




Spatial Distribution of Overhead Power Lines and Underground Cables in Germany in 2016

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Abstract: In the context of transformative energy policy frameworks, such as the German “Energiewende”, state and federal agencies, regulators, and country planners need reliable data on the energy system infrastructure to make substantiated decisions about line routing and extension. The decision-making processes are accompanied by interdisciplinary research efforts in the areas of energy system planning and modelling, economic viability, and environmental impact, e.g., visual amenity or potential impacts on species. Proved data on the spatial distribution of the electricity transmission and distribution network can inform these efforts, in particular when combined with key technological parameters, like installed capacity, total size, and required space. Without these data, adequate assessments of potential impacts, e.g., the collision of birds with overhead lines, are not possible. However, no such comprehensive dataset exists for Germany. The dataset produced in this paper is based on open-source data using OpenStreetMap (OSM). It covers the spatial distribution of overhead power lines and underground cables of Germany, combined with the attributes needed for adequate environmental impact assessment of overhead lines, such as voltage levels, route length, and circuit lengths. Furthermore, the dataset is validated by different publicly available statistics provided by the German Federal Grid Agency and official spatial data of the Federal Office of Cartography and Geodesy.

Dataset: Spatial distribution of overhead power lines and underground cables in Germany in 2016 (<http://www.ufz.de/record/dmp/archive/5368>)

Dataset License: CC BY-NC-SA 4.0

Keywords: validated power lines and cables; Germany; environmental impacts; net development

1. Summary

Worldwide, energy systems are transforming towards low-carbon and renewable-based systems. The increasingly decentralized supply structure raises many research questions regarding structure, dimension and impact of the electricity transmission and distribution network [1–10]. Spatial grid data on overhead power lines, but also underground cables, are essential for these research areas [11]. Nonetheless, the existing public data on the electricity transmission and distribution networks in

Germany [12] does not provide information on crucial parameters, such as voltage levels, route length, number of circuits, and circuit length. These parameters are, however, necessary for a sophisticated applicability of the dataset in spatial planning, energy system analysis, and impact assessments [3]. For example, to estimate the impact of overhead power lines on the avifauna, the number of cables mounted on the power line determines the risk of birds colliding with the power line.

The data described in this paper aim to fill this gap by combining and evaluating different public datasets and complementing it with additional parameters. The dataset has been generated as part of the ongoing research project “EE-Monitor - Monitoring of nature protection implications of the expansion of renewable energy in the power sector and the development of instruments for the mitigation of impacts on nature and the scenic value of the landscape”. This project is supported by the Federal Agency for Nature Conservation (BfN) and is processed by a consortium of several departments of two research institutes (UFZ—Helmholtz Centre for Environmental Research and DBFZ—Deutsches Biomasseforschungszentrum) and three subcontractors (Bosch und Partner, Leipziger Institut für Energie, and Ingenieurbüro Floecksmühle).

2. Data Description

The generated dataset of the power grid is provided in vector format, readable by all common Geographical Information Systems. Its spatial extent covers the area of the Federal Republic of Germany. The projected coordinate system is ETRS89 UTM zone 32N.

While the created dataset has been validated through comparison to official data, the completeness of the spatial distribution of power lines and underground cables cannot be guaranteed. It is possible that some regions are missing individual power lines or attribute values.

The dataset contains the following spatially explicit objects:

- Line data of the overhead power lines for Germany; and
- Line data of the underground cables for Germany.

In addition to their position and dimension in space, the listed objects include information (attributes) on voltage levels of power lines and cables. On this basis, the available power grid data were subdivided into the following voltage levels (grid levels according to [13]):

- medium voltage ≥ 1 and < 72.5 kV;
- high voltage ≥ 72.5 and < 125 kV; and
- maximum voltage ≥ 125 kV

The attributes of the datasets are included in the metadata description [14].

3. Methods

Here, the process of data generation is described; data sources and data availability are explained, followed by an explanation of data generation, the resulting dataset, and the validation process.

