

# EnerGeoPlan

## Grid-aware Planning of Renewable Energies

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### **Abstract.**

The presented approach enables a coherent involvement of the relevant actors like grid operator, municipalities and policy, project planner and citizens by a combined spatial and power system analysis. As a result the approach can be used as a tool to support the „necessary paradigm shift” (BMU, 2013): Not the fast expansion of the renewable energy should be the focus, but the optimized and integrated energy supply taking into account time, costs and the expansion and reinforcement of the grid.

**Keywords:** Land Use Planning, Power Grid, Renewable Energy

## **1. Introduction**

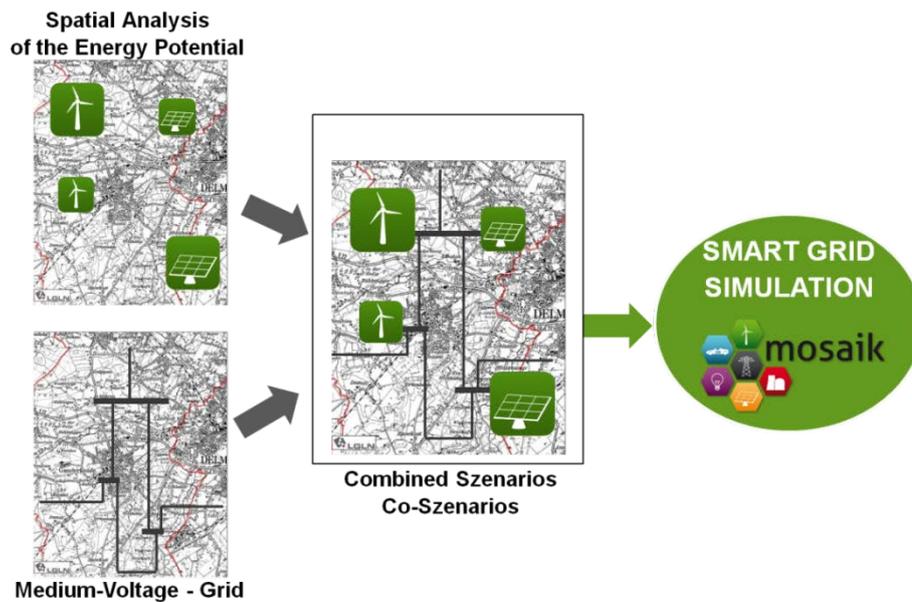
These days the electricity system in Germany and many other countries in Europe undergoes a change towards a so called Smart Grid, a power grid that integrates the behaviors and actions of all actors (generators, consumers, storages) in a smart way in order to provide a sustainable, economic and secure supply of electricity (EU, 2010). This change is mainly driven by the need to increase the number of regenerative energy sources in favor of environmentally harmful fossil and nuclear power sources. Especially in Germany, the number of renewable energy sources increased enormously over the past few years, caused by the subsidies defined in the Renewable Energy Sources Act (Erneuerbare Energien Gesetz (EEG) (BMU, 2012)). This leads to two major problems. First, the ever growing number of renewable sources requires a careful integration into the landscape to avoid that these adversely impact the eco system as well as to increase acceptance in the broad public. Second, the impact of these sources on to the power grid has to be analyzed, as their ever growing number is more and more often causing capacity problems in the power grid. The amount of energy that could not be fed into the grid due to required counter measures increased

dramatically from 127 GWh in 2010 to about 421 GWh in 2012 (BNetzA, 2012). This is because renewable generation and consumption do not match at any point in time.

The project EnerGeoPlan<sup>1</sup> aims to develop a concept for tackling these problems by combining Smart Grid analysis approaches and Geo-Information Systems (GIS).

## 2. Methodology

The analysis approach within the project is based on the combination of different tools shown in Figure 2. A GIS based analysis of renewable energy potential is combined with a simulative analysis of the impact on the power grids (Knies, Schütte, 2012; see figure below).



