that is produced with these plants, shall then be fed into the already existing district heating system and by this saves regional resources (biomass) for producing heat.

6.3.5 Leiedal (Belgium)

The results from the analysis for the implementation of solar energy will be included into the regional energy strategy prepared by the project partner Interkommunale Leiedal. In this strategy all types of renewables are analysed, and the theoretical potential as well as the technical potential for the region is calculated. To develop this strategy, the analysis for the potential on solar power was a helpful tool to calculate the technical potential of PV and solar heat.

Also the regional project partner IMOG has used the result from the transnational project to inform the citizens about the possibilities of using solar power plants. The results were published in an article in IMOG's "energy paper", that was distributed towards citizens.

6.3.6 Dundee (Great Britain)

In Dundee the results from activity 4.5 shall be used as part of the work of the Dundee Sun City initiative to encourage the deployment for solar technologies as part of the city of Dundee's ambitions to reduce greenhouse gas emissions and to address the problem of fuel poverty in the city.

7 Lessons learned

The technology to analyse a certain region on its potential for the implementation of solar power plants based on aerial images was developed at Jade University in Oldenburg (Germany). As up to the project start no experiences were available to state, if the same technology could be used also on transnational level, it was a challenge to face, when the project started. Especially the disposabillity of data (aerial images, image related data) and the available quality of the images were unknown - but of essential importance for the analysis. With this project it could be shown, that this type of analysis is possible to be used in the participating countries. An implementation of this tool is possible by the transnational partners.

With presenting the results to the transnational partners it could be demonstrated, that a significant contribution to the regional energy supply would be possible by using PV plants for the production of electrical energy. This raised interest by private public but also by decision makers on municipal / regional level but also on commercial level and led to first actions in the partner regions, as described in chapters 5.6.2 – 5.6.6 "transformation into regional strategies".

The technology was unknown up to the project start in the participating countries (at least in the involved regions), so that now a new method is available to identify one essential aspect of regional resources for using renewable and regional energies as part of a sustainable energy mix for the future.

8 Presentations

8.1 Lectures

07.12.2009: Evaluation of potential for solar power plants, World Climate Conference, Copenhagen (Denmark)

10.02.2010: Photogrammetric Plotting, Middelfarth (Denmark)

26.04.2010: Potentialanlyse für den Einsatz von Solartechnologien in Grasberg, (Germany)

21.08.2010: Planung von Solaranlagen, Hude (Germany)

06.10.2010: INTERREG IV B - Nordseeraum, Transnationale Zusammenarbeit zur Raumentwicklung, Oldenburg (Germany)

17.01.2011: SMART CITIES GIS Academy, Oldenburg (Germany)

26.05.2011: Klimawandel im Landkreis Oldenburg, Wildeshausen (Germany)

27.05.2011: Klimawandel im Landkreis Oldenburg, Wildeshausen (Germany)

24.06.2011: Solar Cities Scotland Conference 2011, Dundee, (Great Britain)

04.07.2011: X-Border- GDI, Düsseldorf (Germany)

24.03.2012: Energieplanung im räumlichen Kontext, Oldenburg (Germany)

8.2 Poster presentations

26.-28.03.2010: NordHaus, Oldenburg (Germany)

28.08.2010: Solartag, Grasberg (Germany)

21.10.2010: Jade Weser Energietag, Wilhelmshaven (Germany)

13.–15.04.2011: North Sea SEP Midterm Conference, Assen (The Netherlands)

12.05.2011: INTERREG IV B Projektpartnertreffen Niedersachsen, Hannover (Germany)

26/27.05.2011: Klimawandel im Landkreis Oldenburg, Wildeshausen (Germany)

9 Figures

The Interreg IVB North Sea Region Programme

European Community
European Regional
Development Fund

10 Literature

Brinkhoff, Thomas: *Geodanbanksysteme in Theorie und Praxis*; 2., überarbeitete und erweiterte Auflage; Herbert Wichmann Verlag, Heidelberg, 2008

Luhmann, Thomas: *Nahbereichphotogrammetrie;* 2., überarbeitete Auflage, Herbert Wichmann Verlag, Heidelberg, 2003

Quaschning, Volker: *Erneuerbare Energien und Klimaschutz*; 2., aktualisierte Auflage, Hanser Verlag, München, 2010

Schmitz, Jascha; Volkmann, Benjamin: *Ihr Photovoltaik-Ratgeber*, scon-marketing GmbH, 2011

Seltmann, Thomas: *Photovoltaik: Solarstrom vom Dach*; 1. Auflage, Verlag Stiftung Warentest, Berlin, 2011

Gesetz zur Neuregelung des Rechtsrahmens für die Förderung der Stromerzeugung aus erneuerbaren Energien (EEG-Novelle 2012) im Bundesgesetzblatt, August 2011

http://www.focussolar.de

http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php

http://eosweb.larc.nasa.gov/sse/RETScreen/

www.solaranlagen-portal.de