3.1. Data Source and Accessibility

Publicly accessible geodata of the existing power grid in Germany is heterogeneous, especially with respect to different voltage levels. For a comprehensive impact analysis [15], data on voltage levels, numbers of circuits and power pole heights are required. However, such data is not publicly available or cannot be obtained with reasonable effort in the context of scientific analyses.

The dataset of overhead power lines provided by the *Bundesamt für Kartographie und Geodäsie*, Amtliches Topographisch-Kartographisches Informationssystem, Digitales Basis-Landschaftsmodell ATKIS Basis-DLM [12], provides the spatial distribution of overhead power lines ≥ 110 kV, but contains no additional information on the voltage levels (as well as route length, number of circuits, and circuit length). Without the voltage levels, the overhead power lines cannot be differentiated into voltage levels (high voltage ≥ 72.5 and < 125 kV, maximum voltage ≥ 125 kV). Furthermore, the lower voltage

level <1 kV and the medium voltage level ≥ 1 and <72.5 kV are missing completely, as well as the spatial distribution of underground cables. The ATKIS dataset is not free to use, but can be acquired from the BKG.

The Federal Association of the Energy and Water Industries (BDEW) and the Federal Network Agency (BNetzA) hold different statistic information on the electricity grid of Germany, but spatial data is not provided [13,16,17]. The statistical data of the circuit length is later used to validate the OSM dataset.

The dataset of overhead power line and underground cables by OpenStreetMap [18] is publicly available and free to use under the Open Database License (ODbL). It provides spatial information as well as attributes, e.g., voltage levels and, thus, allows differentiating the power lines into different voltage levels. As discussed in the following sections, the dataset is far from complete, but offers good quality data in the higher voltage levels of overhead power lines. Furthermore, it contains useful attributes that cannot be acquired through other sources.

3.2. Data Generation Process

The latest OSM-database for Germany was downloaded from <http://download.geofabrik.de/>. Next, a database query (tag: power) was used to extract all data related to power generation. The result was divided into subsets of overhead lines and underground cables via the keys power = line and power = cable. The resulting subsets were exported to separate SpatiaLite databases. In the SpatiaLite database, the datasets were divided again based on their attribute values "voltage" (which provides the voltage levels of each line/cable) into different datasets for medium, high, and maximum voltage (see Section 2). The resulting vector layers were imported into GIS software. They contain the geographically accurate routes and grid nodes of overhead lines and underground cables of medium to maximum voltage level as well as relevant attributes.

In the GIS, additional attributes were calculated from the imported OSM datasets. First, the spatial route length in km was calculated for every voltage level. This attribute allows the estimation of active space occupied by overhead power lines and underground power cables. Then the circuit lengths in kilometer were calculated based on the number of different voltage levels per power line and the number of cables (both attributes from OSM database). This value allows a comparison to statistical numbers as explained in the next section.

With these additional attributes, the dataset can be used for the derivation of differentiated impact profiles of power grids and their mapping in space (active space of the grid). This dataset forms the basis for evaluation and assessment of the environmental impacts of the existing power grid on birds (cf. Section 4).

3.3. Resulting Dataset and Validation

The spatial distribution of overhead lines and underground cables per voltage level (medium to maximum voltage level) are presented in Figure 1a,b.