**Figure 1.** Spatial integration of planning and power grid aspects (Knies, Schütte, 2012)

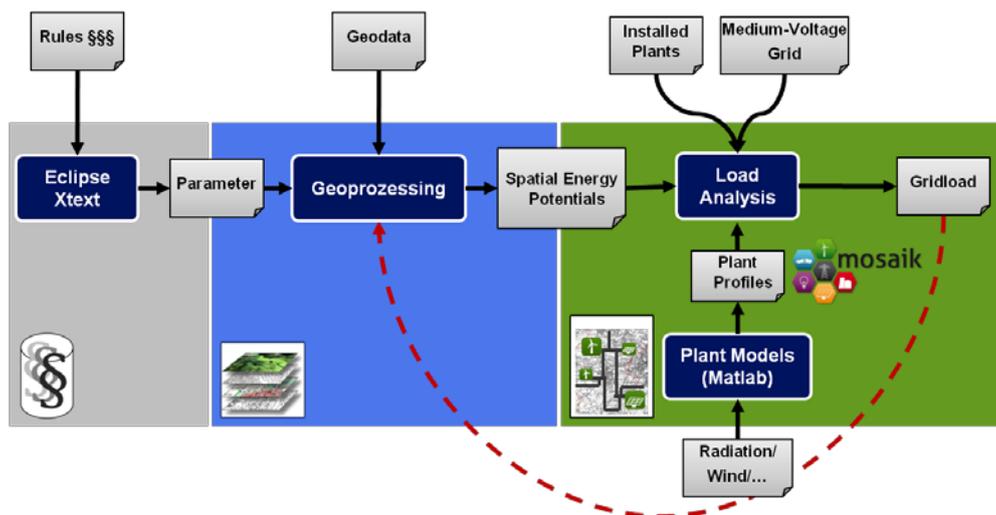
In a first step, statutory provisions and directives (e.g. rules defined in the EEG, planning directives and acts) are formally captured such that they can

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<sup>1</sup> EnerGeoPlan is a preparatory research project, funded by the Ministry of Science and Culture of Lower Saxony.

be automatically processed by the EnerGeoPlan system. Next, for a region of interest, geographic planning and cadastral data is imported. In this case, the municipality of Ganderkesee (Lower Saxony) is the project partner, supporting the project with planning data and information. Both the formalized rules and the geo-data provide the basis for the spatial analysis of potential installation areas of renewable energy plants. The project currently focuses on wind and solar (ground and roof mounted) power plants.

Next, different scenarios can be analyzed for the area of interest with respect to the potential regenerative power that can be installed. These scenarios may include variations of available technologies as well as different interpretations of the legislative rulings. The results of these scenarios are possible installation positions for the different types of energy sources. With these positions, the power system simulation can be parameterized to analyze the effects of the new scenario. For the latter, EnerGeoPlan relies on power system data provided by regional system operators. In a first conceptual implementation, data provided by the local distribution grid operator EWE Netz GmbH were used. The data contains topology and measurement information to approximate the power dissipation and generation along different branches of the medium-voltage grid. Additional, meteorological data is considered within the simulation, in order to increase accuracy. For the simulation part of EnerGeoPlan, the simulation framework “mosaik” is used, which has been developed at the OFFIS specifically for Smart Grid related simulation studies (Schütte et al. 2011).



**Figure 2.** Toolchain of EnerGeoPlan

### 3. Formalizing Planning Rules

Planning rules and political roadmaps are the legal base for planning the spatial installation of renewable energy plants. They determine the location and extend of plant sites. Formalizing planning rules is a helpful step to keep all relevant rules in mind and to allow automated processing of rules being relevant for a specific scenario. Planning rules vary between authority levels and borders (Europe, federal state, county, municipality) and time (different versions of a rule framework, directive, act, statute etc).

In the project, the planning rules of Lower Saxony (Germany) that were valid at the start of the project were used. The following energy sources were considered:

- (large) wind turbines,
- ground mounted solar plants,
- solar plants on roofs.

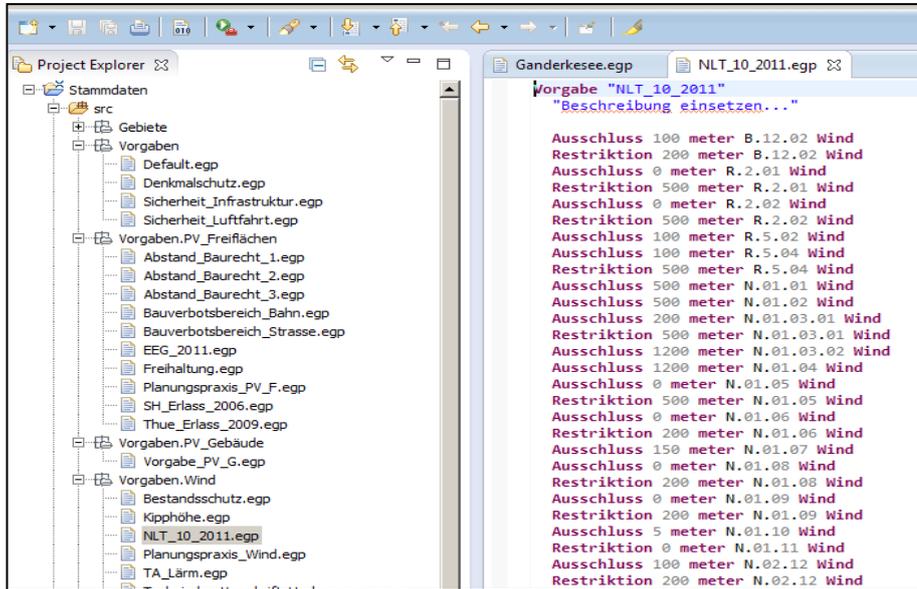
The formalization is implemented with Xtext<sup>2</sup> and offers following functionalities:

- defining exclusion, restriction and positive criteria to place renewable energy plants by referring to nature conservation, urban planning, recreation and other rulings,
- defining the used versions of planning rules,
- defining the planning rules that are to be applied to the study area,
- defining own planning rules and /or changing criteria, to study the effect of potential changes in legislation.