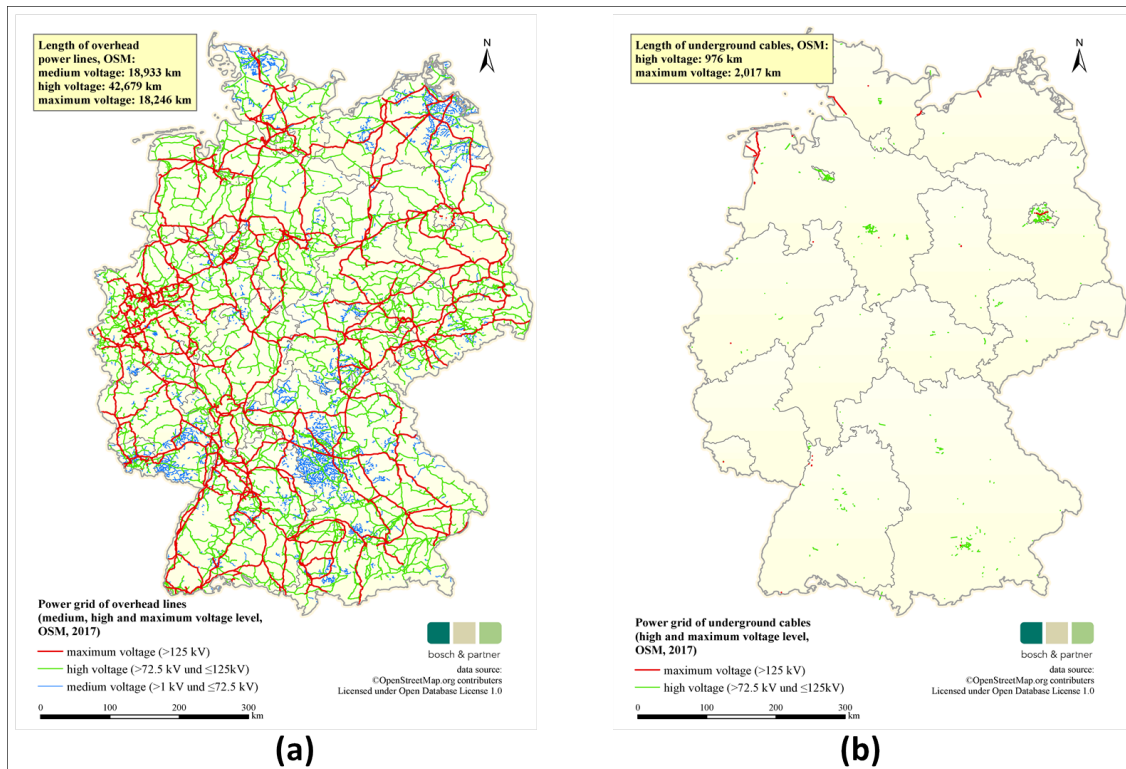


Figure 1. (a) Overhead power lines (medium, high and maximum voltage level, [18]). OpenStreetMap contributors, Open Database License (ODbL), www.openstreetmap.org and www.opendatacommons.org/licenses/odbl/; (b) Underground cables (high to maximum voltage level, [18]). © OpenStreetMap contributors, Open Database License (ODbL), www.openstreetmap.org and www.opendatacommons.org/licenses/odbl/. Administrative borders, represented as the base map, are not part of the dataset.

The calculated route lengths per voltage level of the OSM overhead line dataset are listed in Table 1. However, a validation of the route lengths per voltage level was not possible because of insufficient reference data. The ATKIS dataset, the only other available spatial dataset for overhead power lines, does not differentiate between voltage levels; hence, it cannot be used as reference for validation. Thus, neither the spatial distribution nor the statistical length can be compared based on the voltage levels.

Table 1. Route length of the OSM-covered overhead lines of all voltage levels.

Level of Voltage	Route Length (km)
medium voltage ≥ 1 kV and <72.5 kV	18,933
high voltage ≥ 72.5 and <125 kV	42,679
maximum voltage ≥ 125 kV	18,246

Instead, the spatial completeness and accurateness of the OSM dataset can be validated against the spatial distribution of the official ATKIS dataset [12]. Therefore, the spatial distribution of the high to maximum voltage (≥ 72.5 kV) overhead line grid represented by OSM data was compared with the ATKIS dataset for further evaluation purposes (in ATKIS, the overhead lines are defined by a voltage level of ≥ 110 kV). The total route length of the ATKIS high and maximum overhead voltage grid is approx. 60,581 km, while the OSM dataset ≥ 72.5 kV shows 60,925 km of grid. While the difference of the total length is just about 343 km, this does not mean that the location is identical.

For the analysis of the spatial difference between the two datasets, 70 m corridors (approximation of the surface occupied in reality) were created around the line vectors of the OSM and the ATKIS

data. Through a GIS-technical intersect, the spatial difference was calculated. The route characteristics of the OSM dataset differ by 6.8% from the route characteristics of the ATKIS dataset. Furthermore, the analysis of the location of the overhead lines show both, the OSM dataset is missing power lines included in ATKIS data, as well as lines recorded in OSM data which are not present in ATKIS data. The total amount of overhead lines present in the OSM dataset which is absent in the ATKIS dataset is about 600 km, while ATKIS data contain about 900 km of overhead lines which are not present in OSM data.