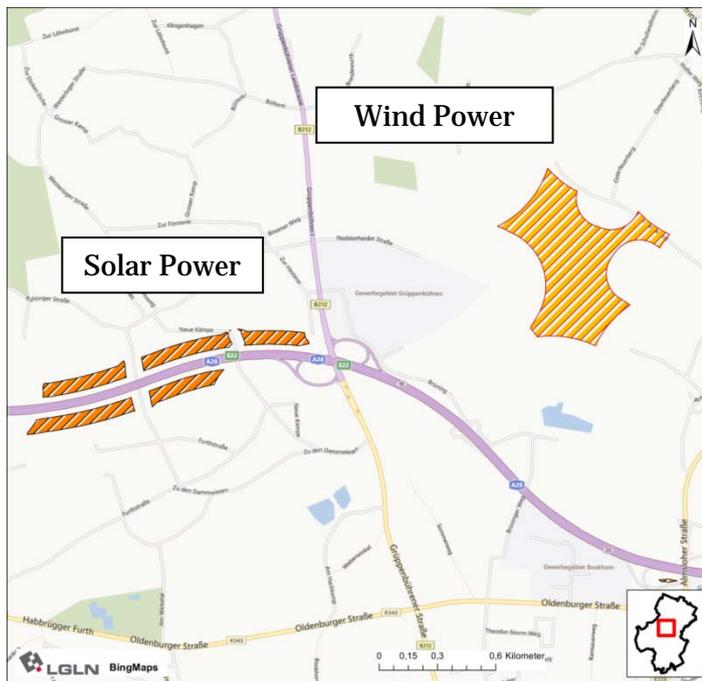
Figure 3 shows the resulting editor to capture planning rules. The geoprocesses discussed in the next section use the formalization of planning rules as parameters for the spatial allocation of suitable areas and energy potentials (see figure below). The concept of formalizing planning rules is extendable and applicable to other federal states.

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<sup>2</sup> <http://www.eclipse.org/Xtext> (accessed on 21 March 2013)



**Figure 3.** Defining Planning Rules in Xtext



**Figure 4.** Spatial Result of the Potential Analysis based on formalized Planning Rules and Planning Data

## 4. Geo-processing

The data of the formalized legislative rulings are used by the geo-processes as input parameters for buffering, clipping, etc. on geo planning and cadastral data. Within the project the following geodata are used:

- Cadastral data (LGLN)
- Land-use plan of Ganderkesee
- Protection Areas / nature conservation (GEOSUM-data of Lower Saxony)
- Regional Planning Program (County of Oldenburg)
- Infrastructural data, e.g. highways, railways, airport zones, high-voltage lines, etc.

Essential for the linkage between the geodata and the formalized planning rules is an accurate coding. In some cases, the internal codes of the used geodata can be used, e.g. the standardized coding of cadastral data. In other cases the coding must be done manually.

Some implementation tests with XPlanGML (Benner, Krause, 2009) and with the specification of cadastral data in the so called GeoInfoDok<sup>3</sup> were made. The concept of these standards is to offer planning data in standardized exchange formats for various applications and analysis. Unfortunately none of the planning data was available in this format and the internal differentiation in XplanGML is not sufficient for the specific application. This is subject to further research.

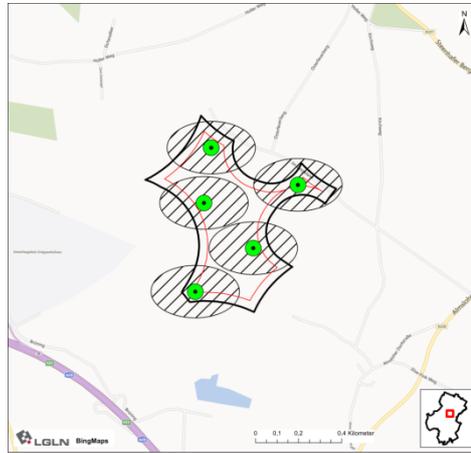
In the following subsections the geo-processes and scenarios of wind and solar (roof and ground mounted) will be described.

### 4.1. Wind Energy

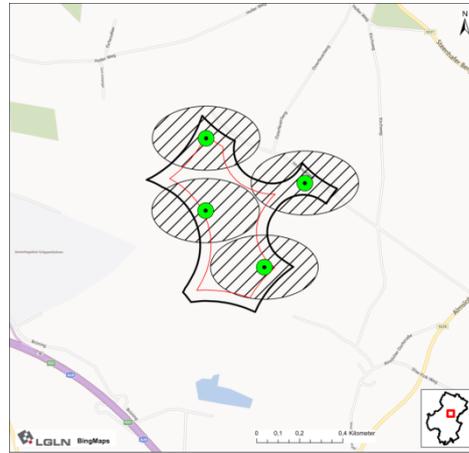
Wind turbines demand a lot of space. This demand is determined by the height of the turbines and the vulnerability of the surrounding land itself. Also, the space between the turbines within a site is determined by the height and rotor diameter of the plants. In order to avoid negative effects (turbulences, to less wind etc.), it is necessary to take into account a certain distance between the plants. In general the wind turbines should have a distance of three times of the rotor-diameter in minor wind direction and five times of the rotor-diameter in main wind direction (U.A.N. 2009). With this information, the number of plants and thus the total amount of installed power within a site can be calculated for the different scenarios.

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<sup>3</sup><http://www.adv-online.de/icc/extdeu/broker.jsp?uCon=68470b36-de06-8a01-e1f3-351ec0023010> (accessed on 21 March 2013)



Scenario 1: Six power plants (rotor diameter of 82 meters)



Scenario 2: Three power plants (rotor diameter of 115 meters)

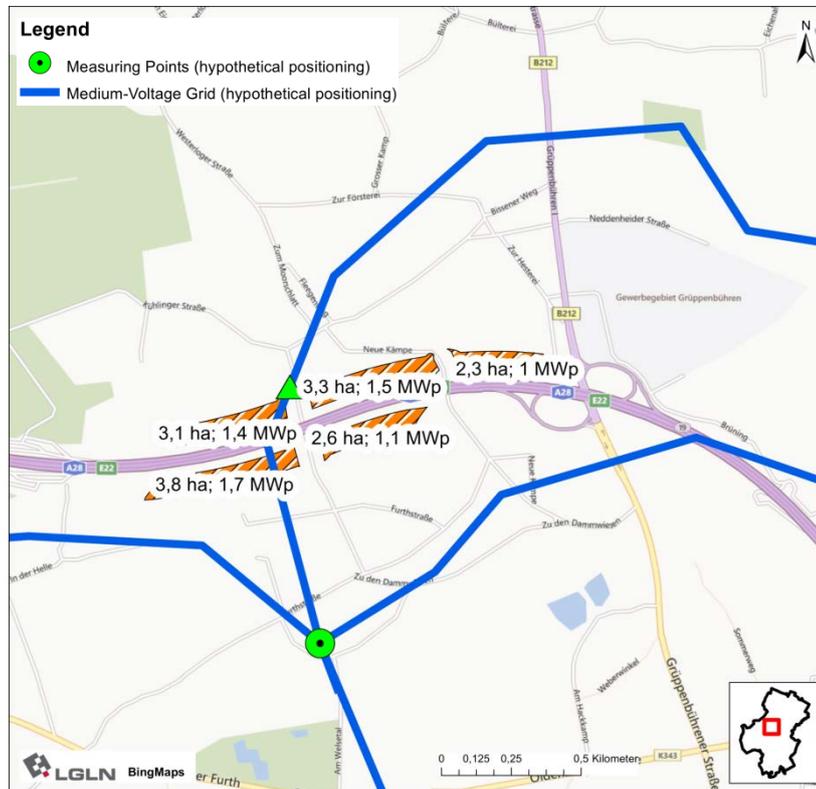
**Figure 5.** Comparison of two wind power configurations

#### 4.2. Solar Power (ground mounted)

Along infrastructural axes like highways and railways, on former military sites, and other areas, ground mounted solar power is subsidized by the EEG (Erneuerbare Energien Gesetz, Renewable Energy Sources Act (BMU, 2012)). The aim is to concentrate solar power plants on preloaded sites. The need of space of such plants is nowadays nearly 2,25 ha per installed Megawatt (peak), ancillary facilities included (based on a evaluation of solar projects financed by the Umweltbank, Nürnberg). Umweltbank<sup>4</sup> is publishing all relevant information of these projects on its website and the information is more accurate than older publications (e.g. Leipe, Zill, 2011; Rylatt et al., 2001; Wouters, 2007) with respect to new projects. The economical minimum size of solar sites is around 3 ha (Holst et al., 2012).