Next, the OSM datasets are validated using the aggregated cable lengths and comparing them with official public data sources [16,17,19]. While the route length of the power lines can be determined by a GIS-based spatial analysis of the data (see section above), the data sources only provide electric circuit lengths e.g., [13,16,19] Furthermore, along a power line, the pylons carry several systems of different voltage levels. Thus, the route length is shorter than the actual lines and the associated electric circuit lengths. We calculated the circuit lengths off the OSM grid based on the number of different voltage levels per power line and the number of cables. The determined lengths were compared to data from different sources to assess the quality and completeness of OSM data (Table 2).

Table 2. Comparison of the data for circuit lengths (km) of the BDEW, the BNetzA, and the OSM data.

Data Source	Type of Cable	Medium Voltage	High Voltage	Maximum Voltage	Total
BDEW [16]	Overhead line	108,968	72,527	35,012	216,507
	Underground cables	405,032	7173	176	412,381
	Total	514,000	79,700	35,188	628,888
BNetzA [17]	Overhead line	NA	NA	NA	NA
	Underground cables	NA	NA	NA	NA
	Total	511,164	96,658	35,970	643,792
OSM [18]	Overhead line	16,017	82,884	37,062	135,963
	Underground cables	959	1124	268	2351
	Total	16,976	84,008	37,330	104,717

The comparison of the current circuit lengths shows a similar dimension of OSM data with BDEW data on the high and maximum voltage levels, in particular for overhead lines. OSM data overestimate circuit length in total of about 6% for the maximum voltage and about 5% of the high voltage level compared with BDEW statistics. Medium voltage levels, however, are incompletely mapped, which is primarily based on the high degree of cabling on these voltage levels. These findings indicate good usability of the OSM dataset for high and maximum voltage levels (≥ 72.5 kV) for overhead lines as well as underground cables. For the medium voltage level, the OSM dataset is not adequate. Relatively large gaps arise for the subordinate voltage levels (< 110 kV). This applies in particular to the overhead lines at the medium voltage level (mainly 10 kV and 20 kV) and underground cables from the low voltage (< 1 kV) to the high voltage level (≥ 72.5 kV and < 125 kV).

Overall, considering the total length of the overhead grid of approximately 60,000 km, the deviation of the OSM grid from the ATKIS grid seems small enough to state that the OSM data represent the current grid in an acceptable spatial precision, providing an almost complete dataset of the current overhead power line grid of Germany. In addition, the analysis of the circuit lengths shows a good match for the high and maximum voltage levels, while the medium voltage level is incomplete. Nevertheless, since the focus of the analysis of the transmission grid lies on power lines ≥ 110 kV, OSM data can still be used to address a broad range of research questions, i.e., the impact on avifauna.

4. User Notes

Within the framework of the research project (see Section 1), the nature conservation conflict of the collision of birds with overhead lines is investigated. This conflict can be addressed

based on various indicators. The approach selected within the project is based on the Driving Forces-Pressures-State-Impact-Responses approach developed by the European Environment Agency [20]. For the development of the indicators, spatial and species-specific sensitivities to overhead lines must be mapped to the effects resulting from power lines. For this purpose, a spatially complete dataset of overhead lines needs to be complemented with data on technical parameters, in particular voltage levels. From the voltage levels, power line-specific attributes (e.g., wire height and diameter) known to be linked to bird collision risk can be directly derived [1,15,21]. In this context, the presented dataset of overhead lines was successfully utilized to analyze the areas of bird sanctuaries and habitats outside protected areas with high potential for conflict in relation to overhead lines (Kinast et al., in publication).

In addition to the outlined analysis, the dataset can be utilized for addressing other conflicts between power lines and objectives of nature conservation, such as the disturbance of scenic value of the landscape or fragmentation analysis [5,22]. For these kinds of analysis, a dataset containing different voltage levels is also needed, as the voltage levels determine height and visibility of the overhead power lines.

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