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<sup>4</sup> [http://www.umweltbank.de/kredit/index\\_kreditbeispiele.html](http://www.umweltbank.de/kredit/index_kreditbeispiele.html) (accessed on 21 March 2013)



**Figure 6.** Potential of installed power in solar sites (ground mounted)

### 4.3. Solar Power on Roofs

There are only a few regulations to be considered when building solar plants on roofs. These are mostly related to monument protection issues and of course structural engineering issues.

A very popular way to calculate the potential of solar plants on roofs is to analyze 3D-data of buildings (Kapfenberger-Pock, 2010; Lanig et al., 2009). Based on the experiences of several 3D - solar projects it is possible to estimate the potential considering the shape, usage and orientation of buildings and their outlines (Klärle et al., 2011). For example, in general 20% of the outline area of a dwelling house is suited for solar panels on the roof (Klärle et al., 2011).

Within the EnerGeoPlan project an approach is tested to calculate the potential with the help of data that is available in municipalities, such as ca-

dastral data. The estimation approach offers a quick scan of the potential of solar plants on roofs on an aggregated level. As 90 % of the renewable energy sources are connected to the distribution grid (BDEW, 2012), it is sufficient for smaller PV installations to estimate the potential of renewable energy plants per low-voltage segment (transformer level). Each of these segments consists of a number of buildings with different usages. At the end of the analysis there is only one aggregated peak power value for all buildings of a segment (see figures 7 and 8).

The estimation parameters that are linked to the buildings are its usage (dwelling, industrial buildings, churches etc.) and orientation. The usage determines the potential suitability according to the outline area of the building. The estimation parameters have to be controlled and adjusted by local experts to meet the local conditions.

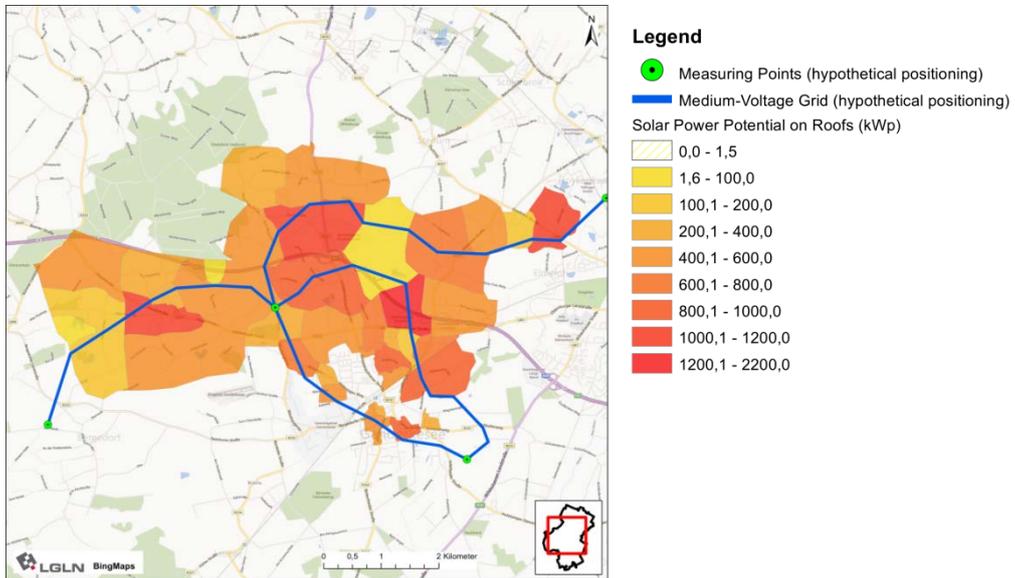
A number of scenarios were created that make different assumptions about the future level of photovoltaic installations. For example, the scenario "100% Plus" includes the assumption that all suitable roofs will be covered by solar plants, even on buildings with sub-optimal orientation. The scenario "Real1" takes into account that buildings with optimal orientation are suitable for solar power, only. Additionally a proportional reduction of the suitability is used to reflect the motivation or capacity of the owners.

It is essential to take into account the existing plants when calculating the potential surplus of plants. Existing plants are taken from the database of EEG-plants in Germany. Following list describes the preset assumptions:

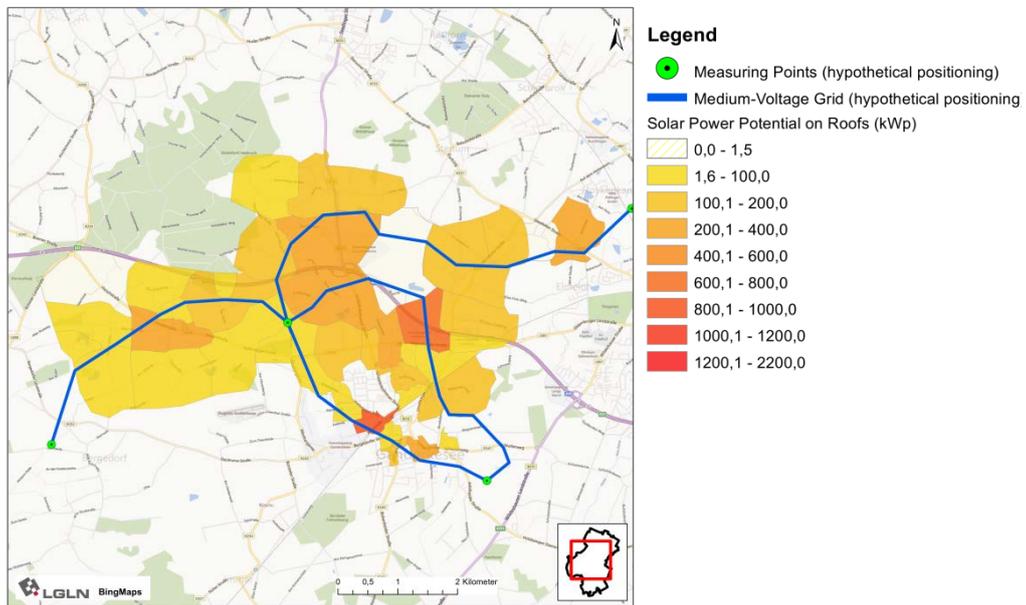
- General preconditions: 2 kWp minimum, 35 degrees slope on saddle roofs
- Existing plants:
  - Efficiency: 8,5 m<sup>2</sup> / kWp
  - Minimum area on saddle roofs: 17 m<sup>2</sup>
  - Minimum on flat roofs: 42,5 m<sup>2</sup>
- Future plants:
  - Efficiency: 7 m<sup>2</sup> / kWp
  - Minimum area on saddle roofs: 14 m<sup>2</sup>
  - Minimum on flat roofs: 35 m<sup>2</sup>

The assumptions are derived from Lödl et al. (2010) and Scheffler (2002). A first cross check with a 3D-analysis of roofs shows a difference of 8 % in total to the assumption method.

The result is spatial overview about the potential surplus of solar plants on roofs for each local grid area taking the scenarios into account (see figures below).



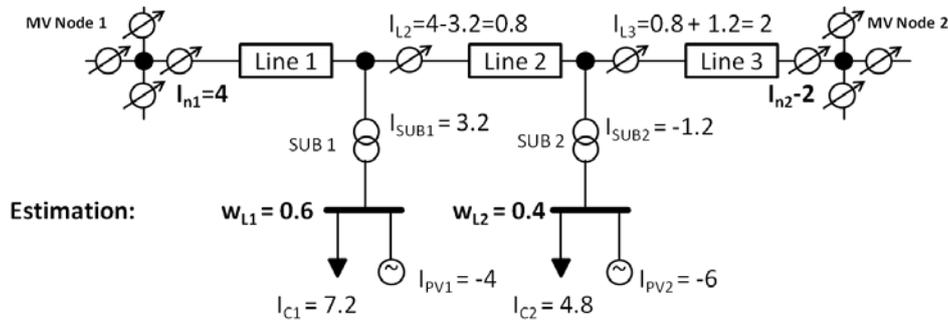
**Figure 7.** Potential of Solar Power on Roofs per substation (Scenario 100% Plus)



**Figure 8.** Potential of Solar Power on Roofs per substation (Scenario Real01)

## 5. Power System Analysis

The last part of the EnerGeoPlan methodology is the simulative analysis of the impact that the planning scenarios have on the power system. Again, the medium voltage (MV) grid is within the focus of this analysis. The topological MV data for the exemplary region Ganderkesee data was provided by the local distribution grid operator EWE Netz GmbH together with a set of measurements. These measurements include the power flows (in Ampere) for one year in 15 minutes resolution at the end of each line segment, i.e. at MV nodes. Figure 9 shows a schematic representation of such a line segment. The values  $I_{n1}$  and  $I_{n2}$  (4, -2) represent the available measurement data for the line segment.



**Figure 9.** Schematic representation of the power flow problem

Nowadays, measurement data for the low voltage (LV) level is usually not available. This poses a challenge on the power system analysis, as the distribution of the measured load along the segments lines is unknown. However, this distribution is crucial to determine if a planning scenario brings a line segment or a substation to its operational limits.

The only option is to estimate the measurement values ( $I_{SUB1}$  and  $I_{SUB2}$  in the given example) of the different substations. Similar to the estimation of the PV potential discussed in section 2.2.3, the building usage data can be used to create the estimation. Two different approaches can be pursued.

## 5.1. Load Profile Synthesis

The first approach tries to create synthetic load profiles by referring to the well known standardized load profiles<sup>5</sup>. In a first step, the different building usage types have to be associated with different load profile types (e.g. H0, H1, G0, G1...). Next, the load profiles are scaled, as not all consumers have the same annual consumption. This could be done, by referring to values from literature which assumes a certain consumption based on the area of a building and the regional specific level of electrification (Kaufmann 1995). Finally, the scaled load profiles for the different buildings can be summed up and result in an overall load curve for the corresponding substation. The used factors for scaling the load profiles for each building type could additionally be used as variable parameters for an optimization algorithm that adjusts these factors to match the resulting load curve of the complete MV segment with the measurement data.

Due to the complexity of this approach and the large number of assumptions that have to be made (assignment of load profile types to building usage, scaling factors) this approach has not yet been implemented for the project EnerGeoPlan.

## 5.2. Weighted Measurement Data

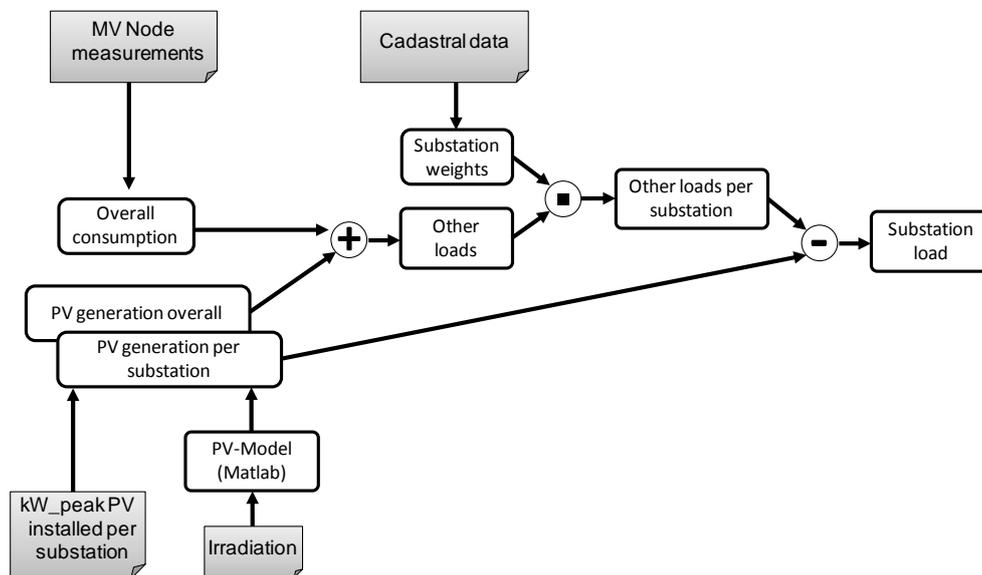
A second approach, presented in this section has been implemented to estimate the substation load curves. Other than the approach presented before, the measurement data is used as input for the estimation. To distribute the consumption (or production) of the MV segment along the different substations, a weight value for each substation is being used. This can be calculated by summing up the number (and/or area) of buildings for each substation (with different weights for the usage type) and putting it into relation to the other substations. When normalizing it to 100% each substation is assigned a factor smaller than 1 such that the overall consumption can be distributed across each substation. But again, a number of decisions/assumptions have to be made which cause the estimation to be inaccurate. But this method does not require additional load profiles and no optimization algorithm. As it relies on actual measurement data the estimation may be less erroneous than the one generated by the other approach. However, this is just a first guess and a comparison of the two approaches is still subject to future work.

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<sup>5</sup> E.g. at [http://eon-mitte.com/de/netz/veroeffentlichungen/strom\\_/standardlastprofil\\_verfahren](http://eon-mitte.com/de/netz/veroeffentlichungen/strom_/standardlastprofil_verfahren) (accessed on 14 March 2013)

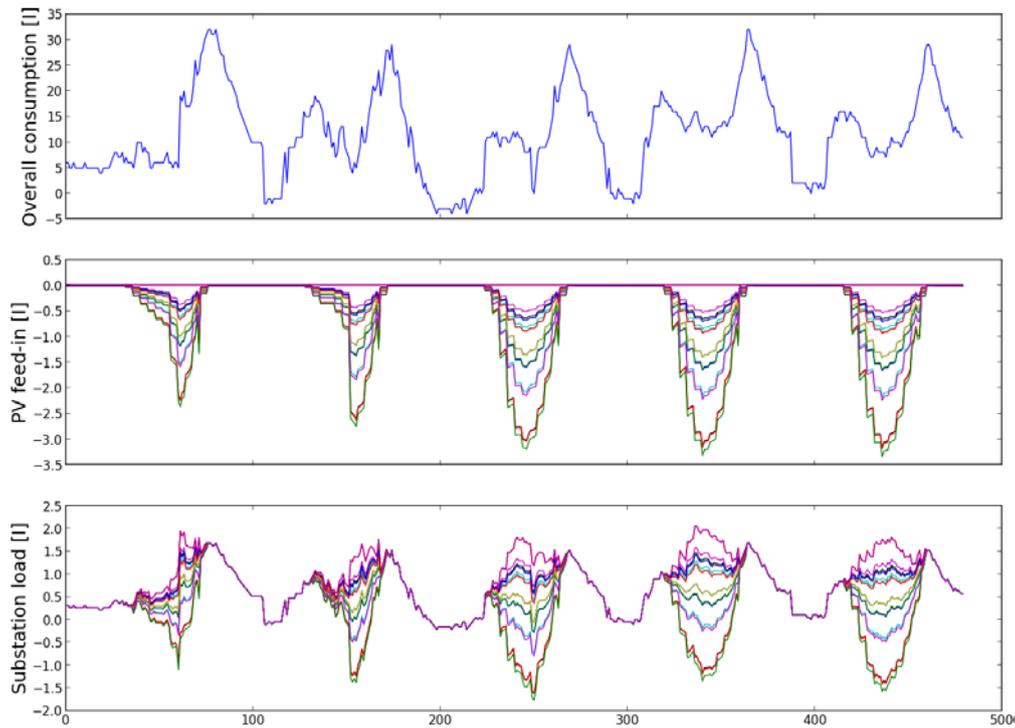
### 5.3. Exemplary, estimation based power system analysis

Some first results to demonstrate the weight based approach have been generated by simply assuming a 50/50 distribution of residential and industrial/commercial loads. The area of the respective objects was ignored first of all, and only the number of occurring objects is considered. So a substation with 50 houses and 50 industrial/commercial buildings has 10 times the weighting factor of a substation with 5 of each category. Figure 10 shows the basic flow of the calculation, once the factors have been calculated.



**Figure 10:** Calculation of the substation load curves

Figure 11 shows some of these curves for an exemplary range of 5 days. The upper plot is the overall consumption based on measured data. The middle plot shows the PV feed-in curves for the different substations and the bottom plot depicts the calculated transformer loads.



**Figure 11:** Estimated substation load curves

Based on these transformer load curves, the branch utilization of the MV segment can easily be calculated using Kirchoffs law (node currents must add up to zero), as shown in Figure 9, above.

#### 5.4. Impact of future installations

The calculation presented above only reflects the impact that current PV installations have on the power grid. The impact of additional renewable energy as result of the geo-processing step has to be added to this calculation. A first step here is to determine the connection points of each renewable source to the power grid. For roof-mounted PV installations this can be done by simply assigning it to the corresponding transformer which covers the surrounding area (based on the data provided by the grid operator). For larger, ground-based PV installations or wind farms, a manual planning is assumed. Automated routing of power lines for such cases is not within the scope of the project EnerGeoPlan. A simple branch utilization calculation including these additional power sources can no longer be done as presented above, as the new power sources are not included within the measurement values. To determine how additional feed-in changes the power flows

at the end of an MV segment, a complex power flow calculation must be performed. This also requires knowledge about the higher voltage levels as the precise electrical behavior of the MV nodes cannot be determined otherwise. This is subject to future work and no results for these further calculations are available, yet.

## **6. Conclusion**

At the end of the project concrete findings but also open issues can be named.

### **6.1. Current findings**

Model based and automatically driven processes lead to verifiable statements about the potential of renewable energy in a region. The presented approach enables a coherent involvement of the relevant actors like grid operator, municipalities, policy and project planner.

Municipalities can use existing geo-data to estimate the potential of renewable energy easily. Also the impact of policies can be assessed onto the implementable potential of renewable energy.

Grid operators could take these potentials into account to their strategic grid planning with the objective of a cost efficient, farsighted solution.

Together with project planners the grid operator is able to localize an optimized grid connection well in advance.

As a result the approach can be used as a tool to support the „necessary paradigm shift“ (BMU, 2013): Not the fast expansion of the renewable energy should be the focus, but the optimized and integrated energy supply taking into account time, costs and the expansion and reinforcement of the grid.

### **6.2. Open Issues**

The most relevant obstacle to use this approach for grid planning is the fact that the legal framework does not allow the operator to use this information strategically, e.g. renewing older or building new grids in respect to expected installations. This is because the actual legal framework of grid planning does not enable the monetary consideration of such predications.

There is still work to do to develop the xplan-GML standard to enable potential analysis easier and to reduce the manual work of coding and preparing planning data.

The processes itself are computationally intensive, so the usage of cloud services could be helpful to relieve the municipalities and grid operators.

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